Computer-Supported Collaborative Learning

Gerry Stahl *Editor*

Theoretical Investigations

Philosophical Foundations of Group Cognition

Springer

Computer-Supported Collaborative Learning Series

Volume 18

The *Computer-Supported Collaborative Learning Book Series* is for people working in the CSCL field. The scope of the series extends to 'collaborative learning' in its broadest sense; the term is used for situations ranging from two individuals performing a task together, during a short period of time, to groups of 200 students following the same course and interacting via electronic mail. This variety also concerns the computational tools used in learning: elaborated graphical whiteboards support peer interaction, while more rudimentary text-based discussion forums are used for large group interaction. The series will integrate issues related to CSCL such as collaborative problem solving, collaborative learning without computers, negotiation patterns outside collaborative tasks, and many other relevant topics. It will also cover computational issues such as models, algorithms or architectures which support innovative functions relevant to CSCL systems. The edited volumes and monographs to be published in this series offer authors who have carried out interesting research work the opportunity to integrate various pieces of their recent work into a larger framework. Book proposals for this series may be submitted to the Publishing Editor: Melissa James. E-mail: melissa.james@springer.com.All books in the series are available at 25% discount to ISLS: International Society of Learning Sciences (http://www.isls.org).

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Editor
Gerry Stahl
Chatham, MA, USA

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To Carol Bliss, for her love and support during these investigations

Foreword

At present, more than at any other time, we think as individuals, as groups, as cultures, and as a species, mediated by powerful tools that yoke the thinking of people around the world, if loosely. Never before in human history has most of the human species been linked by instant telecommunication, nor have we had planetary-scale access to information. While the digital divide remains, a tipping point has been crossed; the International Telecommunications Union estimates that the portion of the human race using the Internet crossed 50% sometime in 2017–2018[1]. These observations are not new. What is new is the need to come up with coherent ways to reconceptualize some very basic ideas in this new reality, including knowledge, research, and learning. In this context, the field of computer-supported collaborative learning, and this book series, offers some important insights.

There are narrow and broad framings of computer-supported collaborative learning. The narrower framing, focused on the intersection of "computer-supported," "collaborative," and "learning," reflects the initial impetus behind much of the work in the field. How could we use the power of new technologies to support innovative pedagogies where learners work together? As Stahl nicely points out in his Introduction, the ideas and people gelling around this possibility were hard to concisely circumscribe or define: Is it a paradigm? A vision? In its narrower conception, CSCL is simply a sub-sub-area of applications of educational technology. However, the particular group of people working in this area and who carried the banner "CSCL" explore much deeper issues.

Unique to the vision described by Stahl is an opportunity to define a much broader perspective, one that unpacks decades- or centuries-old assumptions about thinking, learning, and knowing and the epistemologies we use to explore those assumptions. This volume helps bring forth how studying this one narrow context—teaching kids to learn through technology-supported collaboration—can help us develop philosophical and practical approaches to new ways of understanding the relationship between information and meaning, between the psychological versus the social and cultural sciences, and between our philosophies of science, our sciences of learning, and our models for growing, sharing, and perpetuating knowledge.

There is a dialectic in the field of CSCL, one which is illustrated by both this book series and the journal from which this volume draws. In CSCL there is a constant ebb and flow between what you might call on the one hand the science, or better yet, the natural philosophy, of learning and collaboration, and on the other hand the practical wisdoms encountered by inventing, designing, reforming, and implementing new possibilities for knowledge and learning with the latest technologies. In many cases the dialectic produces astonishing results, not because of some outrageously successful teaching strategy, or because of some thunderous research finding on discourse or learning, but *because the dialectics help us reframe basic assumptions about what it means to know in a global, networked knowledge society*. Other volumes in the series have helped illustrate this in the past, including notably Stahl's (2006; 2009) earlier monumental work on group cognition which helped reframe the

[1] https://www.itu.int/en/ITU- D/Statistics/Documents/facts/ICTFactsFigures2017.pdf

question of “How individual is knowledge anyways?” or the edited volume by Suthers, Lund, Rosé, Teplovs & Law (2013) on productive multivocality which helped reframe the question “To what extent and how is conversation actually knowledge, and knowledge actually conversation?”

This book is in a somewhat unusual format, for important reasons. As a juxtaposition of classic articles from the journal and commentary, it is itself an example of (hopefully productive) multivocality. However, to assume it’s simply a “greatest hits” volume that rehashes old ground would be to misunderstand its contribution. The difficulty in CSCL of synthesizing a common theoretical basis on which to build, a paradigm in the Kuhnian sense, an orthodoxy but also a cumulation, does relate to the ways in which CSCL is an interdisciplinary crossroads, and in which researchers are drawing eclectically on many traditions in ways that have not been solidified. But this is not simply a case of “just wait a few more decades and we’ll have this sorted out into something neat and tidy and paradigmatic.” Rather, it is an example of the field of CSCL struggling with, as the tech startups say, “eating your own dogfood.” If knowledge is socially constructed, if we learn in the middle spaces between monologue and dialogue, if our understandings of knowledge contest both linear, accretive positivism, and kaleidoscopic but subjective interpretivism, then we need to question what forms our scholarly output can take.

This book extends and builds on Wittgenstein’s idea of *investigations*. The book is a learning tool which invites the reader along on a journey that invites not only apprehension of prior scientific, philosophical, and design work but also a reconstruction and co-construction of knowledge. Stahl consistently enhances the work by others in the field with his own research legacy in the VMT project, bringing his own inimitable voice to the analysis. Is it a summary of what *ijCSCL* has produced? Or is it a masterclass in building theories that take into account new models of knowledge (including new roles for the academics most likely reading these words)? I argue it is both: a summation and an invitation to think along with one of the most qualified guides to this way of studying and fostering thinking and learning that we happen to call CSCL.

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Brooklyn, NY, USA Christopher Hoadley

Introducing Theoretical Investigations

By compiling his aphoristic *Philosophical Investigations*, Wittgenstein (1953) provided a provocative image of how philosophy could apprehend the world—in particular how it should understand language about the world. Just as Wittgenstein believed that a certain form of conceptual analysis was needed in philosophy, I am convinced of the relevance of certain kinds of theoretical reflection to the burgeoning field of computer-supported collaborative learning (CSCL). In founding and editing the *International Journal of Computer-Supported Collaborative Learning* (*ijCSCL*)—as a collective effort with many leading researchers from around the world—I intended to craft a venue for CSCL researchers to publish theoretical reflections on their work and on the nature of computer-supported collaborative learning. In addition, I always tried to derive theoretical insights from my own research, with its analysis of recorded student discourse.

In the spirit of Wittgenstein's collection of deliberations, I now assemble highlights of the journal and of my writings that I believe can contribute to an understanding of concepts and themes central to the field of CSCL. Wittgenstein's presentation was self-consciously anti-systematic. His paragraphs (like Einstein's transformative papers in physics) primarily pose "thought experiments," which tend to problematize established ways of thinking that have become second nature. Similarly, the Investigations of the present volume do not intend to lay out a detailed roadway for educational transformation or a logical edifice of theory. Rather, they hope to question outmoded assumptions and stimulate creative exploration in CSCL theory, methodology, and practice—like Wittgenstein providing examples of a different kind of theory. However, in distinction from the thought experiments of Wittgenstein's philosophy, the *ijCSCL* papers and my own research reports are firmly grounded in analysis of empirical interaction data.

Introducing Part I

Looking over the collection of papers collected for this volume of *Theoretical Investigations*, I perceive an emergent vision of CSCL, quite distinct from traditional educational research. I have therefore written two new introductory essays to provide an overview that suggests this vision and that connects it to theoretical concepts. These two essays constitute Part I, a synopsis and foreword to this volume.

- The first of these essays [Investigation 1] argues for a particular vision of CSCL, centered on a specific paradigm of collaborative learning, which is expanded by the sequence of *ijCSCL* papers [Investigations 3-14] that constitute Part II of this volume.
- The second essay [Investigation 2] reviews contributions to a theory of group cognition as foundational for CSCL research and practice. The papers covered by this essay [Investigations 15-25] are gathered from reports of the Virtual Math Teams (VMT) research project I directed. These papers constitute Part III of this volume.

The impetus driving the research field of CSCL has been evolving over several decades. However, the multifaceted knowledge required to implement CSCL pedagogy widely in schools was not available until now. Widespread assumptions (e.g., Schwarz and Wise, 2017) to the contrary, elements of such knowledge now largely exist—albeit in a preliminary, fractured, distributed, and uncoordinated manner. For instance, much of the knowledge needed for educational transformation is described, pointed to or illustrated in past volumes of *ijCSCL*. Unfortunately, however, some of the most innovative or penetrating analyses published there have not been further pursued or integrated with each other and with the accepted wisdom of the CSCL field. The present compendium of selected papers from *ijCSCL* is an attempt to substantiate this claim that the necessary components are available and to indicate a possible path forward to implementing a CSCL vision.

The view that students should be active learning agents is as old as our culture, enunciated by Socrates and Buddha, for instance. Over a century ago, Dewey argued for a progressive-inquiry approach in modern public schools—although, despite widespread recognition, his approach had limited impact on schooling. CSCL was founded to pursue a potential to transform learning from the memorization of facts instructed by authorities to inquiries of student groups assembled and supported by networked computer technologies. Still today, many people conduct research or introduce classroom interventions that they call CSCL, but that lack the elements that we have discovered to be central to effective collaborative learning. It is not sufficient to place groups of students together with arbitrary computer communication apps; one must design, identify, and support the required processes and practices—such as intersubjective meaning making and mediated knowledge building—for establishing a culture of group inquiry and collective knowledge building.

Introducing Part II

The publications selected for this volume from *ijCSCL* build upon historical sources and early CSCL investigations. They suggest: how to simultaneously focus CSCL theory and broaden the field's scope; how to analyze the processes of collaborative learning and mediation of group cognition by computer artifacts or supports; and how to develop innovative technological tools and educational infrastructures to facilitate collaborative knowledge building. Accordingly, they transform and potentially integrate elements of CSCL theory, methodology, and practice that can contribute to an ambitious effort to realize the CSCL vision on an international scale.

The papers included here from *ijCSCL* all emerged out of CSCL labs around the world. Significant CSCL investigations generally require teams of researchers, pooling different expertise and perspectives on cognitive theory, analytic methodology, and educational practice. They often involve consortia of labs. However, the effort to go beyond the scattered research efforts of CSCL to date and to implement the long-range vision in schools would require an even greater collaboration of researchers and educators—one on a global scale. The present volume aims to motivate the claim that this is possible through a review of the central points of selected investigations published in *ijCSCL* and reproduced here. The overview in Investigation 1, written for this volume, indicates how a synthesis of these proposals for CSCL theory, methodology, and practice could allow us to reach toward implementation of a CSCL vision. The effort required for achieving this CSCL vision would involve a global collaboration, supported by computer technologies and funded by progressive political will.

As founding editor (with Friedrich Hesse and a distinguished Board) of *ijCSCL* from 2006 through 2015, I selected favorite articles for this volume and commented on them from the perspective of influences on my own evolving understanding of CSCL. I include some articles related to the VMT project, which is the CSCL research I know firsthand. Several of the other publications represent the work of leaders in the field of CSCL research. Many of these articles were among the most cited and downloaded publications in *ijCSCL*. I selected those that have a strong theory focus and are suggestive for implementing the CSCL vision. There are, of course, many other insightful theoretical papers available in *ijCSCL*; it was not possible to include them all in this volume. I hope this compilation will stimulate readers to return to early *ijCSCL* issues to unearth other gems.

Throughout the history of CSCL, there has been a tension between various paradigms of research, colloquially referred to as "quantitative" versus "qualitative." The thrust of this collection of papers is that the defining characteristic of CSCL methodology should not be the genre of techniques applied in data analysis but a focus on small-group interactions. The focus on the group level is definitive of collaborative learning or knowledge construction in CSCL.

In addition, "socio-cognitive" and "socio-cultural" approaches have often been contrasted. The vision arrived at in this volume moves beyond viewing individual cognition (thinking) as peripherally affected by its social context to considering human cognition as itself an interpersonal, social, or small-group phenomenon, evolving in a biological and cultural background. Today, cognition incorporates a tightly entangled complex of external memories, mediating artifacts, communication partners, and networked interactions. So conceptualized, collaborative learning is no longer a niche educational activity subservient to the needs of individual minds but a foundational mode of being-in-the-world-with-others, from which individual cognition is itself a derived narrative.

Various efforts are underway to harness the opportunities of global networking of information to make course materials from advanced educational centers more broadly available around the world. These include wiring schools for the Internet, distributing networked tablets, offering massive-open-online courses (MOOCs), as well as offering open educational resources (OER), although these initial attempts rarely adopt pedagogies of collaborative learning. A CSCL approach would add support for engaging students in joint inquiry of the available resources, involving intersubjective meaning-making and collaborative knowledge building. This volume stresses the importance of supporting the collaboration in order to make technological innovations truly transformative. Part II concludes with two reports of tentative but systematic attempts to deploy CSCL initiatives at the level of national school systems. They document efforts to develop cultures of collaborative learning in school districts. They are suggestive of an international effort that could prove transformative. As technology transforms and interconnects working, learning, and thinking around the world, it calls for recognition of the importance of collaboration, which currently lags behind. Within the vision of human cognition as increasingly global, the goal of promoting worldwide collaborative learning seems inevitable, if currently challenging.

The selected papers from *ijCSCL* in Part II raise issues of CSCL theory, such as the nature of intersubjectivity, joint attention, shared experience, meaning-making, artifact usage, reference, temporal sequentiality, discourse structure, multiple levels of description, primary unit of analysis, external memory, group practices, and group cognition.

Introducing Part III

These issues are further explored in the VMT research papers in Part III. The Virtual Math Teams (VMT) Project has already been extensively documented in four previously published volumes:

- *Group Cognition: Computer Support for Building Collaborative Knowledge* (Stahl, 2006a). This collection of research reports motivates the design of the VMT Project. It begins with several attempts to design support for collaborative learning and cooperative work. Challenges that arose in these efforts showed a need for deeper theoretic foundations, raising questions concerning the preconditions for productive collaboration. The concept of "group cognition" emerged during the compilation of this book as a label for the shift of focus in research on learning to the small group as the primary unit of analysis for investigation. It seemed important to begin to collect data systematically documenting student interaction within a paradigmatic CSCL setting. Final chapters report on initial findings from students chatting about mathematics problems. At this stage, the proposals that mathematics could be learned collaboratively; that successful CSCL outcomes could be generated, recorded, and analyzed; or that interaction in such data could be understood in theoretical and practical terms were all hypothesized as questions to be investigated.

- *Studying Virtual Math Teams* (Stahl, 2009) documents the VMT Project as it began to explore technology for supporting student mathematical discourse. Core issues of pedagogy, analysis, and theory are considered in relation to technological features. The VMT system integrated a shared whiteboard with text chat. Sessions were automatically recorded so that student interaction could be replayed and analyzed in detail by researchers. First examples of successful CSCL sessions are presented here, along with analysis of many aspects of the technology, pedagogy, and methodology brought to bear. Presented case studies show that collaborative learning could provide a powerful approach to mathematics instruction.
- *Translating Euclid: Designing a Human-Centered Mathematics* (Stahl, 2013) reflects on the final version of the VMT Project from a dozen perspectives. The co-evolution of theory, methodology, pedagogy, and technology through iterative cycles of design and testing illustrates a design-based research approach. At this point, a multi-user version of GeoGebra was integrated into the shared whiteboard, to allow teams of students to construct and explore strategically selected geometric figures and gradually learn to think/discuss geometrically and solve problems collaboratively. This book confirmed the hypotheses about the possibility of generating, recording, and analyzing successful CSCL sessions of collaborative online learning in the illustrative domain of dynamic geometry.
- *Constructing Dynamic Triangles Together: The Development of Mathematical Group Cognition* (Stahl, 2016) provides a book-length longitudinal study of how a specific group of three young girls began to learn dynamic geometry together. The detailed analysis shows how the group successively adopted a productive set of group practices for collaboration, geometric construction, problem solving, and mathematical discourse. This provides a paradigmatic example of a CSCL approach to teaching a student group a challenging school subject involving practices of rational analysis. It illustrates a method for analyzing longer sequences of interaction that build group competencies—showing how interaction in such data can be understood in theoretical and practical terms as collaborative learning and group cognition.

Part III of the current volume elaborates theoretical issues that were raised in these books. It thereby supplements them and completes the documentation of the VMT research effort.

During several years, the VMT Project conducted Fests, in which students were invited through their teachers to participate in online small-group sessions of mathematical problem solving. This generated most of the data analyzed by researchers. Some sessions were particularly well suited for analysis due to continuity of participants. Key examples of interaction data from these VMT sessions appear in multiple Investigations. The most intensively analyzed sessions were those of the following student teams:

- Teams in the VMT Spring Fest 2005, including the students ImH and Jas as well as Sup, Pin, and Avr [Investigations 22, 23] (see also Çakir, 2009)
- Team B in the VMT Spring Fest 2006, including the students Quicksilver, Bwang, and Aznx [Investigations 5, 8, 16, 19, 25] (see also Medina, 2013)
- Team C in the VMT Spring Fest 2006, including the students Qwertyuiop, 137, and Jason [Investigations 12, 16, 17, 19, 21, 24] (see also Sarmiento-Klapper, 2009; Zhou, 2009)

- The Cereal Team in the VMT Winter Fest 2013, including the students Cheerios, Fruitloops, and Cornflakes [Investigations 9, 16, 18, 22] (see also Stahl, 2013)

The Investigations of Part III draw theoretical consequences from the analysis of interaction in these case studies.

It is not necessary to read the Investigations in this volume in order. The 25 presentations are structured so that they can be skimmed, read, studied, or skipped in any order. Each is self-contained, incorporating its own problematic, argument, literary style, and reference section. Most of the Investigations are reprints or adaptations of earlier publications (see Notes on the Investigations), originally focused on a special point for a particular audience. They retain some of the emphasis deriving from their origin during a particular point in the development of the theory of group cognition.

To aid in integrating the whole presentation, connections and references among the Investigations abound—both implicitly and explicitly. It is hoped that the different presentations support and enhance each other, gradually building a sense of the depth, evolution, and power of group-cognition theory, as well as of the potential of the CSCL field to empower students to tackle the daunting challenges of the future collaboratively.

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Part I

Overview

Investigation 1. Advancing a CSCL Vision

Gerry Stahl

Abstract

The field of computer-supported collaborative learning (CSCL)—as a unity of educational practice and academic research—is characterized in this investigation by a specific vision of learning, illustrated by a prototypical research effort. A number of recent publications are reviewed to extend the scope of CSCL in response to contemporary theory and current social issues. This leads to advancing theoretical concepts and frameworks for conceptualizing CSCL research and practice, which contrast with traditional educational approaches. Although these ideas were originally proposed in disparate contexts, they provide the conceptual skeleton of a unified theory for CSCL, which would be distinguished from popular theories of individual learning and would integrate technological support with collaborative cognition. These insights concerning theory have methodological implications for analyzing CSCL interventions in terms of group knowledge-building practices mediated by interactionally appropriated artifacts. Revised forms of analysis can help innovators evaluate CSCL trials during iterations of design-based research, leading to revisions of the collaborative-learning theory and research methods. Bridging from academic research to educational practice, two examples of efforts to bring the CSCL vision to scale within national school systems are then reviewed. Finally, a global collaboration among CSCL researchers is recommended for effective implementation of the CSCL vision in education worldwide, based on the presented conceptualizations of a unified theory of collaborative learning and their implications for evaluation of CSCL technical and pedagogical designs. This could advance the field of CSCL in its theory and practice, toward its underlying vision of cognition at the group level.

Keywords

CSCL theory · Group practice · Design-based research · Scaling up · Cognitive evolution · Group cognition · Sequential analysis · Knowledge objects · Referential resources · Temporal analysis · Instrumental genesis · Intersubjective meaning making

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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Defining a CSCL Vision

Previous attempts to circumscribe the field of CSCL have faltered; the target is so nebulous, controversial, disjointed, multidimensional, and agonistic. Most of these endeavors have tried to specify operational criteria for inclusion of papers in the CSCL corpus (Akkerman et al., 2007; Jeong & Hmelo-Silver, 2016; Jeong, Hmelo-Silver, & Yu, 2014; Kienle & Wessner, 2006; Lonchamp, 2012; Schwarz & Wise, 2017; Tang, Tsai, & Lin, 2014). However, such attempts to apply "objective" standards generally fail to include some of the most important contributions, especially those that are more theoretically oriented. As a multidisciplinary field, CSCL papers bear more of a "family resemblance" (Wittgenstein, 1953) to each other, sharing diverse constellations of characteristics and relationships, rather than fitting a definition with clear and distinct necessary and sufficient conditions (Descartes, 1633/1999).

Perhaps that is why the first definition of CSCL (Koschmann, 1996) presented it as a "paradigm," contrasting it with earlier educational-technology research paradigms like computer-assisted instruction, intelligent tutoring systems, and constructionist exploratory environments—which all focused on learning by individuals, conceived in terms of behaviorist, cognitivist, or constructivist psychology, respectively. However, Koschmann (2001) soon realized that actual CSCL research did not form a neat paradigm, contrasting with earlier, incommensurate research approaches, but included an eclectic mixture of mutually conflicting theories, methods, pedagogies, and settings.

A frequently cited introduction to CSCL (Stahl, Koschmann, & Suthers, 2006) characterizes its approach as "studying how people can learn together with the help of computers." This generic characterization is immediately followed with the warning that CSCL "has a complex relationship to established disciplines, evolves in ways that are hard to pinpoint and includes important contributions that seem incompatible." It suggests that one should "view CSCL as a vision of what may be possible with computers and of what kinds of research should be conducted, rather than as an established body of broadly accepted laboratory and classroom practices."

It seems that what we need is neither a definition of past work nor a paradigm of an ideal science but a focused yet open vision for the future—along with a concrete "prototype" example to serve as a cognitive reference point (Lakoff, 1987). A prototype example is a typical instance that often comes to mind, like a robin is a prototypical bird, although it has various similarities and differences to other birds, like turkeys or penguins. Therefore, I will here sketch a vision of CSCL based on my own efforts to develop a prototypical CSCL design. In addition, I will consider a selection of papers published in *ijCSCL* that I feel have until now been undervalued in setting future directions for CSCL. These papers suggest how to extend existing examples of CSCL research to a growing family of related efforts.

The vision of CSCL advanced here is that students working in small groups can productively incorporate collaborative learning centrally in their schooling and in their intellectual development, taking advantage of appropriate forms of computer support. As CSCL is adopted as a foundational form of learning in educational systems around the world, students will acquire collaborative group practices, individual cognitive skills and technology-enhanced abilities to enable them to address the challenges of contemporary social issues.

Collaborative learning is a primary form of human learning, and facility in collaborating can enhance student participation in other learning. Meanings and practices developed by small groups can result in understandings and skills of the individual group participants—although the correspondence between learning at the different levels is by no means direct or necessary. Increasingly today, with the Internet, students and others can form spontaneous, opportunistic, or long-term networks to discuss, debate, and explore topics of interest—including issues of global importance; students can learn to build knowledge together and refine understanding by sharing perspectives. Formal education in schools can involve mutually supportive mixes of individual, small-group, classroom, and networked activities. Collaborative learning can be extended outside the classroom as well.

Although knowledge has always been a social product in many senses, the ubiquity of computers and networking tremendously expands the potential to collaborate in building knowledge, to take advantage of computational support for knowledge creation, or to share and preserve knowledge. On the other hand, the proliferation of technology has also contributed to enormous societal problems: climate change, income inequality, overpopulation, fake news, nuclear proliferation, and political schisms. The skills acquired during CSCL sessions in working, problem-solving, conceptualizing, and reflecting together in small groups may be critical for addressing such pressing social issues of our times, as this investigation will suggest.

Two major sources for CSCL theory are Vygotsky (1930/1978) and Lave and Wenger (1991); they proposed influential perspectives on mediated cognition and social practices—i.e., shifting the traditional focus from methodological individualism (including positivism, behaviorism, and cognitivism) to the mind in society mediated by artifacts and the community of practice as the primary level of analysis. Two early investigations following these perspectives and also definitive of the CSCL vision were those of Scardamalia and Bereiter (1996) and Teasley and Roschelle (1993); they extended the unit of analysis to the group or classroom and to the joint problem space as represented by knowledge artifacts and as observable in shared discourse. These initiatives have been conceptually elaborated in subsequent CSCL theoretical papers, as we will see in the following.

My prototypical example of computer-supported collaborative learning involves a team of three 13-year-old girls interacting in the Virtual Math Teams (VMT) online environment to investigate dynamic geometry. The software allows a team of students to explore mathematical tasks in a shared dynamic-geometry workspace, which responds interactively to their actions constructing and dragging points, lines, triangles, and so on. The student discourse takes place through textual chat in the same software environment. Tasks from the teacher and curriculum displayed in the workspace include example constructions, technical terminology, and prompts for collaboration and discussion. The analysis of the team's eight hours of interaction (Stahl, 2016) is carried out at the small-group unit, documenting how the team adopted over 60 "group practices" [Investigation 16] of collaborative interaction, geometry construction, problem-solving, and mathematical discourse. Without speculating about what took place in the individual students' minds, the analysis shows how the team achieved impressive geometry accomplishments as a group and documents that each individual significantly increased her geometry skills through participation in the collaborative learning.

This example prototype is specific in many ways that are typical of some CSCL projects but not others: the team is a small group of students meeting online in an after-school club. It interacts through chat and actions in a multiuser application (see Fig. 1.1). Pedagogical guidance is supplied by a carefully crafted sequence of tasks. Interaction in the group takes place as mediated by reference to the task descriptions, previous chat postings, construction actions, and graphical figures. Analysis tracks the sequentiality of chat and math events as they develop within a network of artifacts, meanings, questions, technical terminology (e.g., "dependency"), and practices (e.g., dragging points to test for geometric dependencies). The subject domain has broad implications for learning: studying Euclidean geometry has served since Plato as the classic gateway to logical thinking and deductive argumentation (Stahl, 2013); collaborative, computer-supported dynamic geometry could similarly serve as a training ground for the group cognition required for democratic responses to contemporary social issues through deeper understanding of interconnections among actors and factors.

Each of this prototype's specifics could be expanded by other CSCL efforts with family resemblances to it. The VMT project illustrates one typical approach to CSCL, but it has differences from other current or future instances. To extend from this example, synchronous text chat can be replaced by asynchronous discussions, perhaps increasing reflection but lessening the flow of thinking together.

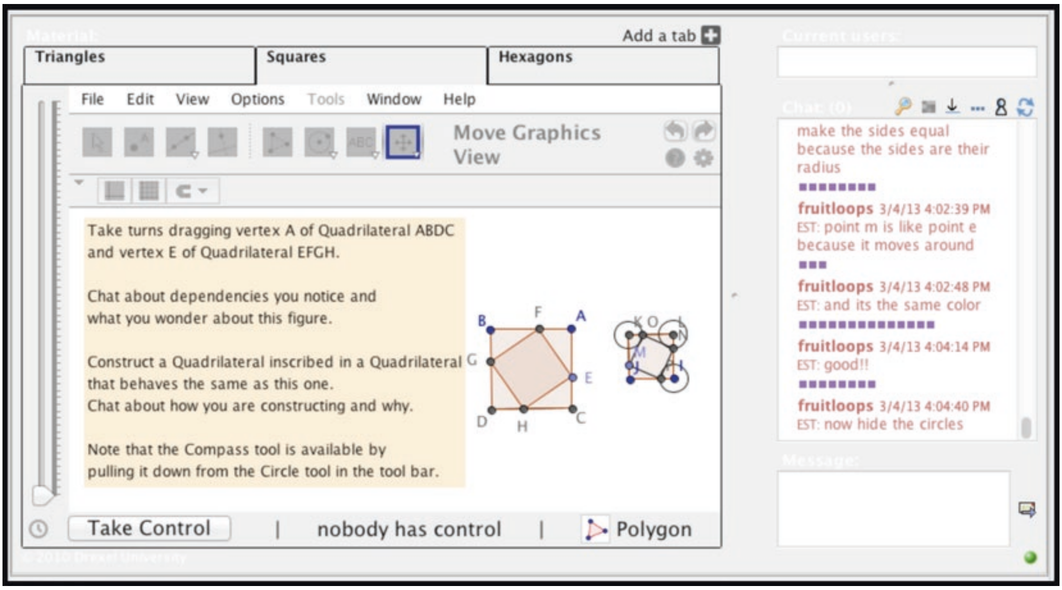

Fig. 1.1 The VMT interface. The team has constructed square IJKL and inscribed another square inside it, based on exploration of the given example of square ABCD and past group experience constructing inscribed triangles

Other knowledge domains can be supported with appropriate tools and curriculum. The role of computers in collaborative knowledge building can switch from communication medium to face-to-face workspace or embodied virtual reality. The after-school math club can grow to international networking, bringing different cultures together. CSCL environments can include scientific models, simulations, or artistic media. They can be supported with feedback and analytics of the interaction for student awareness, teacher overview, and researcher analysis.

The following consideration of several evocative papers in *ijCSCL* suggests possible dimensions for fruitful advances in the scope of CSCL from a focus on the micro-level interaction within small groups of students. This could lead to a growing family of theories, research projects, and institutional interventions resembling each other in various ways and all pursuing the underlying CSCL vision.

We will now review a number of *ijCSCL* papers that are suggestive of directions for progress in CSCL. This will provide an overview and contextualization of the investigations published in part II of this volume. The following comments on these papers are only meant to highlight some themes addressed by the papers and to motivate the careful reading of the investigations themselves.

Extending the CSCL Vision

In the first year of *ijCSCL* publication, Jones, Dirckinck-Holmfeld, and Lindstrom (2006) [Investigation 3] proposed dramatically broadening the concerns of CSCL to include the larger socio-technical context and infrastructure. These authors argue for a relational, indirect, meso-level approach to CSCL design, which would go substantially beyond the traditional paradigm of educational studies. In this approach, the phenomena at the micro level are understood as outcomes of processes of development within their larger contexts.

Most educational research aims at objective results based on a view of the world as having fixed characteristics: it is assumed that technologies have inherent affordances, individual utterances have definite intended meanings, subjects have rational thoughts (logically connected mental representations), and analysis can be carried out algorithmically. Investigation in this tradition is conducted at the individual unit of analysis, classifying student utterances as expressions of imputed intentions of individual speakers.

The paper by Jones, Dirckinck-Holmfeld, and Lindstrom takes a very different tack. It proposes that affordances of CSCL technologies should be understood in terms of how they are taken up by users in the interactions that the technologies mediate. Meaning is here seen as an intersubjective product of the interaction among multiple people within their conversational context, including its technological artifacts and infrastructure. The concern is with the unfolding process of (group) meaning making within these settings, rather than in traditionally conceived (individual) learning outcomes.

Analysis in this approach is complex, viewing each aspect of task, technology, personality, role, utterance, response, or knowledge as interrelated or relational. Data is not directly determinant but negotiated by participants and necessarily interpreted by researchers who understand colloquial language and human interaction. Furthermore, analysis of CSCL interactions is understood on many interpenetrating levels: the micro level of individual utterances and brief interactions, the small-group level of interacting teams of learners, the classroom level of teacher-led instruction, the local-culture level of schooling, and the global level of geopolitical and historical influences. Such multifaceted analysis requires computer-supported collaboration among the multidisciplinary researchers themselves; it is notable that Investigation 3 was written by authors from three different countries.

The meso level of the community points to the realm of social practice as the locus within which interactional processes are situated; the social practices are taken up in small-group activity. This focus corresponds to the "practice turn" in contemporary social theory (Schatzki, Knorr Cetina, & Savigny, 2001). In a practice-oriented analysis, structures are emergent; they grow out of recursive interactions among people, technologies, and social action. In this post-cognitivist view [Investigation 15], it is not mental representations in individual minds or designed properties of technology that directly structure the practice. Rather, it is through a recurrent and situated practice over time—a process of enactment of a relevant practice by a group—that people constitute and reconstitute a structure of technology use.

CSCL designers have only limited direct control over how their designs are actually used by students. How learners respond to, understand, and enact artifacts in relation to any educational design is a complex structuration process that has to be studied in practice. Investigation 3's authors contend that the CSCL tradition has pursued a relatively narrow focus that places in the background issues concerning the politics, policies, institutions, and infrastructures in which the processes of CSCL take place. They argue for a greater inclusion of what they call the meso level of collaborative learning, as opposed to the trend toward networked individualism—the conception of collaborative groups in terms of their individual members. They asked—already back in 2006—whether CSCL, and education more generally perhaps, should act as a critical opponent to some of the trends identified in the networked society and stand up against networked individualism.

Several books published in recent months highlight the acute and growing importance for the survival of modern society of issues at the technological meso level or the knowledge infrastructure. Collaborative learning could prepare students to address such issues in the future, if CSCL develops effective appropriate interventions. The social issues have arisen in part as a result of the prevalence of individualism: understanding things from the epistemological perspective of a rational individual mind seeking its own personal benefit, rather than seeing how things are increasingly interrelated and interdependent. By bringing multiple personal perspectives together to analyze dependencies in studied phenomena, collaborative learning provides both an approach and a model that transcend the individualistic in favor of the collective or collaborative.

With agent-network theory (ANT), Latour has expanded the group to include artifacts as well as humans as interacting agents of change. Climate change and ecological corrosion are widespread concerns, which Latour views as results of complex networks of dependency and interaction. In his last major book, Latour (2017) argues that the unforeseen consequences of industrialization have gone so far as to transform our relation to the natural world in a threatening way. What is needed is not a set of technological fixes but a reconceptualization of the distinction between nature and society. Not only are the new-age strictures about living in harmony with Mother Earth inadequate, but even the metaphors of ecological science need to be rethought. The complexity of climatic trends involves networks of interactions among countless human and nonhuman actors. The analysis of these interactions requires collaborative knowledge building on a global level, as does the designing of effective responses.

CSCL curricula can acculturate student teams to such knowledge building on a novice scale. CSCL software like Knowledge Forum, VMT, and argumentation-support apps provide illustrative forms of computer support. For instance, many lessons in classrooms around the world using Knowledge Forum (Fig. 1.2) already focus on group theorizing about environmental phenomena and historical conflicts; the geometric dependencies explored in VMT provide a metaphor for team thinking about interdependencies affecting the climate; argumentation-support systems model the forms of discourse needed for meaningful and democratic discussion of climate policy.

Computer technology—such as social media—provides a powerful infrastructure role in our society, including influencing the economy and politics. Technological tools, social institutions, and human roles are not independent fixed entities. Ekbia and Nardi (2017) suggest that the very nature of capitalism is being transformed as people turn to online sources of information generated by unpaid participants. Companies can produce new products without having to supply manuals and training, as these are provided by the public through YouTube videos and product reviews. Other corporations provide information services through apps like Siri, Google, Alexa, or Facebook, which rely on volunteer-generated information like Wikipedia and the World Wide Web. This shifts labor costs from corporate wages to the unpaid public—from the producer to the consumer. Economically, this can be seen as a new strategy of capital to reduce its production costs. Consumer inputs are monetized by software giants like Facebook, Amazon, Apple, Microsoft, and Google for use by corporate and political targeting.

The pervasive technological infrastructure of social media also plays a central role in the production and dissemination of "fake news," leading to the chaotic and simplistic character of public com-

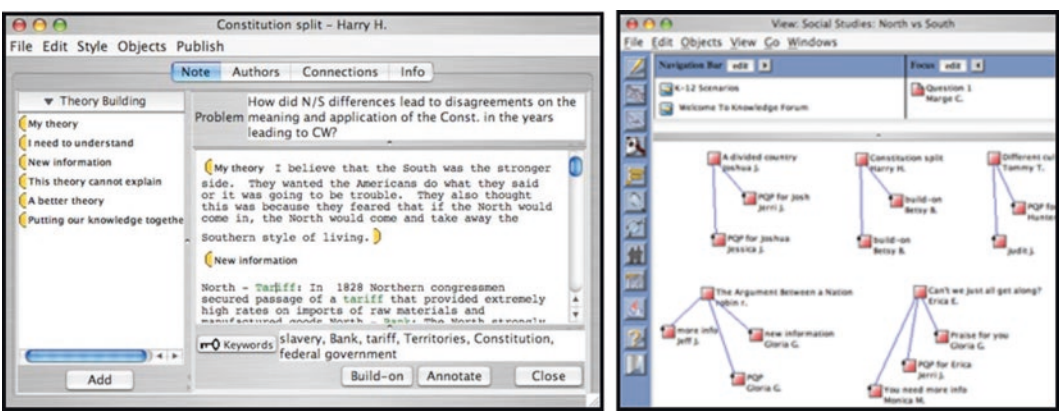

Fig. 1.2 Knowledge Forum interface. Students enter theory-building notes (left). A view of interrelated notes is displayed graphically (right)

prehension of the political world. Rushdie (2017) provides a sense of some of how this emerged with the Trump campaign. The modern-world ideals of rational thought, reasoned discourse, and graspable truth seem to have dissolved in a flash. Training in thoughtful group cognition and deliberative argumentation may be the best antidote to the destructive "groupthink" of emotionally charged political bubbles.

CSCL research has explored argumentation-support environments (as illustrated in Fig. 1.3) to accustom students to logical debate, to teach them to view social issues from multiple perspectives, and to discuss controversial topics through discourse platforms that support rational argumentation. These systems are often designed based on Toulmin's popular theory of argumentation structure. However, as Schwarz and Baker (2017) make clear, the Toulmin (1958) model is most appropriate for legal briefs; it does not apply to deductive mathematical proofs or to scientific hypotheses, let alone to informal debates, which feature emotion, prejudice, identity politics, and power relationships. The book by Schwarz and Baker reviews in detail traditions of multiple world cultures that led to the potential of deliberative discourse as a basis for informed democracy. Such deliberation in small groups of students can prepare them to make sense of the world and to negotiate equitable shared understandings. Skill in conducting reasoned discourse and collaborative knowledge building is the only antidote to the spin of fake news and the blinders of emotionally charged political bubbles. Students need to internalize critical debate practices in order to evaluate online information analytically.

Investigation 3 has opened up the CSCL vision, suggesting a post-cognitive epistemology centered on group interaction. The application of this vision to various domains of understanding could have positive implications for addressing current social issues. The following investigations zoom in and

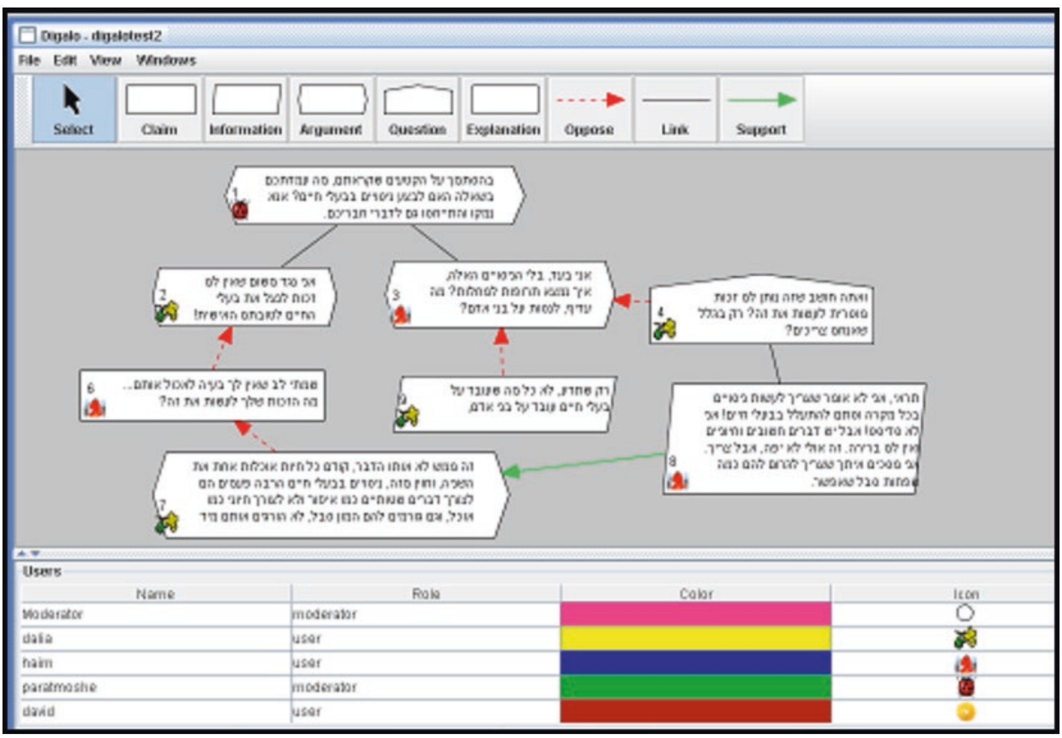

Fig. 1.3 The Digalo interface. Students contribute elements of an argument and represent their role in the overall structure of the argument

detail some of the theoretical and methodological issues involved in this expanded view of CSCL, such as intersubjective meaning making, discourse reference, artifact affordance, instrumental genesis, and knowledge practice.

Conceptualizing the CSCL Vision

One of the first *ijCSCL* papers to make an important contribution to a conceptual framework for the extended CSCL vision suggested above was another paper from *ijCSCL*'s first year. It proposed an analytic focus on intersubjective meaning making. Suthers (2006) [Investigation 4] claims that to study the accomplishment of collaborative learning, we must necessarily study the practices of intersubjective meaning making. In contrast to individualist epistemologies, where the individual is the learning agent, in intersubjective epistemologies the group is the learning agent. Collaborative knowledge construction locates the meaning making in its group context; the process of meaning making is itself constituted of social interactions. In CSCL, even if we sometimes ultimately want to track learning by individuals, we need to understand the processes of learning highlighted by intersubjective epistemologies, at both the interpersonal (group) and social (community) levels.

Meaning making in CSCL environments generally involves reference to representations, such as icons, words, and drawings. Jointly constructed representations become imbued with meaning for the participants by virtue of having been produced through an interactional process of negotiation (discourse aimed at a consensual conclusion). These representational constituents then enable reference to prior interpretations with deictic pointing (through gesture or language) or by direct manipulation in a digital environment. In this manner, collaboratively constructed external representations facilitate subsequent negotiations—increasing the conceptual complexity that can be handled in group interactions and facilitating elaboration of previous conceptions. The expressive and indexical affordances of a technological medium affect its value as a referential resource.

The notion of referential resource is further elaborated in terms of practices and usage by Zemel and Koschmann (2013) [Investigation 5]. They analyze how a group of students in a VMT session specify how they understand the mathematical problem they are given on the computer screen and what for them might count as a solution to that problem. The authors focus on referential practices, understood as the ways that actors refer to and represent problems and solutions. References are indexical, that is, dependent on their situation or circumstances of their occurrence for their local sense or meaning; they point or index into their context of production.

Math problems, for instance, are indexical phenomena that can be indexed in various ways. Students constitute the problem on which they are working by indexing it, pointing to it, and referring to its constituent properties, elements, and features in particular ways. (E.g., a line "looks perpendicular," it forms a right angle, it was constructed to be perpendicular.) The more refined their referential work, the more developed their understanding of the problem.

If some object or matter is something students communicate about and work with, they must have a set of shared interactional resources that allow them to refer to that object or matter in mutually intelligible ways. Thus, collaborative learning necessarily and centrally involves the interactional, shared construction of intersubjective meaning using referential resources. (See also Garfinkel (1967); Stahl (2015)).

Investigation 5 details the work of problem-solving as involving referential practices. Zemel and Koschmann show how when students in the VMT session build a representation of a problem in a particular manner using some combination of text and graphics the key to meaning making is not the representation per se. It is the process of building the representation and working with it in a way that allows for the selection and identification of its relevant indexical properties. (The building of representations and the identification of indexical properties—which take time or effort and distract from immediate accomplishments—may explain the intriguing paradox of "productive failure" in CSCL groups (Kapur & Kinzer, 2009)). The specific indexical or referential properties of a math problem emerge through the way in which whiteboard objects and text postings are sequentially produced in relation to each other.

The idea that the meaning embodied in representations and other artifacts is interactionally constructed as a group repeatedly uses them is further explored by Overdijk, van Diggelen, Andriessen, and Kirschner (2014) [Investigation 6]. They refine the concept of affordance (Dohn, 2009) by arguing that a technical artifact's potential for action only becomes available when learners and artifact connect and that the availability and realization of this potential are relative to the students who interact with the artifact and to the sociocultural context in which this takes place. When a group uses an artifact, the meaning of the artifact for the group undergoes a process of "instrumental genesis" (Rabardel & Bourmaud, 2003), in which the artifact is taken up in a specific way by the group, determining its possible significance for the group. To evaluate an innovative CSCL technological artifact, one must observe how it is used in practice. This implies a methodology of design-based research (DBR) and the identification of adoptions of group practices, as discussed below.

How a CSCL artifact is brought into use, or appropriated by students, involves a tension between the artifact, as it is used by students, and the intentions invested in the artifact by the designers or teachers. This tension may develop within a brief period in the context of joint activity and be eventually resolved through a complex set of group negotiations. The effective affordances of CSCL technology result from the interaction of the implicit intentions invested in the artifact by instructional designers and the active intentionality of the learners who perform actions upon the artifact. In this way, utilization of a technical artifact can be seen as a process of social construction that is generated through a dialectic of resistance and accommodation between human agency of the student group and material agency of the designed artifact.

When groups bring an artifact into use, they call upon sets of routines and procedures that have developed around previous use of that artifact or similar artifacts. In other words, the use of artifacts is situated in group practices and motivated by routines and procedures that have become sedimented in those practices. The set of group practices incorporates resources for communication as well as classroom norms, procedures, and other available technical artifacts. The group practices adopt and adapt specific social norms of the classroom that are relevant to the task at hand and the social practices that have formed around this task. Overdijk et al. describe the appropriation of an artifact as meaningful by a group that is using that artifact as a series of enactments whereby social norms and group practices become gradually associated with the artifact. Such appropriation is framed within the constraining and enabling conditions of the local situation; through it, the group produces new conditions, affordances, meanings, and understandings for future learning and action.

The idea that artifacts are brought into use and thereby granted specific meaning through the enactment of group practices is reconceptualized at a global level of human evolution by Ritella and Hakkarainen (2012) [Investigation 7]. At the same time, they reflect on the difficulties of implementing appropriate educational responses implied by this new conceptualization. The key to both their theoretical and practical considerations is the concept of "knowledge practices." Knowledge (or epistemic) practices are defined as routine (recurrent and appropriated) personal, group, and social activities related to working with existing knowledge and creating new knowledge. They include deliberate efforts to expand available intellectual resources by creating and building epistemic artifacts—symbols, concepts, technical terms, theories, inscriptions, visualizations, models, tools, etc.—which contribute to extending and preserving group knowledge.

Human beings do not have sufficient innate cognitive capacities to engage in the development of complex ideas within their individual brains; in order to pursue complex trains of thought, they have to, for instance, work on paper, make sketches, record information, and talk things out. Inscription and visualization allow human beings to establish a theoretic culture by gradually accumulating a wide variety of external symbolic storage systems. Experts can then internalize complex reasoning and memory capabilities through sustained habits of externally embodied cognitive practices. A crucial role in the evolution of our civilization was the emergence of external memory fields (lists of numerals, art, diagrams, writing, maps, spreadsheets, wikis, networked webs) that allow us to use our powerful visual system for elaborating, sharing, and building on externally represented ideas and creating exponentially growing external symbolic storage systems. In this way, human biological evolution over epochs has been extended by much more rapid cultural evolution (Donald, 1991, 2001), now amplified by technological evolution.

CSCL environments are designed to support the collaborative building of knowledge through construction of knowledge artifacts, which constitute locally created cognitive-cultural networks and mediate knowledge building. However, these goals must be brought into practice by students using them. Learning to engage in knowledge building requires the deliberate transformation of classroom-learning activities and student-participation routines, in order to capitalize on the potential epistemic mediation designed into these external artifacts. CSCL technologies allow for delegating cognitive processes to digital systems, creating mechanisms for fusing intellectual efforts in collaboration, and complementing personal epistemic resources with global networks that are accessible online. The vision of CSCL is to take advantage of forms of media in a way unthinkable in the past. Rather than assessing digital artifacts as merely isolated tools and signs, we should examine how they might radically transform human cognition and activity.

Conventional education focuses mostly on using the Internet for acquiring and consuming facts, rather than for creating new knowledge. By contrast, CSCL creates foci around which collaborative knowledge-building practices can be organized. Such environments could provide the material agency that enables even elementary-school students to participate in deliberate knowledge advancement, with adequate guidance and facilitation by teachers. The current textual practices prevailing at school, however, often guide students to use writing mostly for reporting what their textbooks say about issues being studied rather than using writing as a tool for extending thinking and deliberately generating new ideas and working theories. Adopting and cultivating a cognitive-cultural system that enables effective use of writing as a tool of thinking is difficult; it is an extended struggle to acquire embodied, largely tacit capabilities rather than direct assimilation of well-specified skills.

The CSCL vision involves educating students for future forms of cognition: technology-supported and collaborative—in groups and globally. The potential of human cognition continues to expand dramatically, and CSCL can help prepare students to appropriate the required practices and modes of learning. However, technological artifacts become instruments of human activity only through sustained and iterative efforts of using them in practice, a process through which cognitive-cultural activity gradually transforms and adapts according to evolving practices of using technologies. This evolution is reflected in deep-level changes in mental processes. Unfortunately, this must overcome considerable resistance and inertia. This is clear in the fact that it is still rare for students to appropriate the full potential of the written word after millennia of literacy (Ong, 1998). Not surprisingly, CSCL researchers have generally underestimated the in-depth challenges associated with students enacting new cognitive practices at the personal and collective levels.

Ritella and Hakkarainen argue that all successful cultures of CSCL are simultaneously also expansive-learning communities (Engeström, 1987) focused on problematizing current practices, envisioning changes, and gradually, step by step, consolidating novel inquiry practices. Through sustained collaborative activity, ideas, artifacts, methods, and practices—that do not belong to any one of the individual participants—emerge situationally and interactionally within groups from self-organized collaborative processes as meaningful and effective.

The expansion of the vision of CSCL with theoretical elaboration of concepts like intersubjective meaning making, referential resources, artifact affordance, knowledge practice, instrumental genesis, and cultural evolution prepares the way for understanding how CSCL in the future could contribute to intellectual development of new generations. The problem becomes a more practical one of evaluating the potential impact of proposed innovations. How can these theories guide the CSCL design process in analyzing trial interventions of CSCL prototypes?

Analyzing the CSCL Vision

The conceptual framework discussed in the previous sections has implications for CSCL methodology. It means that it is no longer sufficient to run simple controlled studies with some student groups using an experimental CSCL tool and the other students not using it—and then concluding that if the students in the experimental condition individually tested higher, then:

(a) The new CSCL tool led to more learning,
(b) The tool worked as designed.
(c) Collaborative learning is effective.

Rather, the theory suggests, for instance, that:

(a) Collaborative learning is a complex process that is in each case situated in specific group contexts and requires the understanding and analysis of meaning-making interactions.
(b) CSCL tools must be appropriated by user groups over time to determine their affordances in specific contexts.
(c) CSCL environments ultimately aim at enhancing the power of human knowledge building by providing artifacts that extend external memory, computational ability, and conceptual depth.

Analyses of interventions with new CSCL tools need to explore how teams of users take up—or fail to appropriate—the designed artifacts as knowledge-building tools. This generally involves scrutinizing:

(a) The discourse and actions within the team of students as it constitutes the team's intersubjective meaning making
(b) The temporal unfolding of interaction and, in particular, the instrumental genesis of CSCL tools as used by the team
(c) The team's adoption of group practices associated with the CSCL approach and resources

A number of *ijCSCL* articles in the past address aspects of methodology appropriate to accomplish such analysis of CSCL interventions.

The focus on student discourse is perhaps the primary consideration. This is motivated by theories focused on discourse, such as the theory of "commognition" (communication-based cognition). Sfard (2008) proposed that human cognition (thinking) is a derivative form of communication (speaking). Young children first learn to talk in family interaction, later engaging in self-talk, which eventually evolves into silent thought (see Vygotsky, 1930/1978, 1934/1986). Language was the first step in cultural evolution, leading to cognition by nomadic hunting teams, extended-family tribes, and eventually individuals (especially with the advent of written language). Commognition incorporates the response structure of interacting multiple voices even in an individual's solitary reflection (Bakhtin, 1986). In CSCL data, the sequential nature of discourse can be made visible in the structure of external-memory artifacts, including captured transcripts. Techniques of sequential analysis can be adapted to CSCL from conversation analysis, as systematized by Schegloff (2007), analyzing how utterances evoke and respond to each other in interactional processes of intersubjective meaning making, group cognition, and collaborative knowledge building [Investigation 25].

Sfard's book on thinking as communicating was reviewed in *ijCSCL* by (Stahl, 2008) [Investigation 8]. Sfard emphasizes how mathematical cognition can be conceived of and analyzed as particular discourses. How children come to participate in these discourses and individualize the dominant social language of mathematics into their personal math thinking involves discursive social processes—not rote acquisition of memorized facts and procedures but participation in co-construction of "realizations" (representational resources that index mathematical terms and figures). Sfard conceives this as participation in social "routines." Routines are meta-level rules that describe recurrent patterns of math discourse. Like Sfard's discussion itself, routines depict mathematical discourses rather than math objects. She describes in some detail three types of routines: deeds, explorations, and rituals. Deeds are methods for making changes to objects, such as drawing and enumerating squares on a digital whiteboard. Explorations are routines that contribute to a theory, like a student's proposal. Rituals are group practices that maintain the flow of social activity, like questioning and taking turns.

Learning mathematics can be conceptualized as participation in a discourse in which people engage in the social construction of mathematical objects. In collaborative learning of math, groups of students adopt group practices that mirror social practices of the school-math tradition as they explore math problems, propose solutions, and gradually employ technical terms. Through such participation, individual students can subsequently understand and personalize elements of the discourse.

Deep knowledge does not consist of memorizing discrete facts. There is not a single meaning of an equation or a theorem but a network of interrelated potential realizations. To deeply understand the object, one must be conversant with multiple such realizations, be competent at working with them, be cognizant of their interrelationships, and be able to recognize when they are applicable. This implies that evaluation of learning should not consist of testing individual memories but of observing the application of these key practices.

Consider how students might learn the concept of perpendicular bisector and its construction in Euclidean geometry. Öner (2016) [Investigation 9] analyzes how a group of students enrich their collective understanding of this math object during a session in the VMT environment. She employs Sfard's commognitive framework to examine how the student team's word choice, use of visual mediators, and adoption of geometric construction routines changed their character during an hour-long collaborative problem-solving session. Her findings indicate that the team gradually moved from a visually oriented discussion toward a more formal discourse—one that is primarily characterized by a routine of constructing geometric dependencies.

Öner's particular analytic focus is on the changes in (a) the team's use of the word "perpendicular," (b) the visual mediators the team acted upon (i.e., the example perpendicular bisector in the workspace), and (c) their mathematical routines, since the shifts in these features were the most salient aspects of their changing discourse. Öner's study investigates two routines:

1. The production of the perpendicular: This routine was gradually altered from drawing by visual placement to construction by creating dynamic-geometry dependencies.
2. The verification of perpendicularity: This routine for substantiating whether a line is in fact perpendicular to another line shifted from visual judgment or numerical measurements to use of theoretical geometry knowledge to justify proposed solutions.

Initially, the student team's notion of perpendicular referred to a visual image. It gradually evolved toward one that represented a mathematical relationship based on defining dependencies. These transformations of discourse and of construction practices took place within the context of group interaction, enacting task instructions and interacting with the VMT software, as analyzed in her sister paper (Öner, 2008). The team's shift to increasingly abstract thinking corresponds to a major development in human cognition—both in the evolution of the species and in the intellectual maturation of the group or its individual members.

The way that actions and conceptualizations shifted in starts and fits during the hour of interaction involving perpendiculars highlights the importance of temporality in learning. An article by Reimann (2009) [Investigation 10] addresses the need for temporal analysis in CSCL research more generally. For both the sociocultural and the individual-cognitive views of learning, the nature of the learning process is temporal: learning unfolds over time. Because human learning is inherently cumulative, the sequence in which experiences are encountered affects how one learns and what one learns. This applies to the communication and interaction processes that take place in groups as much as in the silent reflections of individual learning.

Reimann contends that the quantitative, variable-centered method dominant in most experimental learning research makes restrictive assumptions on the kind of data useful for analysis and on the forms of causation allowed to explain change. Adapting a process-analysis approach focused on temporality and sequentiality provides an alternative, still rigorous method to analyze group processes. Temporal-event analysis can offer a methodological link between those researchers in CSCL who are producing descriptive, **"**thick,**"** interpretive accounts of groups' computer-mediated interactions and those who work experimentally and quantitatively. However, existing process models in CSCL, which predominantly describe short-term interactions, will need considerable theoretical extension to connect with theories of longer-term change.

An example of temporal analysis is provided by Damsa (2014) [Investigation 11] in her examination of productive interactions. For her, "productive interaction" refers to knowledge co-construction within the context of a knowledge domain, entailing joint actions directed toward mutual goals, increased intersubjective understanding of concepts, and actions that contribute de facto to the construction and progress of shared knowledge objects. The emergent epistemic (knowledge) objects are key to collaborative learning because they influence the course and productivity of interaction. The knowledge objects become both outcomes and mediating elements in the interactional process. Damsa's study finds that groups who manifest shared epistemic agency produce knowledge objects that are more complex and better suited to the problems addressed. More than technological artifacts, which are adopted as mediating instruments, a group's knowledge objects can remain problematic and open to transformation and further exploration by the group.

It is essential to define the nature of productive interactions:

(a) How they are different from other types of interaction and how they lead to knowledge construction
(b) The temporality involved in the interaction
(c) The multiple analytic layers that comprise this process—including interactions, knowledge objects, agency, and their interconnections

The unit of analysis is not the individual student's mind but the joint action (verbal or otherwise) directed at the co-construction and elaboration of the knowledge objects involved—in other words, the mediated interaction. This leads us to the combination of the productive interaction, the objects that variously mediate this interaction, and the agency of the group as a construct of multiple individual engagements and collective action. The way these are woven together is intimately related to the temporality of the longer collaborative-learning process and to how these components combine while unfolding in time.

One distinctive contribution of Damsa's empirical examination is its effort to follow, along with the unfolding interaction, the knowledge that emerges and gains shape through the interaction. This analysis focuses on the trajectory of the knowledge from the moment it enters the interaction process until it has materialized and is elaborated into the final objects produced by the groups. The productivity of the interaction manifests itself through the sequence of actions in the interaction that leads to the co-elaboration of knowledge objects. Organizing and attending to the sequential structure in which knowledge is not only generated and discussed but also taken up, elaborated upon, and refined are of essential importance. (See Suthers' notion of "uptake" in Investigation 4.) Early versions of knowledge objects often play a catalyzing role in groups' extended interactions, influencing how interaction changes or adjusts with time, in order to become meaningful for the co-construction of shared knowledge objects.

Analysis of the temporal structure of interaction can take many forms. Çakir, Zemel, and Stahl (2009) [Investigation 12] show how participants in a VMT session sequentially construct graphical animations of their shared mathematical representations in order to build intersubjective meaning. In order to collaborate effectively in group discourse on a topic like mathematical patterns, group participants must organize their activities in ways that share the significance of their utterances, inscriptions, and behaviors. This case study investigates the moment-by-moment details of the interaction practices through which the students organize their chat utterances and whiteboard actions, highlighting the sequentiality of action and the implicit indexicality of the intersubjective meaning making. This is a nice example of the use of graphical inscription to take advantage of visual skills.

A student constructed the whiteboard diagram of the stack of blocks at the bottom of Fig. 1.4 (left) by successively adding columns of blocks. The student first took the highest existing column and copied it to form an additional column and then added an extra block at the top. The sequentiality of this construction process made the mathematical pattern clear to everyone in the group: that the number of blocks increases with each new column by one more that the amount it increased with the last column. This visual articulation of the structure to the pattern allowed the group to quickly derive its formula. Similarly, the array of hexagons in Fig. 1.4 (right) is overlaid by one of the students with colored lines that first divide a composite hexagon like the outlined hexagon into six symmetrical sec-

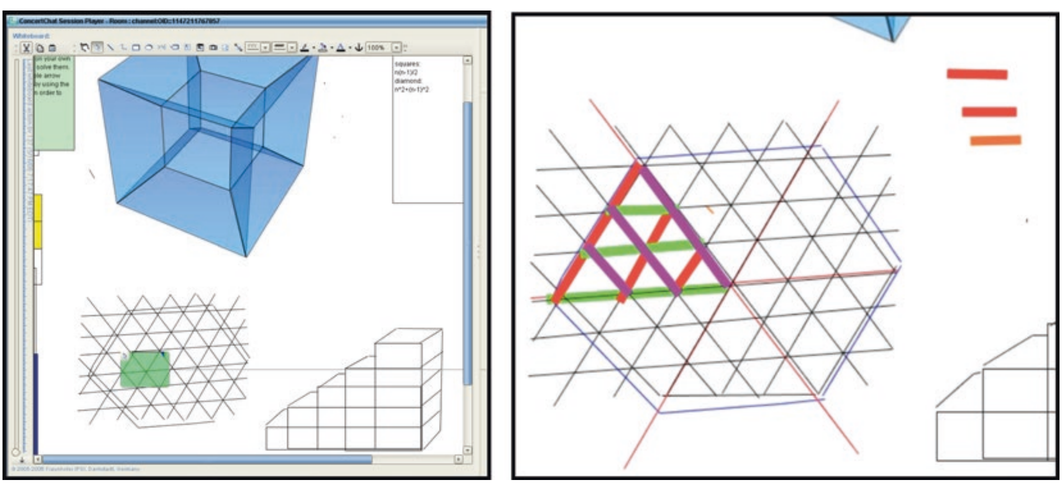

Fig. 1.4 The VMT interface with a student construction of a hexagon array and of stacked blocks (left). Colored lines decompose a large hexagon into sequences of small triangles (right)

tors. Then the lines crossing one of these sectors are overlaid by lines of different colors. The sequentiality of drawing these lines makes visible and consequent the structure of short lines constituting a hexagon with sides of N units. Namely, there are 1 + 2 + 3 + … + N units in each of the three directions within each of the six sectors. This visually observable structure leads the group directly to a mathematical expression for the number of unit triangles and lines for any size hexagon.

The sequential temporal analysis by Çakir et al. treats the whiteboard as a kind of shared external memory or "joint problem space" (Teasley & Roschelle, 1993) where the group builds up, shares, and preserves a record of agreed-upon facts, opinions, hypotheses, or conclusions. Shared visible communication media like this can provide places where the group does its work—where it cognizes. Ideas, concepts, meanings, and so forth can subsequently be taken up by individuals into their personal memories as referential resources for future social or mental interactions. There is no need to reduce group meaning to identical individual mental contents; the location of the group cognition and group memory is the visible discourse medium, with all its particular affordances and modes of access (e.g., graphical, representational, symbolic, spatial, highlighted, color-coded, labeled, etc.). Mental representations in individual minds inaccessible to each other, when they exist, are derivative of the public presentations.

In another temporal analysis of collaborative learning in the same sequence of VMT sessions, Medina and Suthers (2013) identified a set of group practices that the student team adopted as representational resources. This included the use of colored lines to establish shared indexicality. The analysis was based on a detailed tracking of the development of several practices that individual students introduced to the team and that were gradually adopted as shared group practices. Interestingly, the tracking of this development was done retrospectively, by successively following the usage backward through the group sessions (Medina, 2013). This analysis also demonstrated that the practices were collectively understood as group practices and effectively shared as personal practices (knowledge, skill) in the end because each student was ultimately able to initiate use of each practice within the group interaction.

In these papers, the problem of common ground—controversial in CSCL [Investigation 20]—is reconceptualized from an issue of converging personal mental representations (e.g., in Clark & Brennan, 1991) to a practical matter for the group of being able to jointly relate semiotic objects to their indexed referents [Investigation 5]. The analyzed references do not reside in the minds of particular actors but have been crafted into the presentation of the chat postings and drawing inscriptions through the details of wording and sequential presentation. The references are present in the data as affordances for understanding by group participants as well as by researchers studying transcripts of the interaction. The meaning is there in the visual presentation of the communication objects and in the network of interrelated references, rather than in presumed mental representations of them. The understanding of the references is a matter of normally tacit social practices, rather than of rationalist explicit deduction [Investigation 15].

The analysis of group practices in CSCL interaction data shows how the group discourse negotiates the adoption of practices (whether invented by the group or derived from personal or community practices) (Stahl, 2017). The group practice may be subsequently used without further explicit discussion. The use of this practice is then shared in common by the group and grounds the group's further activity. This reconceptualization of common ground overcomes the problematic tension in previous psychological versions of the concept as personal mental representations that somehow become shared by a group or community.

The practices of the group may be related to personal skills of the individual group members as well as to countless social practices established in the larger community or culture. For instance, the students in the VMT team brought in the mathematical practice of summing the sequence 1 + 2 + 3 + … + N to Gauss' well-known summation expression (N + 1)/2. On the other hand, the practice of overlaying colored lines on a whiteboard diagram had to be explained by one student to the others, who did not know how to select colors for lines in the interface. Both of these practices were adopted by the team and then understood and used repeatedly by all team members as "group practices" [Investigation 16] contributing to productive interaction.

The considerations about analysis and evaluation of CSCL interactions discussed in this section indicate how to address the theoretical views of collaborative learning presented in the previous section:

(a) Analysis focuses on the group discourse and visible actions as contributing to intersubjective meaning making.
(b) The temporal development of the group's use of tools, terminology, and referential resources is followed closely.
(c) The team's adoption of group practices—which may indirectly contribute to group members' individual intellectual development—is tracked and documented.

It seems that CSCL research may be on the verge of fostering significant, urgently needed development of human cognition through the design of instruments of collaboration or external memory and by promoting the acquisition of associated group practices that exploit those tools in productive ways. Then the next question is how we can proceed to disseminate the early successes, innovative approaches, and timely visions of CSCL. There is no point in waiting for some technical perfection of the field, for maturity and impact of CSCL will only come with experience meeting authentic needs in genuine educational circumstances.

Delivering the CSCL Vision

CSCL is advanced through pioneering forms of computer support, as well as theoretical and methodological innovation. Many CSCL research labs have focused on the development of new forms of computer support and/or the design of online environments to foster collaborative learning. This book is not the place to review such efforts, as important as they may be for transforming theoretical understanding of collaborative learning into practical efforts to promote and sustain knowledge building within student groups. However, three rather diverse examples of innovative pedagogical design and technological support are recommended to illustrate inventive ways to extend the CSCL paradigm. Although they could not be included in this already thick volume, they are available in back issues of *ijCSCL*:

1. Schneider and Pea (2013) explore the use of eye-tracking hardware in an online collaboration environment. The traces of where the participants' eyes are looking can be made available to the students themselves in real time, as well as to researchers retrospectively. When the students see where their partners are looking, they adjust their own visual attention. This can enhance joint attention. Just as we see in Investigation 12, joint attention can be required for productive collaboration. This component of shared understanding and intersubjectivity will be discussed at length in the theoretical and philosophical investigations of part III. Access to eye-tracker traces for CSCL researchers can be useful for formulating objective measures of common ground.
2. Chen, Scardamalia, and Bereiter (2015) provide a new feature within Knowledge Forum for classes to promote what the students identify as "promising ideas." This provides support for the group to reflect upon directions to pursue in their own collaborative discourse. This feature appears to be a promising idea for extending this popular software, even for use by students as young as 8 years old.

3. Kapur and Kinzer (2009) discovered one of the most intriguing results of CSCL experimental research. They determined that allowing collaborating student groups to struggle and even fail at tasks that are ill-structured and beyond their skills and abilities may be a productive exercise in failure. The "failed" groups may develop relevant group practices of conceptualization, decomposition, representation, inscription, or problem-solving that are useful in subsequent efforts, whether collaborative or individual. This discovery has implications for sequencing the presentation of problems and challenges for collaborative work—an important but subtle part of CSCL curricular design. The efficacy to long-term group learning of temporary failure also problematizes the traditional emphasis on testing the short-term success of individuals.

As emphasized above, new technologies and curricular interventions need to be tested, investigated, and developed in realistic settings. Designers need to see how groups of students use and enact the designed objects. Simple pre-/posttests of learning effects are not generally adequate, although they may play useful roles within the larger research context. Sequential analysis is often necessary to see how interacting student teams make intersubjective meaning through the mediation of the designed artifacts and how they produce knowledge objects over time [Investigation 2]. Identifying the adoption of group practices may inform and even guide this analysis.

Design-based research (DBR) is widely recognized in CSCL as a necessary approach to technology design. This provides a research structure for observing how student teams take up the intended affordances of innovative technology, pedagogy, and curricular resources. In the DBR process, theory and analysis methodology coevolve along with the design of the various components of the intervention. There is no corresponding accepted methodology for evaluating the performance of designs as they go through iterations of testing, evaluation, and redesign. The methods for critiquing the design of the technology, pedagogy, and curricular resources must be derived from the theory, which emerges from analysis of the student interaction during sequences of trials. This is where the focus on intersubjective meaning making, referential resources, instrumental genesis, epistemic objects, temporal sequentiality, and adoption of group practices is needed.

Nevertheless, even once one has determined that a CSCL innovation has been adequately refined, there is still much to do to put it into widespread practice. One key to delivering the CSCL experience to students in a systematic way is the involvement of qualified teachers. As illustrated in the following, each of the major efforts so far to implement CSCL in schools has emphasized teacher preparation. Experience has shown that CSCL requires a classroom culture of collaboration. Establishing such a culture requires the leadership of experienced teachers, who know how to guide student discourse and encourage student agency without being invasive and interfering in the collaborative interactions themselves. It generally takes at least 3 years for even a motivated early adopter teacher to transition from leading a teacher-centric classroom to facilitating a collaborative-learning one.

The VMT project offered teacher-professional-development credits in teaching collaborative dynamic geometry through the Math Forum and masters level courses at Drexel and Rutgers-Newark Universities for in-service mathematics teachers. In these courses, teachers participated in the same VMT curriculum as their students would later use, although the teacher discussions included pedagogical issues as well as a more sophisticated mathematical discourse (Alqahtania & Powell, 2017).

In Singapore, Hong Kong, Canada, Finland, and other countries in which CSCL has been systematically introduced into school systems, teacher training has always been the emphasis. Researchers worked with individual teachers over extended periods, and early adopter teachers served as mentors for other teachers in their schools. The most commonly used CSCL technology in these countries has been Knowledge Forum. Bereiter and Scardamalia (2018) comprehensively review all major aspects of this technology and pedagogy, including teacher preparation. The lead researchers in Singapore and Hong Kong have provided insightful reflections on their experiences as well, as summarized in the following review of two reports in *ijCSCL*.

In Singapore, the national government legislated transformation of schooling to meet twenty-first-century cognitive needs. They established an academic research lab to plan, spearhead, and evaluate this effort. The lab recruited CSCL researchers from around the world as staff and collaborators. Some of the leaders at that lab reflected on their approach in *ijCSCL*. Looi, So, Toh, and Chen (2011) [Investigation 13] note that research supported by individual grants to researchers has produced interesting ideas and small-scale proofs of concept. However, when one thinks about transforming school systems, one sees that the CSCL tools are fragmentary and scattered. Putting together a coherent classroom program requires a variety of work that has not yet been done for CSCL. This requires a serious commitment from all concerned.

In Singapore, the authors report, there exists a combination of strong, explicit top-down directives and bottom-up desire for transforming and improving the educational system. Looi, So, Toh, and Chen argue for design-based research as the methodological framework for designing and enacting school-based research that can impact school practices, as well as for refining theoretical understandings on how beliefs about the premises of CSCL are shaped and changed in the course of research implementation. They discuss their research innovations from a systemic-change perspective that includes the micro, meso, and macro levels of educational systems. Their paper reviews policy imperatives governing Singapore's educational landscape as macro-level actions; sociocultural factors of the school's learning ecology as meso-level considerations; and contextualized classroom-based interactions as micro-level factors.

The Singapore educational national plan (adopted in 2008) explicitly foregrounds a central role for technology-enabled learning: to develop students to be collaborative learners. Significantly, it also recognizes the need to address the curriculum and assessment conundrum in order for technology-enabled pedagogical practices to really take off in schools. This was addressed through four major phases of systemic-change processes for sustainability at the macro level: (1) creation of readiness, (2) phasing of changes, (3) institutionalization, and (4) ongoing evolution and creative renewal of the policies.

The Singapore effort to bring CSCL to scale in a (relatively small, culturally homogeneous) national school system addressed the complex interrelationship among teachers, school culture, leadership, and educational policies. Effectively scaling up encompassed four interrelated dimensions: depth, sustainability, spread, and shift in reform ownership. Depth refers to consequential change in classroom practice, altering teachers' beliefs, norms of social interaction, and pedagogical principles as enacted in the curriculum. Sustainability involves maintaining these consequential changes over substantial periods. Spread is based on the diffusion of the innovation to large numbers of classrooms and schools. Shift requires districts, schools, and teachers to assume ownership of the innovation—deepening, sustaining, and spreading its impact. Beyond these dimensions comes evolution, in which the innovation, as revised by its adapters, is influential in reshaping the thinking of its designers and creating a community of practice that continues the innovation process.

Design-based research was iterated in selected Singapore schools, as researchers who were engaged in design of technology and curriculum worked with teachers to enact the design in classroom settings, researched the contextualized learning processes, developed or refined theories of collaborative learning, engaged in redesign, and continued the cycle of redesign and implementation. With the realization that both teachers and students initially lacked the expertise to facilitate collaborative learning, the researchers and teachers co-designed many classroom sessions using a relatively simple CSCL tool, Group Scribbles. This digital Post-it-Notes technology allowed students to compose, share, and compare notes combining text and drawings.

A number of factors listed below were key to eventual success:

- Routine use was emphasized in the classroom from the outset. In the first school worked with, the teachers were supported for a period of 2 years in the routine use of the technology in weekly lessons. The routine practices helped alleviate the novelty effect of experiencing a new technology and the associated innovative pedagogy.

- The technology was simple and easy to use. However, there was not a technology focus at the outset. Instead, enculturation opportunities were provided for the teachers and students to enact collaborative practices first, before using the technology.
- Face-to-face CSCL technology was used in class to mediate student-student and student-teacher conversations, increasing the bandwidth of communication.
- Design principles were adopted and refined to empower teachers to design collaborative activities. The objective was for the teachers to be ingrained with sound design principles for designing pedagogy, so that even without the use of CSCL technology, the teachers would incorporate notions of rapid collaborative idea improvement in their teaching.
- New lessons tapped existing curriculum and thus were integral to the learning of the curriculum.
- The lessons were co-designed by the teachers and researchers, providing ownership by the teachers of the lesson plans and resources. Toward the later part of the intervention, teachers were able to devise their own CSCL activities to share their experiences and lesson plans with teachers at other schools.
- There was extensive professional development for the teachers, especially to help them orchestrate collaborative-learning activities in the classroom.
- Going to scale involved systematic expansion, eventually leading to deeper pedagogical changes in teaching and learning practices.
- Maintaining ongoing dialogues between researchers and teachers was important so that schools could ultimately benefit from the enduring and synergistic alignment of policy, practice, and research.

The effort to adopt CSCL in Hong Kong had a somewhat different approach but many parallel lessons. Chan (2011) [Investigation 14] reports on the establishment of classroom cultures and communities of practice among teachers in schools and systems. She draws on experiences in Hong Kong and examines research-based CSCL classroom innovations in the context of scaling up and sustaining a knowledge-building model in Hong Kong classrooms.

Classroom innovations involve complex and emergent changes occurring at different levels of the educational system. The experience of CSCL knowledge-building classroom innovations in Hong Kong schools included research, interventions, and teacher support at three major levels: the macro-context of educational policies and educational reform, the meso-context of a knowledge-building teacher network, and the micro-context of knowledge-building design in classrooms. At the macro level, the Hong Kong case study begins with educational reforms and the policies of the Hong Kong government that provided a favorable context for CSCL classroom innovation. At the meso-level, its focus is on how a knowledge-building teacher network supported teachers' changing attitudes toward classroom innovation. The study also addresses the micro-level classroom design to illustrate how principles, pedagogy, and technology are integrated, considering the sociocultural context, for example, the strong emphasis on examinations in Hong Kong schools. Three interacting themes—(1) context and systemic change, (2) capacity and community building, and (3) innovation as inquiry—are proposed for examining collaboration and knowledge creation for classroom transformation.

The transition from micro-level case studies of isolated small groups using CSCL technology to *whole school systems* adopting the CSCL vision is challenging. Epistemological and cultural factors, such as student beliefs and the tradition of teachers working as individual (largely isolated and autonomous) professionals, are generally not congruent with research in learning sciences and CSCL. Organizational and school-level constraints make it very difficult for teachers to reflect collectively on their practices and engage in sustained expansive learning in CSCL environments.

Furthermore, the current CSCL tools are limited and require surveying what is available; adapting it to the local conditions; setting up infrastructure; carrying out missing research; adopting long-term approaches to training and supporting teachers; and affecting a cultural change of public expectations, understanding, and attitudes. These require massive funding for resources such as coordinated research, infrastructure, administrative support, training, teacher time for mentoring, textbook materials, and public education.

Addressing these barriers and needs, various teacher communities emerged in Hong Kong, some spontaneously and some supported by the government and universities. Through technological advances and CSCL research, a new kind of structure—a teacher network—emerged as a type of meso-level bridge from government policy via *capacity building* to classroom implementation. The knowledge-building teacher network—organized and supported by Chan's research group with national funding and commitment—initially focused on helping teachers to reflect on their pedagogical beliefs or practices and to contrast them with the knowledge-building model of collaborative learning associated with Knowledge Forum software.

The teacher-network community played a central role in supporting change in Hong Kong schools. Research revealed that teachers go through different phases in adopting technology and that communities of practice are useful for scaffolding and connecting technology use with principle-based understanding. One approach is to engage teachers in using technology in ways that are aligned with principles, pedagogy, and assessment, thus affording them deeper insights. Teachers in the network were encouraged to contribute their reflections to community discussion boards, to help them experience how technological affordances connect with pedagogy. Tool development for the assessment of knowledge building is not just for research analysis; the tools can be placed in the hands of teachers and students so that they might take agency to reflect on their work.

The key lesson is that researchers do not just ask schools and teachers to adopt pedagogy developed in other classrooms; they work together with teachers to create new usable knowledge, to *innovate* themselves. Co-inquiry and knowledge creation—not the imposition of ready-made innovation—is a central theme in designing and facilitating collaboration in professional communities. Within the teacher network, researchers and early adopters (often supported with paid leave from their classrooms to work with other teachers) collaborated with teachers new to the network.

One can consider such group teacher professional development as knowledge creation, with teachers working collectively to build shared knowledge. More broadly, a teacher network may provide a meso-level structure that coordinates and regulates macro-level political, institutional, and cultural influences on micro-level classroom processes and student change. The Hong Kong researchers adapted CSCL discussion technologies to support the teacher network throughout Hong Kong. They also employed CSCL methods of discourse analysis to analyze the meso-level interactions among teachers reflecting on their classroom experiences.

Singapore and Hong Kong are both special cases of national school systems under pressure to prepare a workforce for leadership in a technologically sophisticated global economy. It is striking that the results of the first PISA study of collaborative problem-solving (OECD, 2017) ranked Singapore number 1 and Hong Kong number 3 out of 51 countries tested in 2015, a couple years after the interventions reviewed here. PISA uses a very different methodology than what has been discussed here. However, the case studies by the Singapore and Hong Kong researchers demonstrate that propagation of CSCL approaches is possible in mainstream classrooms. Furthermore, their thoughtful reflections on the efforts in these countries provide multiple important lessons and recommendations.

Propagating the CSCL Vision

In this investigation, we have considered a vision of collaborative learning, illustrated by the VMT prototypical research effort. The scope of CSCL was then extended in response to contemporary theory and current social issues, clarifying the distinctiveness and priority of intersubjective meaning making, instrumental genesis, epistemic objects, and other theoretical and analytic constructs. These conceptualizations suggested approaches to evaluation of CSCL interventions in terms of sequential analysis of discourse and adoption of group practices mediated by appropriated artifacts—filling a need for a methodology appropriate to CSCL theory. Examples of efforts in Singapore and Hong Kong to bring the CSCL vision to scale in educational practice were then reviewed. Now we need to consider how to realize this vision of CSCL more generally.

We begin by considering how our prototypical example of CSCL could be scaled up for routine use in schools around the world. After 15 years of grants and collaboration with many international researchers (see Stahl, 2009), VMT had been developed to the point at which it establishes a proof of concept for the VMT vision and the associated theory of group cognition (Stahl, 2006), applied to collaborative dynamic geometry. The software is robust enough for classroom usage—in both desktop and mobile versions. A core concept of the domain has been identified: dependencies in geometric constructions. Corresponding to this concept, curriculum for introducing dynamic geometry has been developed through numerous iterations and has been used in trials with researchers, math teachers, and students in and outside of school (Stahl, 2013). Teacher professional development has also been offered, using the same curriculum, supplemented with resources for teaching using collaborative learning.

It seems clear that the VMT prototype could be scaled up. Dynamic-geometry software like Sketchpad and GeoGebra are already used in many math classrooms worldwide, although without support for online collaboration or a systematic curriculum. The VMT project ported the free, open-source GeoGebra software to the VMT multiuser collaboration platform. The developers of GeoGebra would be willing to adopt and support this kind of multiuser version if they saw a broad demand for it. Their software is already used in 190 countries and translated into 65 languages. The Math Forum subsequently became part of the National Council of Teachers of Mathematics, an ideal dissemination center in the USA. Thus, the technical infrastructure and access to individual teachers seems to be at hand.

The VMT curriculum was largely based on Euclid's original, orderly presentation of geometry and on the US Common Core geometry curriculum. It could now be further elaborated to tie in to major textbooks so that online collaborative sessions could be held in conjunction with traditional lectures, textbooks, YouTube videos, and homework assignments. Teachers could orchestrate the collaborative learning to serve different functions within math courses: exploration, challenge problems, or roles that are more central. Teacher guides could be prepared, directing teachers how to modify, excerpt, extend, or adapt the session presentations to their classroom contexts. The curriculum could also be developed for use in different cultures or countries, translating the approach as well as the language. Finally, additional curriculum could be written for other math topics—GeoGebra is designed for all middle-school, high-school, and early college mathematics, not just geometry. Once students, teachers, and schools have positive experiences with collaborative learning or with a given CSCL technology in one course, they are much more prepared and motivated to use it in other areas.

Similarly, other proven CSCL interventions—bearing family resemblance to the VMT prototypical example—could be scaled up to global adoption. One could, for instance, identify a core underlying concept of a selected domain to target or specify certain social practices that would be important for groups to adopt to facilitate their knowledge building in that domain. For example, just as Stahl (2013) identified dependency as fundamental for geometric thinking, Roschelle (1992) identified acceleration as fundamental for physics and analyzed student discourse for signs of adoption of group practices associated with this concept. Then, carefully sequenced and articulated topics could be presented for collaborative exploration, with guidance to stimulate productive interaction and knowledge-building discourse.

This could be coordinated with related course materials and instructional approaches and accompanied by support for teachers to adapt and orchestrate the various resources. Researchers would need to collaborate with teachers over extended periods, as adoption of the CSCL intervention spread gradually and systematically through school systems. Given new educational networking platforms like MOOCs, collaborative curricula could be made available to students globally to learn together. This could both establish personal international cooperation among students and share curricular resources among developed and developing nations.

Such an envisioned scaling up of CSCL would require significant long-term commitment from government agencies to finance the research, dissemination, training, evaluation, and support—as began to take place in Singapore and Hong Kong. CSCL research labs involved in such efforts would need to pool expertise in domain knowledge, learning theory, educational practice, teacher training, discourse analysis, software design, research expertise, grant management, and other skills. Ideally, this would involve global networks of researchers. The kaleidoscope funding during the late 1990s in the European Community might be considered the golden age of CSCL, where networks of researchers across Europe collaborated, resulting in some of the research reviewed above. Now a broader worldwide initiative is required, eventually including an emphasis on dissemination in school systems.

Advancing the CSCL vision is feasible today. CSCL theory can be refined and integrated to provide a unified conceptual framework for understanding collaborative learning as distinctive and as foundational for all learning. CSCL methodology can incorporate the sequential analysis of adoption of group practices. CSCL curriculum can be extended to meet worldwide needs. CSCL can play a driving role in evolving humanity to meet the challenges of the twenty-first century.

Significant progress in CSCL, especially including propagation to regular classrooms, is not a task for an individual researcher or even a single lab. It requires too many advanced professional capabilities and too great a long-term commitment. The CSCL community cannot manage this on its own. However, if the CSCL field is not centrally involved in setting the agenda and designing the direction, then the power of the CSCL vision to advance human cognition is unlikely to reach fruition. If the vision of CSCL can be maintained and exert a broad impact, then the discourse of humanity might be able to evolve a more complex understanding of phenomena like ecological sustainability, world peace, economic equity, and informed political involvement. That would profoundly advance the CSCL vision and benefit the world.

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Investigation 2. A Theory of Group Cognition in CSCL

Gerry Stahl

Abstract

The digital age of computer support has transformed human cognition. Although thinking always had social origins in the small-group interaction of family units, tribes, work teams, and friendships, cognition is now enmeshed in networks of social media, technological infrastructure, online knowledge sources, and global production. Computer-supported collaborative learning (CSCL) stands at the crossroads of this historic transformation. CSCL research provides a laboratory for studying the nature of collective intelligence or group cognition. It explores how collaborative learning by small groups can become a foundational form of knowledge building—including for the individual group members and for the society in which the groups live. This introductory Investigation presents a paradigmatic CSCL setting and highlights the role of group practices as vehicles for collaborative learning. It addresses the dual questions of how intersubjectivity is possible and what the preconditions are for establishing, supporting, and maintaining intersubjectivity—providing central pillars of a theory of group cognition and suggesting implications for educational practice. It then delves into the structure of collaborative discourse, analyzing data from exemplary CSCL sessions. The analysis of group interaction points to a multilayered structure, in which individual, small-group, and cultural cognition are intertwined.

Keywords

CSCL theory · Group practice · Paradigm example · Social practices · Co-experienced world · Intersubjectivity · Discourse structure · Multilayered analysis

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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A Theory of Extended Cognition

The notion of group cognition proposes that human thinking and learning is at root interactional; the origin, influence, and effect of human cognition extend essentially beyond the skull. We acquire our ability to think and to learn by adopting practices that arise within small-group interactions, such as in our family, work teams, or collegial circles. Our thinking is responsive to and conditioned by our embeddedness in a physical, interpersonal, and cultural environment—particularly the immediate discourse or action context. Our thought is oriented toward potential futures, which it opens for our interaction with others.

Group cognition theory poses an alternative to psychological theories of mental phenomena in individual minds as well as to sociological theories of societal structures existing independently of the people who inhabit those structures. According to group cognition theory, thinking and learning take place in the interactions among people and across the small groups of interacting individuals.

The theory of group cognition arose from study of student discourse in CSCL settings. It is aligned with the writings of Vygotsky, Lave, Bereiter, Koschmann, Engeström, and Hutchins as well as with sociocultural, distributed-cognition and embodied-cognition approaches generally. However, it maintains a systematic focus on the small-group unit of analysis, which others often lose to a psychological or sociological priority for the individual or society. It is also in keeping with twenty-first century post-cognitive philosophy, such as that of Marx, Heidegger, and Wittgenstein—who critique mentalism and individualism.

Theoretical Investigations of Group Cognition

The theory emerged in the writing of *Group Cognition* (Stahl, 2006, MIT Press). Aspects of the VMT research project and technology were developed and described in *Studying Virtual Math Teams* (Stahl, 2009, Springer). Various perspectives on the research were extended and explicated in *Translating Euclid* (Stahl, 2013a, Morgan & Claypool). A detailed longitudinal study of a team of students engaged in successful collaborative learning of dynamic geometry was analyzed and presented in *Constructing Dynamic Triangles Together* (Stahl, 2016, Cambridge). The theory of group cognition has important consequences for the methodology of the learning sciences and for educational practice, as well as for CSCL technology design and design-based educational research.

The implications of these studies of the VMT Project (2002–2016) for the theory of group cognition are taken up in the Investigations of Part III of this volume. Investigation 2 presents an introduction and overview of those essays, which represent my most important recent theoretical reflections on group cognition:

- Investigation 15. *A Paradigmatic Unit of Analysis*. A specific example of CSCL research is presented as a useful prototype for thinking about the field of CSCL: the Virtual Math Teams (VMT) Project. It was designed to develop a technology platform and pedagogy for sustaining collaborative learning within small groups of students discussing mathematics and solving problems together. The VMT online environment was instrumented to collect data of student interactions. Using this example, it is argued that CSCL can offer a distinctive and timely new vision of educational research, focused on the small-group unit of analysis.
- Investigation 16: *Group Practices*. Using multiple examples from VMT sessions, it is suggested that the adoption of shared practices by student teams is central to the collaborative learning that takes place in these groups. Group practices may or may not be derived from or related to either individual or cultural practices (such as rules from school mathematics), but they are adopted by

the group in its collaborative work. Effective curriculum can be designed to encourage adoption of strategic group practices that contribute to skilled behavior in the contemporary world. Collaborative learning can be defined, designed, supported, fostered, and evaluated in terms of the adoption of specific relevant sets of group practices.

- Investigation 17: *Co-experiencing a Shared World*. CSCL raises the question of how multiple individuals can "share" practices, learning or thinking as proposed by the concept of group cognition. In this Investigation, examples of discourse data from several VMT sessions show how the members of an effective group participate together within a shared world. This experience of interacting within a co-experienced world provides a basis for their shared understanding. There are many ways that group members negotiate and sustain joint attention to objects, experience them together, negotiate their shared understanding, and repair potential misunderstandings.
- Investigation 18: *From Intersubjectivity to Group Cognition*. The question of how people can share understandings and understand each other is a philosophical issue. It has been discussed by a series of philosophers and social scientists. This Investigation tracks an evolving analysis of this discussion through about a dozen stages, culminating in the theory of group cognition.
- Investigation 19: *The Constitution of Group Cognition*. The analysis of three VMT examples of interaction shows typical mechanisms used to achieve intersubjectivity. In particular, groups engage in extended sequences of dialogical responses to each other, building longer argumentation structures, such as informal derivations of mathematical conclusions. They remain involved in persistent co-attention to shared objects of interest. By co-experiencing these microworlds, they establish and maintain shared understanding.
- Investigation 20: *Theories of Shared Understanding*. The usual view on how shared understanding among multiple minds is possible involves the notion of "common ground." This Investigation considers several prevalent, competing theories, including that of common ground. They are subjected to analysis in terms of evidence of how small online groups of students develop, check, and maintain shared understanding, thereby constituting group cognition.
- Investigation 21: *Academically Productive Interaction*. The recent pedagogical theory of "academically productive discourse" or "accountable talk" is primarily oriented toward individual cognition. Accordingly, it adopts the approach of cognitive convergence, guiding individual students to converge their own understandings with the understandings of other students, the teacher, or the community. In the alternative paradigm of group cognition, one tries to guide groups of students to maintain and build on their copresence and intersubjective, shared understanding to articulate their largely tacit shared group understanding.
- Investigation 22: *Supporting Group Cognition with a Cognitive Tool*. CSCL is motivated by the potential to design technologies to support collaborative learning. In this Investigation, the use of a pointing tool in the VMT environment is explored. The tool permits a student to point with a graphical connecting line from a current chat-text posting to a previous post or to an object or area on the shared whiteboard. This supports deixis, the ability to direct the attention of others to an object of interest. Pointing is a ubiquitous means for supporting joint attention; this tool provides an effective digital analog of physical pointing.
- Investigation 23: *Sustaining Interaction in a CSCL Environment*. Interaction in groups takes place through sequences of actions, such as text-chat postings, spoken utterances, drawing movements, or bodily gestures. These can often be analyzed in terms of pairs of actions, such as the posing of a question followed by the offering of an answer. Here, the question elicits an answer, setting the stage on which a respondent is encouraged to provide an answer. In turn, the answer confirms by its responsiveness that the preceding action was taken as a question and completes the meaningful question/answer interaction. While a question encourages interaction to continue with an answer,

the answer could end the interaction. To sustain interaction, such response pairs must themselves be combined in larger structures.

- Investigation 24: *Viewing Learning and Thinking in Groups*. This Investigation proposes a systematic approach to revealing larger structures in CSCL settings. It provides a view of group interactions such as those analyzed in the VMT Project as hierarchically structured, with events (like VMT Spring Fests), composed of sessions, covering multiple themes, and built out of sequences of discourse moves, consisting of adjacency pairs and linking utterances, including references. This hierarchy provides a framework for analyzing student interaction with a view toward structurally understanding group cognition.
- Investigation 25: *Structuring Problem-Solving*. An extended interaction in VMT is here analyzed in some detail to show how a sequence of discourse moves is built up out of adjacency pairs, eventually carrying out a mathematical derivation by a small group. It is common to consider mathematical derivation the work of an individual thinker; however, here we see a group construct a result that no one of the individual students involved would have been able to do. The analysis of the derivation must be conducted at the unit of analysis of the group interaction.

This set of studies raises several central problematics of a theory of group cognition. These are particularly germane to CSCL, which focuses on small groups of students communicating over networked computers. The theory of group cognition claims that "groups can think." This is a new idea, reflecting that our era of digital technology has changed the nature of knowing, understanding, and thinking. Now there can be various collective levels of interacting groups, networks, or communities who interact across computer-based media. For researchers, the collective basis of cognition raises many issues, necessitating a rethinking of how to generate, collect, and analyze data for studying collaborative learning and group cognition. The following aspects of these issues will be discussed in the remainder of this Investigation:

(a) *The nature of intersubjectivity*, including the conditions necessary to establish and maintain it. Investigations 15, 16, and 17 take different approaches to conceptualizing the collective group and understanding the ways intersubjectivity can be established within the groups. See "Conceptualizing the intersubjective group" below.
(b) *A methodology for studying and understanding intersubjectivity*. Investigations 18 and 19 trace theories of intersubjectivity and common ground. A key to the analysis of intersubjectivity is derived from ethnomethodologically informed conversation analysis, which developed the analysis of adjacency pairs in discourse. The theory of group cognition draws upon this for its analysis of the response structure of group interaction. See the section "Ethnomethodologically informed" below.
(c) *The relationship of group cognition to artifacts*, including tools to support collaboration. Investigations 20, 21, and 22 consider ways to foster collaborative learning through pedagogical and technological systems of support. This is critical for effective CSCL learning, which is necessarily mediated by technological artifacts (e.g., communication media and/or subject-domain representations). We need to consider how such mediation takes place. See "Artifacts and collective minds" below.
(d) *The interrelationships among multiple levels of description*, such as individual, small group, and community. Investigations 23, 24, and 25 are concerned with the structure of interaction at the small-group unit of analysis. It is important to consider this within the larger context of the relation of the small-group level to the individual and social layers of thinking and learning. See "Traversing planes of learning" below.

These thematic areas are discussed here based on editorial introductions to issues of *ijCSCL* that emphasized these areas (Stahl, 2012a, 2012b, 2012c, 2013, 2015), and some of the papers pubished in those journal issues.

These editorials and papers are reviewed here to motivate reading the Investigations of Part III, which delve into these themes in greater depth and build on them as foundations of the theory of CSCL. They also serve to point to relevant discussions published in *ijCSCL* that were not able to be reprinted in full in this volume. They indicate the wealth of theoretical considerations in the back issues of the journal that could contribute to elaborating the vision of CSCL sketched in Investigation 1 and the theory outlined in this Investigation.

This set of themes defines central questions for a theory of CSCL, conceived as an attempt to understand and support learning at the small-group unit of analysis. They provide an understanding of intersubjectivity and of the group level of description in relation to nonhuman artifacts, individual subjects, and encompassing communities or cultures. This Investigation thereby clarifies the conceptual background for the theory of group cognition elaborated in the Investigations of Part III.

Conceptualizing the Intersubjective Group

Intersubjectivity may be considered the defining characteristic of CSCL [Investigation 15] because it is what makes collaboration possible. *Intersubjectivity* is a concept that indicates *shared understanding* among people [Investigation 18]. This "sharing" is not a matter of individuals having similar understandings, but of them participating productively in a joint meaning-making discourse within a communal world.

Collaborative learning cannot take place if group participants do not have a shared understanding of what they are talking about or working on. On the other hand, "cooperative learning" can take place because this approach that was popular prior to CSCL involved individuals dividing up learning goals into small tasks that group members could accomplish individually, without extensive shared understanding and without engaging in processes of intersubjective meaning-making. Many groups and team members opt for cooperation rather than collaboration because it is easier in that it does not require the establishment and maintenance of extensive intersubjectivity. However, it also lacks the power of collaboration to build knowledge across individual understandings. In cooperation, thinking takes place primarily in individual minds; the conclusions may subsequently be collected by the group. In such cases, the meaning of conclusions is relative to the individual understandings of the group members and may or may not be similar for different participants. Cooperation typically lacks the thinking together that involves intersubjective meaning-making and results in shared knowledge resulting from joint activity.

Many experimental interventions and published analyses of learning involving groups of students lack the focus on intersubjectivity, but still use the term CSCL. They may in fact be studying cooperative learning or even individual learning. In this volume, CSCL refers to learning that takes place at the group level of interaction and intersubjectivity. Unfortunately, such learning is relatively rare, even in the field of CSCL.

A group has achieved intersubjectivity if the members of the group interact well enough to pursue the group's aims together. Intersubjectivity must be built up gradually through interaction and be repaired frequently. CSCL research should explore the conditions and processes that are conducive to the establishment and maintenance of intersubjectivity among groups of learners. CSCL pedagogies should be structured to promote the intersubjectively shared understanding that makes collaborative learning possible. CSCL technologies should be designed to support intersubjectivity by providing media of communication and scaffolds for meaning-making within specific domains of learning.

When CSCL theories discuss "groups," they are not referring to arbitrary gatherings of multiple learners but to functional groups that have achieved a degree of intersubjectivity. The concept of collaborative learning in CSCL does not refer to a sum of individual learning that takes place among a group's members but to the increase in intersubjective understanding or collaborative knowledge building within the group that results from joint meaning-making in a shared context. It involves the understanding expressed in the group discourse and the knowledge encapsulated in group products, such as texts or artifacts produced by the group. The group's understanding may differ from what any individual member might say, write, or think when not interacting within the group.

This focus on the intersubjective group differentiates CSCL from other approaches to the study of human learning and educational instruction. It implies a research paradigm that prioritizes the group unit of analysis and studies groups that have achieved intersubjectivity. Analyzing an utterance (or chat posting) as part of a group interaction involves seeing how its meaning is constructed sequentially through its response to previous actions and elicitation of future behavior by other group members. The meaning of the utterance is inherent in the working of that utterance within the shared world of the group, not to be explained in terms of some purported individual mental thoughts accompanying the utterance. As in Ryle's (1968) thick description of a wink, the meaning of an utterance (or wink) is expressed by the utterance (wink) itself as an interactional action, not by assumed additional mental intentions of the speaker (winker).

Despite the centrality of the notion of intersubjectivity to CSCL, this concept has not often been explicitly discussed in the CSCL literature. Newcomers to CSCL therefore have difficulty determining the boundaries of the field. They may assume that CSCL is the same as traditional educational psychology or instructional design, except that it involves small groups and online technology. However, the importance of analyzing intersubjectivity at the group unit of analysis has become increasingly clear to many established CSCL practitioners. For instance, the *ijCSCL* Mission Statement specifies that the journal "features empirically grounded studies and descriptive analyses of interaction in groups, which investigate the emergence, development and use of practices, processes and mechanisms of collaborative learning." The central research questions are no longer what experimental conditions produce the most valued learning experiences or outcomes at the individual unit, but how intersubjective meaning-making and understanding is established, maintained, and increased within the *interaction in groups*, by social practices, small-group processes, and interactional mechanisms analyzed at the group unit.

The shift of research from assessing individual student outcomes to analyzing group-level phenomena has been slow in coming and is still difficult to implement consistently. In the cooperative learning of the late 1900s, educational researchers like Johnson and Johnson (1999) or Slavin (1980) explored the effects of group interaction on learning outcomes of individual students. The focus was on individual cognition, but in cases where the individual was somehow influenced by being in a group. With the advent of CSCL, interest changed to the group processes that could be supported with networked-computer technologies. In their report on the evolution of research on the new approach of *collaborative* learning, Dillenbourg, Baker, Blaye, and O'Malley (1996) noted that new methods were now necessary to study group phenomena. Although Koschmann (1996) proposed that this involved a paradigm shift, it has not been widely recognized what a radical change in perspective and methodology this shift to the group level implied.

Subsequently, Koschmann (2002) defined CSCL in terms of "joint meaning-making." The centrality of intersubjective meaning-making to the concerns of CSCL as a research field has been stressed programmatically in scattered proposals and examples, for instance, in Investigations 4, 5, and 12. Multiple attempts to define new methods corresponding to this agenda of group-level analysis were also proposed, as in Investigations 6, 7, 8, 9, 10, and 11 as well as several other *ijCSCL* articles.

After 20 years, CSCL researchers are just beginning to work out group-level conceptualizations, such as group cognition, group knowledge construction, group agency, group engagement, group metacognition, group practices, and so on. Some researchers now see CSCL as pursuing a post-cognitive paradigm distinguished from the cognitivism of traditional learning sciences based on cognitive psychology [Investigation 15].

Cooperative Action

Intersubjectivity goes by many names. Goodwin (2013, 2018) has recently developed an analysis of the essential intersubjectivity of human cognition within a post-cognitive perspective, grounded in a number of ethnomethodologically informed analyses of interactional data, including family members conversing, children playing and arguing, anthropologists or chemists learning analytic skills, and videotaped evidence being presented in a courtroom. As diverse as these settings are, they all involve small groups of people in face-to-face interaction. In this volume, we will adopt much of Goodwin's perspective, but apply it within computer-mediated scenarios.

Like group-cognitive theory, Goodwin's post-cognitive approach is not focused on psychological states as making human cooperation possible, but rather on "public social practices that human beings pervasively use to construct in concert with each other the actions that make possible, and sustain, their activities and communities" (2018, p.7). In place of a model of the speaker that takes as its point of focus mental phenomena within the individual actor, Goodwin identifies how people constitute their participation in discourse through their ability to "engage in appropriate but differentiated ways in a field of interactively sustained action constituted through the public organization of language use" (2013, p.15). These ways correspond to what Investigation 16 calls group practices.

The accumulation of group practices is central to the organization and evolution of human culture, collective knowledge, and social life (Investigations 7 and 16); the adoption and use of these practices by small groups pervade social life. Goodman, citing the philosopher and semiotician Pierce, highlights in particular the central importance of diagrammatic reasoning in human thought, noting that geometry provides a perspicuous example. The historic role of Euclidean geometry as a training ground for cognitive practices which integrate visual, logical, gestural, and representational practices was a motivation for the VMT Project's focus on collaborative dynamic geometry as a subject domain.

Goodman provides an analysis of cooperative action that can usefully be applied to the study of VMT interaction data. He chose the term "cooperative" because people typically perform specific operations in coordination with each other. For instance, a speaker may decompose materials provided by a previous speaker and then reuse them with transformations. Goodman takes this process of decomposition and reuse of resources to be a very general and unique characteristic of human cognition. Mankind innovates by analyzing (taking apart) ideas and tools accessible in the social world and synthesizing (recombining) them in transformed ways. In particular, our speech is generated by decomposing and reusing with transformation the resources made available by the preceding speech of others. So their language becomes ours, and ours is a form of theirs: "We inhabit each other's actions" (Goodman, 2018, p. 1).

The operations of decomposition and transformation take place in multidimensional settings, resulting in what Goodman calls environmentally coupled gestures. These require for their understanding not only a gesturing hand but also the environment being pointed at and co-occurring language that formulates what is to be seen there in a specific way. For instance, anthropologists train their students to see and discuss subtle shades of ground at an excavation by pointing to color charts and using technical terminology. Similarly, students in VMT learn to construct challenging geometric dependencies by highlighting or making salient specific graphical elements on the computer screen and chatting about them using geometric terminology. This kind of cooperative action or group cognition is a fundamental way in which groups accumulate group practices, group members become more skilled, and the community builds knowledge. As Goodman puts it:

> The accumulation and differentiation through time within local co-operative transformation zones of dense substrates create a multiplicity of settings for action. Each of these must be inhabited by competent members who have mastered the culturally specific practices required to perform the activities that animate the lifeworld of a particular community. Through the progressive development of, and apprenticeship within, diverse epistemic ecologies, communities invest their members with the resources required to understand each other in just the ways that make possible the accomplishment of ongoing, situated action. (2013, p. 21)

Not only does this process make possible new professions and realms of knowledge, it recursively forms the basis of intersubjectivity, required for all mutual understanding.

Translating Goodman's view of cooperative action to the concrete situation of the VMT paradigmatic case of CSCL, we can observe student teams decomposing and transforming each other's contributions. Trausan-Matu (Trausan-Matu, Dascalu, & Rebedea, 2014; Trausan-Matu & Rebedea, 2009) has analyzed VMT transcripts using Bakhtin's notion of polyphony, showing how students build on each other's word use to inhabit an inextricably interwoven shared world.

Perhaps even more striking would be an analysis of how a team working on geometry decomposes and transforms each other's construction efforts. Interaction in VMT includes graphical (geometric construction) actions as well as linguistic (chat postings). Although it would be tricky to present a detailed study of this concisely, the construction data is now available in the recordings of the Cereal Team in their Winter Fest 2013 interaction, especially Session 6 (Stahl, 2015). Here, the three students took turns extensively exploring how to construct points, lines, circles, triangles, squares, and polygons with specific dependencies. There was lots of trial and error, but an adequate analysis would show that it was by no means random efforts. Each student closely observed the dead ends that the others ran into. They decomposed the false starts by erasing the shared workspace and then reconstructing the effort with key transformations, which eventually led to success. The successes were immediately recognized by the whole group and adopted into the future work of the group and of its members. This resulted in a shared understanding of their intersubjective meaning-making in the shared VMT world.

The Conditions of the Possibility of Intersubjectivity

Several articles in the 2015 *10*(3) issue of *ijCSCL* focused on intersubjectivity; they illustrate and further develop a group-level focus of CSCL research. For instance, the first article provides a discussion of Habermas' philosophy as it relates to CSCL issues and introduces to the CSCL audience the work of the contemporary author who has written the most on the concept of *intersubjectivity*. Then, three papers analyze the intersubjectivity of small groups of students in different ways. One looks at how *groups learn how to learn together* with support from specific CSCL tools. A second transforms the concept of engagement to the group unit of analysis as collaborative *group engagement*. The final one makes a parallel move for *formative feedback and metadiscourse*, applying them at the group level. Together, they offer stimulating glimpses of CSCL theory, technology, meta-learning, and analysis focused on the group as agent.

In his introduction of Habermas' philosophy of communicative action to the CSCL community, Hammond (2015) translates from Habermas' application of this theory in the public sphere of traditional media to the online world of CSCL. For Hammond, Habermas is relevant because he brings a fresh, well-considered, and critical perspective to the discussion of joint knowledge building. In particular, Habermas' writings provide a framework for judging the evidence we bring to the analysis of collaborative learning as well as for valuing the evidence that our student subjects provide in their argumentation. Habermas defines the conditions necessary for the establishment of intersubjectivity, such as the inherent assumption of an ideal speech situation underlying communicative action. What Kant's *Critique of Pure Reason* did for the individual mind, articulating the conditions of the possibility of human knowledge, Habermas translated to the group level, explicating fundamental discourse conditions necessary for intersubjective meaning-making in social collectivities.

Consider a student chat, a discussion forum or a medium like Wikipedia. How should we judge the quality of the knowledge building that takes place there? Moreover, how should one judge the quality of researchers' analysis of that knowledge building? Habermas provides a standard for judgment that is grounded in the nature of human discourse. He argues that effective communication would be impossible without the underlying postulation of an ideal speech situation—even if this ideal is never in fact fully achievable (Habermas, 1981/1984). The act of communicating with the aim of establishing intersubjectivity, making shared meaning, and building knowledge together assumes that there is no other force of persuasion at work than that of the better argument and no other motivation than the cooperative search for truth. Enlightened discourse is only possible under the assumption of this goal. Of course, there always are other forces and motivations present. But the character of the ideal speech situation that underlies collaborative dialog provides a basis for critiquing those systematically distorting forces. For instance, if knowledge building assumes that no one can impose his or her views through force rather than through supported reasoning, then appeals to authority or intimidation can be soundly censured.

Habermas' theory is, additionally, more complex and nuanced. A major contribution of his work was to distinguish realms with different criteria within the public sphere (Habermas, 1967/1971). There is, as Hammond puts it, the objective world (of nature and labor), the social world (of institutions and interaction), and the subjective world (of personal experience). Each has very different criteria of validity. The objective world follows the laws of physics and involves human mastery over nature through technical, goal-oriented, instrumental calculation; the social world, in contrast, involves normative rules reached through negotiation, while the subjective world is a matter of one's self-narrative.

Consider the research task of analyzing an online team of students collaborating on a geometry construction. Certainly, this involves comparing the team's work with mathematical knowledge developed in the axiomatic world of mathematical relationships. However, it also involves tracking the development of the team's adoption and mastery of its own group practices of collaborating and of working on geometry in the team's intersubjective world. Furthermore, it may be possible to assess individual learning by team members as a personal-world spin-off of their teamwork. Each of these dimensions has quite different methodological criteria. Seeing how each is accomplished with the mediation of specific CSCL pedagogical approaches or CSCL technological tools can feed into design-based research for improving support for collaborative knowledge building.

Habermas' distinction between the objective, social, and subjective realms gives him leverage for his critiques of modernism and other popular philosophies, extending the critical social theory of the Frankfurt School. As cited by Hammond, Habermas' concern with mutual recognition led him to criticize classical liberalism for reducing ethical liberty to a "possessive-individualist reading of subjective rights, misunderstood in instrumentalist terms." There are many analogous examples in the CSCL literature, where social phenomena are inappropriately reduced either to individual subjective criteria or to instrumental objective criteria. Hammond suggests that a focus on intersubjectivity could provide a corrective in such cases and open up new perspectives for design and research. It is important to distinguish different levels of analysis carefully and to apply the appropriate evaluative criteria or analytic methods to each.

Intersubjective Learning to Learn

As a foundation of all communication and cognition, intersubjectivity applies to education specifically. Teaching students to learn how to learn or to develop "thinking skills" has long been considered important—particularly in the information age, where knowledge evolves rapidly (e.g., Investigation 13; Wegerif, 2006). In their research report in the same *10*(2) *ijCSCL* issue, Schwarz, de Groot, Mavrikis and Dragon (2015) extend this goal to the group level with their construct of learning-to-learn-together. A core component of this approach is supporting groups of students to engage in argumentation as a form of intersubjective meaning-making. Schwarz and colleagues situate computer support for argumentation in an innovative dual-interaction space.

The authors take an iterative design approach to developing a software environment, curricular tasks, and teacher roles for supporting learning-to-learn-together. They hypothesize that mutual engagement, collective reflection, and peer assessment may be three critical group processes to encourage and to investigate. To explore these, they design a prototype with two primary components: a construction space and an argumentation space. The construction space includes a selection of domain-specific modeling applications to support student inquiry in specific topics of mathematics or science. This provides a mutually visible "joint problem space" for collective reflection by the group on the progress of its inquiry. The software creates a shared world for mutual engagement, as opposed to individuals trying to solve a challenging problem on their own. As one group member performs an action in the space, the others assess that action in the argumentation space, either affirming it or questioning it. This prompts the students to build on each other's actions, producing a joint accomplishment.

In some dual-interaction systems, like VMT, a text-chat feature accompanies an online construction space. This provides the possibility of engaged discourse, group reflection, and peer assessment when group members are not situated face-to-face. However, the described argumentation system goes beyond this with a sophisticated planning/reflection tool. Even if the students are sitting together around a shared computer, this tool prompts, guides, and supports team efforts at planning steps for the group to take (collective agency), and it facilitates team reflection on the current state (collective responsibility).

While the software mainly displays advice and ideas from the teacher or from individual students, its persistent visibility and its manipulable structure allow it to influence group agency and meta-learning. The potential power of this approach seems to come from the integration of the support for argumentation and reflection by the group with the inquiry activity itself in the shared inquiry environment. As always in CSCL, success also depends on a culture of collaboration: appropriate motivations/rewards, careful training in collaboration, and subtle mentoring. The emphasis of the pedagogy and the support throughout is on the group as meta-learner. Group learning here is a form of intersubjective meaning-making, incorporating group agency, and group responsibility.

Intersubjective Engagement

In the next presentation of the *10*(2) issue, Sinha, Rogat, Adams-Wiggins and Hmelo-Silver (2015) provide a multifaceted conceptualization and operationalization of intersubjectivity based on aspects of what they term "group engagement." Using this approach, they provide a clear illustration of a team of students that does not form an intersubjective group contrasted by one that does. The construct of group engagement developed in this paper allows the authors to identify this contrast and to analyze it using both quantitative and qualitative methods. The quantitative approach includes statistical correlations based on ratings of several aspects of group engagement, measured in 5-min intervals. The qualitative approach involves thick descriptions of illustrative excerpts of group discourse. The descriptions relate the interactions within the groups to their work (or lack thereof) of meaning-making in establishing the engagement of the group as a whole in its problem-solving task.

A major achievement of the paper is to shift the analysis of engagement—which is increasingly popular in CSCL—from the psychological individual to the intersubjective group unit of analysis. The authors are explicit about this. Their observational protocol is designed to situate engagement within the collaborative group, its joint problem, and its shared situation. For instance, the dimension of social engagement reflects group cohesion, or evidence that the task is conceptualized as a team effort, rather than as an individual activity. The contrast of one group's use of the subject "we" versus the other's use of "I" reflects in the details of the discourse the distinction documented in the ratings—showing that the distinction is actually one made by the group.

The paper is an impressive response to the cited prior research on engagement. According to the literature review, earlier studies generally operationalized engagement as consisting of a single dimension, as a stable state and as a characteristic of the individual learner. In addition, the cited work decontextualized engagement from concomitant conceptual and disciplinary tasks. By contrast, this study proposes a differentiated, evolving, multifaceted, and group-based model of engagement and applies this model to explore an insightful example from actual classroom practice. The paper's mixed methods analysis reflects a careful attention to the unit of analysis, operationalizing engagement at the group level. Thereby, it adds in a rich way to our conceptualization of intersubjective meaning-making.

Intersubjective Metadiscourse

Like the preceding paper, the one by Resendes, Scardamalia, Bereiter, Chen and Halewood (2015) also uses mixed methods, with both quantitative and qualitative analysis. While collecting data at both the individual and group units of analysis, its focus is also at the group unit. In fact, it goes a step further than the previous paper and most other CSCL reports by capturing the outcomes at the group level. Here, because the main data source is a Knowledge Forum database, the group product of shared notes responding to each other within the group is the most important object for examination in response to the primary research question. Thereby, the correlation of the experimental condition with resultant collaborative learning or knowledge building can be conducted at the group level.

The social-network analysis of the Knowledge Forum data shows the effect of experimental feedback tools on the group process and the degree of intersubjectivity established by each group. The paper's analysis strikingly indicates that in the control condition, most students are not strongly connected to other students, whereas in the experimental condition, everyone is strongly connected to everyone else. Because the social-network connections here represent sharing of vocabulary terms—such as those displayed in the experimental condition's feedback tool—this means that there is a higher degree of intersubjective, shared understanding in the experimental groups. Shared understanding at the group unit of analysis is not dependent upon individuals' cognitive states, internal representations, or personal understandings, but is visibly displayed in the team's unproblematic use of shared language.

We are shown further evidence of increased group metadiscourse through the analysis of group discussion in a number of propitious interaction excerpts. While these demonstrate the experimental group's comprehension of the visualizations of their group discourse (displays of its use of domain vocabulary and of Knowledge Forum epistemic markers), the primary metadiscourse moves (prompting the group to plan, question, analyze, explain) were made by the teacher, rather than by the student group. The experimental intervention at the group level led to productive metadiscourse, but this was not at all independent of the teacher. Thus, the study merely indicates a potential for the design of formative assessment visualizations that represent group-level behaviors and that support group metadiscourse. It does not demonstrate that the implemented tools led to metadiscourse by student groups on their own. The students may need more experience with this approach or more maturity to take on this form of agency by the student group. Nevertheless, the paper offers stimulating design suggestions: group-level formative feedback can represent group vocabulary; support the group to evaluate its own progress; give feedback on secondary processes (like vocabulary building, rather than directly on learning or task accomplishment); suggest positive steps (rather than just identify deficiencies); facilitate self-assessment by the group; and guide individual students to become more effective group members.

Together, the papers in issue *10*(3) of *ijCSCL* suggest the centrality of intersubjectivity to a theory of CSCL and provide inspiring examples of how to explore and articulate aspects of our conceptualization of group intersubjectivity.

Ethnomethodologically Informed

The research field of CSCL is ethnomethodologically informed, or at least ethnomethodologically influenced. This has not always been the case, although there is a logic to this growing tendency.

Ethnomethodology (EM) is an approach to conducting research in the human sciences founded by Harold Garfinkel and largely defined by his *Studies in Ethnomethodology* (Garfinkel, 1967; Garfinkel & Rawls, 2012). EM addresses the "methods" that members within a given linguistic community use to establish and maintain intersubjective understanding. Since CSCL can be characterized as being focused on joint meaning-making, the analysis of prevalent meaning-making methods seems particularly relevant to the methodological quandaries of CSCL research.

Ethnomethodology has been slow to catch on in CSCL, in contrast to its role in allied fields like CSCW, where it seems to be a dominant research paradigm. There are a number of theoretical and historical reasons for this. For instance, as discussed below, practitioners of EM eschew research questions and theoretical framings because these could obscure the meaning-making perspective of the people whose interactions are under investigation. This injunction against guiding theory makes it difficult to integrate EM studies into the educational and design agendas of CSCL investigators. In addition, the case-study approach of EM to analyzing naturally occurring events is at odds with the traditional emphasis in educational and psychological research on controlled experiments and statistical generalizations. CSCW is based more in social sciences, in contrast to the psychology backgrounds of many CSCL researchers.

On the other hand, there are strong arguments for viewing the ethnomethodological approach as especially appropriate for analyzing computer-supported collaborative learning. In particular, a major stream of research within EM has been conversation analysis. This is the analysis of talk-in-interaction, as pioneered by Sacks (1965/1995) and other colleagues of Garfinkel. An early finding of conversation analysis was the system of turn taking in face-to-face informal conversation. While this system does not apply directly to such CSCL interactions as online text chat about an academic topic (Zemel & Çakir, 2009), the underlying techniques of sequential analysis (systematized by Schegloff, 2007) seem highly applicable to the analysis of meaning-making in CSCL settings. Such sequential analysis explicates the evidence embodied in instances of discourse that reveal meaning-making processes taking place in small groups [Investigation 25]. It looks at the semantic, syntactic, and pragmatic details of how utterances respond to each other and elicit new responses in the flow of group cognition.

The Historical Traditions of CSCL Research

Largely, early CSCL investigators turned from inspirations in computer science and artificial intelligence to the fields of educational psychology and sociology to find methods of studying the effects of using CSCL systems in classrooms or in laboratories. The theories and research paradigms that they brought in from these established fields focused on either the individual student or the larger society as the unit of analysis. Educational theory operationalizes learning as a hidden change in mental state of student knowledge from before an intervention to after, as measured indirectly by pre- and posttests of individual students. At the other extreme, social science approaches hypothesized societal forces that could not be observed directly, but could be inferred and measured by controlled experiments using statistically significant numbers of randomly selected subjects.

Ethnomethodology—drawing on philosophical influences from phenomenology and reacting against functionalist approaches to sociology—takes a different tack, centered on what is made visible in the interactions between people. EM argues that one can observe the meaning-making processes at work by carefully studying the discourse between people; one does not have to make inferences about hidden changes in mental models or invisible social structures. Furthermore, EM studies can focus on the small-group unit of analysis, which seems most appropriate to analyzing collaborative learning. While other areas of education and of sociology may seem centrally concerned with individual or societal units of analysis and while collaborative learning may also involve processes and phenomena at those levels, the meaning-making in contexts of joint activity which is definitive of CSCL takes place primarily at the small-group level, even if a complete understanding will ultimately need to tie all the levels together.

The ability to conduct microanalysis of interaction was historically made possible by recording technologies, which allowed utterances to be replayed and slowed down. Conversation analysis arose in the age of the tape recorder. That technology made it possible to hear exactly what was said and how it was articulated. It allowed the production of detailed transcripts, which represent intonation, pauses, emphasis, restarts, and overlaps so that the mechanisms of verbal interaction could be studied. Subsequent development of video recording led to analysis of gesture, facial expression, gaze, and bodily posture as important but generally unnoticed aspects of interpersonal interaction. For online communication typical of CSCL, computer logs and even the ability to replay synchronous interaction can provide adequate data sources necessary for the study of how students actually engage in computer-supported collaborative learning.

Applied to CSCL, the approach of EM implies that we can observe and report on the ability of given technologies and pedagogies to mediate collaborative interactions between students in concrete case studies. EM suggests ways to do this systematically, with intersubjective validity, and to generalize the findings. Insights from this can be used to critique the designs of interventions and to suggest redesign criteria. To make these claims about EM plausible, we will need to review some of the principles of EM.

The Theoretical Framing of CSCL Research

There is a prevailing notion that EM is atheoretical or even anti-theoretical, and that it rejects all theorizing. Yet Garfinkel and Sacks (1970) were highly theoretical thinkers, influenced by philosophy, sociology, and communication theory. In fact, EM represents a strong theoretical position about the nature of human reality and the possibilities of comprehending it. EM claims that human social behavior is structured by a large catalog of "member methods"—patterned ways of making intersubjective sense with other members of one's linguistic community. Furthermore, these member methods are "accountable" in the sense that they provide an observable account of their own character. People's actions are designed so that the meaning of the actions will be recognizable by others within the given discourse situation. This accountability is necessary for intersubjective understanding among members. But it has the secondary consequence that researchers can understand the methods as well (given certain conditions). The theory of EM thereby explains how EM is possible as a scientific enterprise.

The member methods of a linguistic community contribute significantly to the social order of activities within the community. The social structure is enacted in the very interactions of the members by virtue of their use of these methods; the accountability of the methods, as they are realized, reveals to the other participants (and potentially to researchers) evidences of what is being enacted. As Garfinkel put it, "any social setting [should] be viewed as self-organizing with respect to the intelligible character of its own appearances as either representations of or as evidences-of-a-social-order" (Garfinkel, 1967, p. 33). There is reflexivity at work between the meaning of an elemental interaction (e.g., an utterance/response pair) and the local context of the ongoing discourse, in which the utterances are situated within a context whose significance they interpret in a continuously emergent way. The theory of EM is formulated in its concepts of member methods, accountability, reflexivity, etc.

The reason that EM is often considered to be atheoretical is that it systematically rejects the kind of theoretical framing that is associated with many other research approaches. For instance, in other paradigms an experiment and its analysis are motivated and structured by a theory or conceptualization of the phenomena to be studied. There may be a specific research question that the researchers have in mind. There may even be hypotheses about how the experiment will turn out based on preconceptions. While scientific researchers must remain open to their hypotheses being disproven by the evidence, the posing of research questions and hypotheses define a research perspective within which the evidence is pre-interpreted. For instance, CSCL discourse data might be coded according to a set of codes designed to make distinctions relevant to this perspective, experimental conditions will be structured to test these distinctions, and coders will be trained to categorize their data from this perspective—all before the students even interact or produce their utterances.

EM, in explicit contrast, wants to understand the data from the perspective of the participants in the study (e.g., students). Because the analysis of discourse is a human science, it must take into account what the discourse means for the speakers and audience. The participants are viewed as people engaged in meaning-making, and EM researchers want to understand the meaning that the participants are making. EM researchers do not want to impose a perspective on the data analysis that is based on their own preconceived theories about the interaction. Rather, they want to engage in "thick description" (Ryle, 1949) of the discourse to explicate the meaning-making that is taking place in the discourse and that is displayed in the accountability of how it is formulated. The fact that the discourse is accountably intersubjectively understandable allows the researcher to analyze the meaning that is implicit in the discourse as it sequentially unfolds.

This is the sense in which EM rejects theory: that it adopts the participant perspective on understanding the meaning in the data, rather than imposing a perspective based on a theoretical research framing. There has been considerable debate within CSCW about how EM analysis can be used to guide design of collaboration systems if it cannot be directed toward theoretical issues (e.g., see Crabtree, 2003). But the stricture against theory in EM is only against imposing an a priori analysis framework, not against drawing theoretical consequences from case studies. So one can, for instance, study the discourse of students embedded in a computer-supported interaction and analyze the nature of the methods they use—which they enact, adapt, or create—for achieving their collaborative tasks. The details of these methods can have design implications, such as addressing technical barriers that resulted in unnecessarily cumbersome behaviors. Thus, EM can contribute to the analysis phase of design-based research (DBR Collective, 2003), which is a widespread approach in CSCL to the design of effective collaboration technologies.

The Ubiquity of Methods

Ethnomethodology posits the existence of member methods pervading all of social life. EM research for the past 50 years has documented many such methods, for instance, in informal conversation, in doctor-patient discussion, in mathematical proof, in criminal interviewing, and in workplace communication. These methods are often sedimented in the traditional design of the tools we use and in the clichéd turns of speech within our vernacular. They constitute our myriad overlapping cultures.

Sacks (1965/1995) argued that the pervasiveness of member methods meant that one could profitably study almost any interaction and learn from it about the nature of social existence. He argued that the universal application of these methods was necessary if people were to understand each other. In the CSCL literature, one often talks about the establishment and maintenance of "common ground" (Clark & Brennan, 1991) as providing the foundation for intersubjective understanding. However, according to EM, it is not a matter of the participants having corresponding mental models of propositional knowledge, rather, intersubjectivity is founded on co-experiencing a world through using shared methods of communication [Investigation 17]. These methods provide "resources" for engaging in specific domains of the social world. According to the EM viewpoint, collaborative learning does not consist in the storing of propositional knowledge as mental contents in individual minds, but in the increasing ability to enact relevant resources or shared practices in interactions with others.

By looking carefully at interactions in CSCL settings, we can analyze the methods being applied. Because the acceptance of these methods is widespread within a culture, the results of a single-case study can have quite general ramifications. Of course, to accept the implications of a single-case study—or even a small catalog of case studies analyzing variations on a method—as valid and of general applicability, we need to ensure lack of bias or idiosyncrasy. This is usually addressed in EM by "data sessions" and other mechanisms to involve multiple analysts (Jordan & Henderson, 1995). If discourse under analysis displays an account of itself, then a group of experienced analysts who share the relevant cultural understanding with the discourse participants should be able to reach a consensus about the meaning being created in the discourse. EM case-study publications frequently include very detailed transcripts of the relevant discourse excerpts to enable readers to confirm the analysis based on their own cultural understanding.

Group Practices

The identification of group practices—their adoption and use by groups—seems central to analyzing intersubjective meaning-making and collaborative knowledge building in CSCL. Investigation 16 delineates a theory of group practices and proposes that CSCL methodology be centered on this.

Group practices are routinized behaviors that a group adopts and that ground intersubjectivity by providing shared understanding. They may mirror established social practices or EM-style member methods, such as procedures commonly used by experts in their work but as yet unknown to the students. The theory argues that the analysis of group practices can make visible the work of novices learning how to inquire in science, mathematics, and other fields. These ubiquitous social practices are invisibly taken for granted by adults in their professional lives, but can be observed as they are brought into usage, and rigorously studied in adequate traces of online collaborative learning.

The analysis of the enactment of group practices by teams in CSCL contexts can systematically inform the design, testing, and refinement of collaborative-learning software, curriculum, pedagogy, and theory. Applied to the evaluation of trials of CSCL innovations, the analysis of how student teams adopt or fail to adopt desirable group practices contrasts with traditional pre-/postcomparisons that miss sequential interactional processes or that reduce group phenomena to either individual or social factors. Investigation 16 concludes by proposing that CSCL can be reconceptualized as the directed design of technology to foster the adoption of targeted group practices by student teams.

The theory of group practices emerged from a longitudinal case study of a team learning the basics of dynamic geometry in 8 h-long VMT sessions. This data provides the prototypical example for the vision of CSCL being offered in the present volume. The interdisciplinary VMT research team at the Math Forum conducted a year of weekly data sessions on this data, resulting in a book-length analysis of the collaborative learning that took place (Stahl, 2016). A daylong workshop on the data was also held involving international researchers, and findings were discussed during visits by the author to European research labs.

During 8 h of chat and manipulation of geometric representations, the group employed countless social practices, most of which were intuitive, tacit, and nonproblematic for the students. However, over 60 group practices were also identified in the analysis as practices that had to be explicitly negotiated and adopted through group interaction processes.

The catalog of these adopted group practices agrees well with lists of social practices enumerated in the research literature. For instance, it includes online analogs of group practices ("member methods") defined by face-to-face conversation analysis: sequential organization (response structure), turn taking, repair, opening and closing topics, indexicality, deixis, linguistic reference, and recipient design. Other group practices correspond to practices CSCL has previously investigated as providing foundations for intersubjectivity: joint problem spaces, shared understanding, persistent co-attention, representational practices, longer sequences, and questioning. As observed in various VMT studies, practices in mathematics education include mathematical discourse and technical terminology; pivotal moments in problem-solving; and the integration of visual/graphical reasoning, numeric/symbolic expression, and deductive narrative. In addition, there were group practices that are necessary for constructing figures with specific dependencies in dynamic geometry.

It is likely that the VMT team picked up many group practices unproblematically, without having to go through an explicit negotiation process because the available resources—including the curriculum texts or classroom presentations before the online collaboration—guided smooth, tacit adoption of the practices. The curriculum, software environment, and teacher guidance were based on careful study of what sorts of practices are involved in productive interaction related to collaborative dynamic geometry. This involved the researchers and the teachers developing personal experience with, for instance, constructing figures in Euclidean and dynamic geometry. They also read research reports about how students learn this domain. There are many physical practices involved in constructing different geometric elements on the computer screen and additional practices involved in dragging them to make sure they behave as desired. There are practices involving physical dexterity, computer manipulation, geometric relationships, communication, terminology, problem-solving, explanation, and so on. In a collaborative setting, these must often be shared as group practices.

The identification of group practices has substantial implications for the design and evaluation of CSCL software, curriculum, pedagogy, and experimental intervention. According to the theory of instrumental genesis described in Investigations 6 and 7, it is not sufficient for a CSCL designer to have good ideas and honorable intentions; one must develop an initial prototype environment and try it out with groups of students. Based on observation of problems, the prototype must then be iteratively redesigned and refined. By observing breakdowns in group interaction and the gradual enactment of new group practices in response to the breakdowns, a designer can identify problem areas and constructive processes that need additional support. The analysis of group practices provides a systematic analytic method for driving CSCL design.

The analysis of adoption of group practices can be conducted either informally or rigorously. For instance, in browsing through the just completed online interaction of student groups one day, I noticed that one group had accomplished something impressive in their geometrical construction.

However, they had not had time to reflect on what they had done in terms of negotiating new group practices or engaging in discourse about the "dependencies" that they had established in their construction. I had designed the tasks with the goal of deepening the students' understanding of mathematical dependencies, so I wanted the students to spend more time interacting around their accomplishment. I emailed the teacher and suggested that she extend her groups' work on this task the next day. Because I knew that I had designed the intervention with the intention of facilitating the adoption of group practices of discourse and construction related to the concept of dependency, I was oriented to scanning for this when replaying the student sessions. Informal analysis could drive design, altering the sequencing of topics and changing the wording for the next iteration of the course.

By contrast, to develop a deep understanding of what the student team accomplished in that session and how they built their knowledge interactively, I had to go over the data many times, in slow motion, and analyze it with other researchers experienced with mathematics learning. Eventually, we developed a nuanced sense of the development of the team's group cognition. We saw how its shared understanding of mathematical concepts like dependency had developed significantly, but was still not robust. We catalogued the repertoire of group practices the team now shared, which provided it with an initial fluency in collaborative dynamic geometry, as intended by the design of the eight-session curriculum. We could then document the longitudinal development of mathematical cognition at the group level and observe the articulation of that newly acquired understanding by the team members' discourse. We could specify the vaguely characterized cognitive evolution from concrete visual to abstract conceptual thinking in terms of the accumulation of adopted group practices, which we could observe and document.

Analysis of how the Cereal Team developed their mathematical understanding as a group illustrates the working of intersubjective meaning-making through the interaction among team members. However, it is also important to take into account the role of artifacts, such as geometry constructions and labeled diagrams in this computer-supported collaborative learning.

Artifacts and Collective Minds

The age of simple objects like well-designed artifacts, minds confined inside of skulls, and cultures cloistered in the tacit background has been left in the fading past according to current sociocultural theory [Investigation 3]. We are now enmeshed in dialectical processes of social enactment, whereby designed objects continue to evolve well after they enter into the structuring of our thought patterns [Investigation 6].

Biological human evolution has long since transformed itself into cultural evolution, proceeding at an exponential pace [Investigation 7]. Along the way, thought overcame the limits of individual minds to expand with the power of discourses, inscriptions, digital memories, computational devices, technological infrastructures, computer-supported group cognition, and virtual communities [Investigation 8]. Both human cognition and its mediation by technological artifacts morph from fixed nouns into process verbs [Investigation 10], like "cognizing mediating" (Stahl, 2012a)—where human cognition and technological media shape each other in ways we are just beginning to conceptualize.

The owl of Minerva flies only at night, according to Hegel's (1807/1967) metaphor: theory—which is one's time grasped in concepts—lags behind the continuous unfolding of practice. As today's viral software successes rapidly outstrip our design theories, we must try to understand the ways in which new generations of users adopt and adapt their digital tools, thereby defining and redefining their conceptual, social, and pragmatic ties to their worlds. Hegel theorized the dialectic between subject and object, proposing that the identity of the human subject is formed when a subject subjects an object to goal-oriented design (Stahl, 2006, p. 333f), creating an artifact within the effort to forge intersubjectivity and its spin-off, the individual's self.

Vygotsky (1930/1978) recognized the role of double stimulation in mediated cognizing: that the subject's access to an object is mediated by tools such as hammers, names, and physical-symbolic inscriptions, so that in higher-order human cognizing, we are stimulated by both an intentional object and a cognizing-mediating tool. It is this mediation of cognition by artifacts and via other people that opens the zone of proximal development, allowing the individual mind to first exceed and then later extend its limits. Engeström's (1987) concept of expansive learning added the cultural dimensions from Marx' social theory to Vygotsky's simple triangle of subject-artifact-object. Henceforth, socio-technical understandings of artifacts have to situate them culturally, historically, and politically.

We have considered the labyrinthine nature of the artifact's affordances previously within theories of human-computer interaction (Hutchins, 1999; Norman, 1991), cognitive science (Gibson, 1979; Hutchins, 1996), and CSCL [Investigations 3, 4, 5, and 11]. For instance, based on Merleau-Ponty's (1945) philosophy, Bonderup Dohn (2009) argued that the affordances of an artifact were potentials realized in response to human behaviors.

The 2012 *7*(2) issue of *ijCSCL* focused on the role of artifacts in CSCL. The issue opens with Investigation 6, which explores the nature of artifacts by comparing the theory of affordances with the theories of structuration and of instrumental genesis. Structuration (Giddens, 1984; Orlikowski, 2008) is a well-known theory developed to account for the dialectic between social structures and the local interactions, which are both constrained by these structures and reproduce them. Instrumental genesis is a recent theory developed in France by Pierre Rabardel and his colleagues. Investigation 6 introduces the theory of instrumental genesis to the CSCL community and explores how the theory might impact work in CSCL, at methodological, technological, and theoretical levels.

Investigation 6 compares the three major recent theories about the interaction between artifacts and people, using a concrete case study of a typical CSCL setting. It argues in favor of the general approach of instrumental genesis as an analysis of the micro-genesis of artifacts and as the best available description of the nature of tools, particularly for CSCL. The theory of affordances tends to focus on the individual, for instance, with Gibson's biological perspective, Norman's use of mental models, or Piaget's schemas in individual minds. In contrast, the sociological theory of structuration focuses on the societal or cultural level. The theory of instrumental genesis can more naturally be applied to the small-group collective level central to CSCL, as Investigation 6 does in discussing how triads of students enacted a feature of an argumentation-support software system.

Investigation 6 presents a "theoretically grounded" conception of the artifact-agent connection. A next step would be to explore an empirically grounded analysis of the connection. While Investigation 6 referred to data from a CSCL experiment, it simply used high-level descriptions of the data to illustrate aspects of the theories being described. It will be important to also analyze such data in detail to see if the connections of groups of students to computer-supported systems follow the contours of one or more of the three theories, or whether they display different lines of development. Furthermore, it will be useful to consider more complex technologies, whole meso-level infrastructures [Investigation 3] rather than isolated functions. For instance, in an online course, small groups may have to negotiate the coordinated use of hundreds of functions in Blackboard, Google Search, Wikipedia, Facebook, Google Docs, iChat, Gmail, Word, and PowerPoint in order to produce a 1-week assignment. Such an undertaking invokes the use of individual experience or expertise, established social practices in the school culture, consideration of course requirements and project goals, as well as collaborative discourse and trials by the small groups. The resultant computer-supported effort assembles and interprets a complex technical infrastructure, increases the expertise of the group participants, and provides a medium for group knowledge building. The connection of the collaborative group with the technical infrastructure continuously evolves through use during an academic term.

Having glimpsed the potential relevance of the theory of instrumental genesis to CSCL, issue *7*(2) of *ijCSCL* turns next to a discussion of that theory within the context of CSCL system design. Lonchamp (2012) argues for applying Rabardel's theory by expanding Engeström's (1987) Activity Theory triangle of mediations, to explicitly represent both the processes of mutual shaping of agent and artifact and the specific role of the teacher in CSCL classrooms: He pictures the various mediated interconnections among tool, designer, teacher, student, peer, and tutor. Furthermore, he discusses how the agent-artifact connection—embodied in Rabardel's conception of the instrument—evolves over time through usage and redesign.

Lonchamp's paper concludes with a review of CSCL system-design approaches to supporting "instrumentalization" by teachers and students. Although it comes close to describing design-based research (Brown, 1992; DBR Collective, 2003), this review does not name it. DBR is a dominant approach within CSCL research to integrating system design, usage analysis, educational research, and practical classroom interventions. It was developed in response to the need to conduct user-centered design of innovative educational software for collaborative groups—a realm lacking in detailed theories, specific analysis methods, and adequate software or design guidelines. Perhaps an explicit combination of Rabardel's theory with data from DBR projects could provide empirically grounded insights into the mutual shaping of CSCL software and group cognition in ongoing design and usage processes.

The third paper in *ijCSCL 7*(2) is Investigation 7. It situates Rabardel's theory within the context of knowledge-building practices, as these are conceptualized in recent work at the Scandinavian-led Knowledge Practices Laboratory (KP-Lab). This context is populated with social practices grounded in knowledge-building artifacts (Hakkarainen, 2009) and structured in space and time by chronotypes (Ligorio & Ritella, 2010). The knowledge-building artifacts are instruments in Rabardel's sense; they provide for advanced forms of Vygotskian double stimulation (Lund & Rasmussen, 2008). The whole context is the result of the cultural evolution (Donald, 1991, 2001) that led up to our involvement with digital information and communication technologies in an increasingly powerful, distributed, and mediated cognitive universe.

From prehistoric times to the present, the proliferation of forms of inscription (Latour, 1990) transformed the human cognitive architecture as profoundly as earlier leaps in biological evolution, allowing radical externalization and collectivization of cognition. In a sense, CSCL aims to push this further, designing collaboration media to foster group cognition that can lead to new forms of individual learning, team knowledge building, and community social practices. To the extent that this is true, we need to design new tasks for computer-supported teams, aiming for cognitive achievements beyond the reach of individual team members without computer supports. The goal of CSCL research should not be to simply demonstrate repeatedly that individuals learn better in online groups, but to design and investigate tasks that go beyond traditional instruction. Recent findings concerning "productive failure" (Kapur & Kinzer, 2009) illustrate how groups with challenging tasks may be learning in ways that defy standard testing indicators but that contribute to increased problem-solving skills of the groups and ultimately of their members.

The analysis of instrumental genesis within the framework of knowledge building points to both the potentials of CSCL and the barriers to widespread dissemination. The historical evolution of tools as "epistemic artifacts" can itself be seen as a knowledge-building accomplishment of the greatest cognitive consequence, related to Vygotsky's—perhaps misleadingly named—notion of "internalization" by individuals of skills germinated in intersubjective circumstances. On the other hand, the complexity involved in successful instrumental genesis translates into severe barriers when, for instance, one tries to promote adoption of CSCL technologies, pedagogies, chronotypes, and educational philosophies in established school communities and institutions. Parallel to the difficulties of the students struggling to enact the technological affordances are the difficulties of the researchers, trying to document, analyze, and conceptualize the tortuous paths of instrumental genesis in CSCL.

While research on CSCL focuses on the small-group unit of analysis to understand the collaboration, this does not mean that it should ignore processes at the individual or the community levels. Group cognition theory does not ignore individual learning or cultural influences. While many educational researchers inside and outside of the CSCL field have investigated processes at the individual and social levels, few have systematically delved into the relations and influences between these levels, beyond hypothesizing relationships based on common sense presuppositions.

Traversing Planes of Learning

Planes of Learning in CSCL

Learning, cognition, and knowledge building can be studied at multiple units of analysis. For instance, analyses of CSCL are often conducted on one of three levels: individual learning, small-group cognition, or community knowledge building. One can identify and analyze important processes taking place at each of these levels of description. This tripartite distinction is grounded in the practices of CSCL. With its focus on collaborative learning, CSCL naturally emphasizes providing support for dyads and small groups working together. In practice, CSCL small-group activities are often orchestrated within a classroom context by providing some initial time for individual activities (such as background reading or homework drill), followed by the small-group work, and then culminating in whole-class sharing of group findings. Thus, the typical classroom practices tend to create three distinguishable levels of activity. Often, the teacher sees the group work as a warm-up or stimulation and preparation for the whole-class discussion, facilitated directly by the teacher. Conversely, the importance of testing individual performance and valuing individual learning positions the group work as a training ground for the individual participants, who are then assessed on their own, outside of the collaborative context. In both of these ways, group cognition tends to be treated as secondary to either individual or community goals. By contrast, the role of intersubjective learning is foundational in Vygotsky (1930/1978), the seminal theoretical source for CSCL. Regardless of which is taken as primary, the three planes are actualized in CSCL practice, and the matter of their relative roles and connections becomes subsequently problematic for CSCL theory (Dillenbourg et al., 1996; Rogoff, 1995; Stahl, 2006).

While these different units, levels, dimensions, or planes are intrinsically intertwined, published research efforts generally focus on only one of them, and current analytic methodologies are designed for only one. Furthermore, there is little theoretical understanding of how the different planes are connected. To the extent that researchers discuss the connections among levels, they rely upon commonsensical notions of socialization and enculturation—popularizations of traditional social science. There are few explicit empirical analyses of the connections, and it is even hard to find data that would lend itself to conducting such analyses.

The individual student is the traditional default unit of analysis. This assumed approach is supported by widespread training of researchers in the standard methods of psychology and education. In the era of cognitive science, analysis made heavy usage of mental models and representations in the minds of individuals (Gardner, 1985). With the "turn to practice" (Lave & Wenger, 1991; Schatzki, Knorr Cetina, & Savigny, 2001), the focus shifted to processes within communities-of-practice. Group cognition lies in the less-well-charted middle ground. It involves the semantics, syntax, and pragmatics of natural language, gestures, inscriptions, etc. The meaning-making processes of small-group interaction involve inputs from individuals, based on their interpretation of the ongoing context (Stahl, 2006, esp. Ch. 16). They also take into account the larger social/historical/cultural/linguistic context, which they can reproduce and modify.

Computer technologies play a central role in mediating the multilevel, intertwined problem-solving, content-acquiring, and knowledge-building processes that take place in CSCL settings. From a CSCL perspective, innovative technologies should be designed to support this mediation. This involves considering within the design process of collaboration environments how to prepare groups, individuals, and communities to take advantage of the designed functionality and to promote learning on all planes—e.g., through the provision of resources for teacher professional development, scripted collaboration activities, and student curriculum.

The Theory of Interconnected Planes

How are the major planes of learning connected? How can we connect investigations at different units of analysis? To consider a more intuitive physical case initially, a highway ramp or bridge often creates a possibility that did not otherwise exist for going from one level to another at a given point. To traverse from a local road to a limited-access expressway, one must first find an available on-ramp. To cross a river from one side to the other, one may need a bridge. This is the individual driver's view. From a different vantage point—the perspective of the resource itself—the ramp or the bridge "affords" connecting the levels (Bonderup Dohn, 2009).

By "affords" we do not simply mean that the connecting is a happy characteristic or accidental attribute of the bridge, but that the bridge, by its very nature and design, "opens up" a connection, which connects the banks of the river it spans. In his early work, Heidegger analyzed how the meaning of a tool was determined by the utility of the tool to the human user, within the network of meaning associated with that person's life and world; in his later writings, he shifted perspective to focus on things like bridges, paintings, sculptures, pitchers, and temples in terms of how they themselves opened up new worlds, in which people could then dwell. In considering the intersubjective world in which collaboration takes place on multiple connected levels, we might say that the work of artifacts like bridges is to contribute the spanning of shores within the way that the world through which we travel together is opened up as a shared landscape of places and resources for meaningful discourse and action.

This transformation of perspective away from a human-centered or individual-mind-centered approach became characteristic for innovative theories in the second half of the twentieth century. It is a shift away from the individualistic, psychological view to a concern with how language, tools, and other resources of our social life work. It is a post-cognitive move since it rejects the central role of mental models, representations, and computations [Investigation 15]. The things themselves have effective affordances; it is not just a matter of how humans manipulate mental models in which the things are represented to the mind. In phenomenology, Husserl (1929) called for a return to "the things themselves" (*die Sache selbst*) and Heidegger (1950) analyzed "the thing" (*das Ding*), separate from our representation of it. In ethnomethodology, Garfinkel and Sacks (1970) followed Wittgenstein's (1953) linguistic turn to focus on the language games of words and the use of conversational resources (Stahl, 2006, Ch. 18). In distributed cognition, Hutchins (1996) analyzed the encapsulation of historical cognition in technological instruments. In actor-network theory, Latour (1990) uncovered the agency of various kinds of objects in how they move across levels in enacting social transformations. Vygotsky (1930) used the term "artifact" to refer to both tools and language as mediators of human cognition. The broader term "resource" is frequently used in sociocultural analysis (Furberg, Kluge, & Ludvigsen, 2013; Linell, 2001; Suchman, 1987) for entities referenced in discourse. Such artifacts

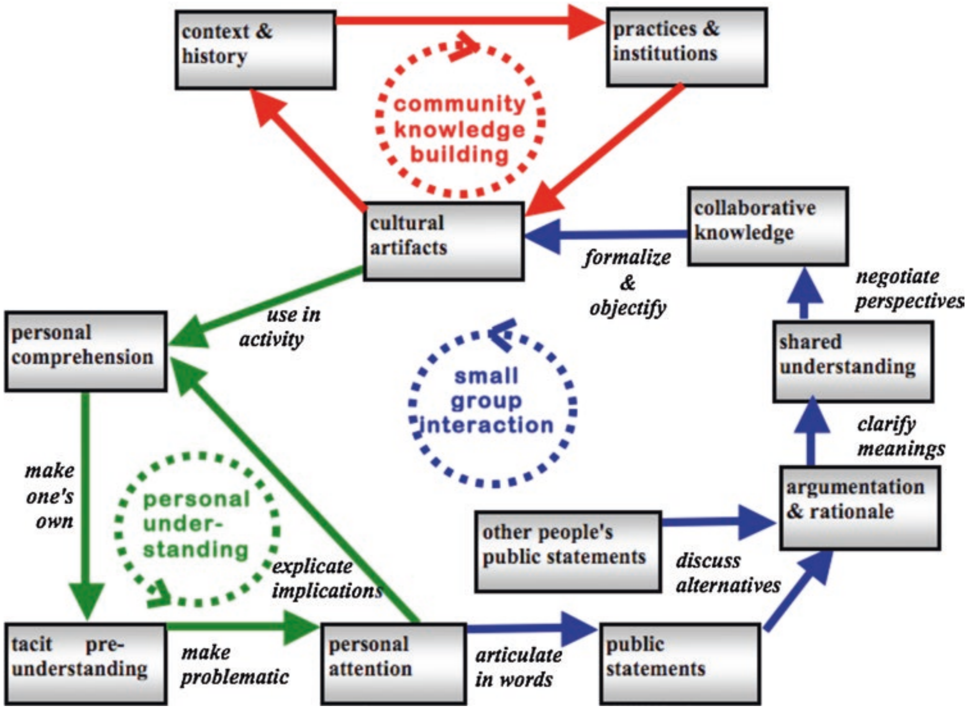

Fig. 2.1 A model of collaborative knowledge building. (Adapted from Stahl, 2006, Ch. 9)

or resources are identifiable units of the physical world (including audible speech and physical gesture) that are involved in meaning-making practices—bridging the classical mind/body divide.

A central research issue for CSCL is how collaborative knowledge building takes place. The main problem seems to be to understand the role of individual cognition and of societal institutions in small-group meaning-making processes. Figure 2.1 indicates (without claiming to explain or model) some typical processes on each of the primary planes of learning in CSCL and suggests possible paths of influence or connection, as events unfolding on the different planes interpenetrate each other. This figure is not meant to reify different levels or activities, but to sketch some of the constraints between different phenomena and possible flows of influence. The distinctions represented by boxes and arrows in the chart are intended to operationalize an infinitely complex and subtle matter for purposes of concrete analytic work by CSCL researchers.

Some researchers, such as many ethnomethodologists, argue against distinguishing levels. For instance, in their description of conversation analysis, Goodwin and Heritage (1990, p. 283) open their presentation with the following claim: “Social interaction is the primordial means through which the business of the social world is transacted, the identities of its participants are affirmed or denied, and its cultures are transmitted, renewed, and modified.” Social interaction typically takes place in dyads and small groups, so interaction analysis may be considered to be oriented to the small-group unit of analysis. However, CSCL researchers also want to analyze the levels of the individual and the culture as such—e.g., the individual identities and learning changes or the social practices and institutional forces: How do the identities of participants get affirmed or denied as a result of social interaction? How are cultures transmitted, renewed, and modified through social interaction?

In general, the sequential small-group interaction brings in resources from the individual, small-group, and community planes and involves them in procedures of shared meaning-making. This interaction requires co-attention to the resources and thereby shares them among the participants, who co-experience the shared resources. Such a process may result in generating new or modified resources, which can then be retained on the various planes. The resources that are brought in and those that are modified or generated often take the form of designed physical artifacts and sedimented elements of language. We would like to study how this all happens concretely within data collected in CSCL settings.

Resources Across Levels in CSCL

The question of how the local interactional resources that mediate sequential small-group interaction are related to large-scale sociocultural context as well as to individual learning is an empirical question in each case. There are many ways these connections across levels take place, and it is likely that they often involve mechanisms that are not apparent to participants. In the following, we explore one way of thinking about how such connections can occur: thanks to interactional resources.

In his study of how social institutions can both effect and be effected by small-group interactions, Sawyer (2005, p. 210f) argues that we can conceptualize the interactions between processes at different levels as forms of "collaborative emergence": "During conversational encounters, interactional frames emerge, and these are collective social facts that can be characterized independently of individuals' interpretations of them. Once a frame has emerged, it constrains the possibilities for action." The frames that emerge from small-group interactions can take on institutional or cultural-level powers to influence actions at the individual unit. This interplay among levels involves both *ephemeral* emergents and *stable* emergents. Sawyer's theory of emergents suggests a relationship among different kinds of resources along the lines pictured in Fig. 2.2.

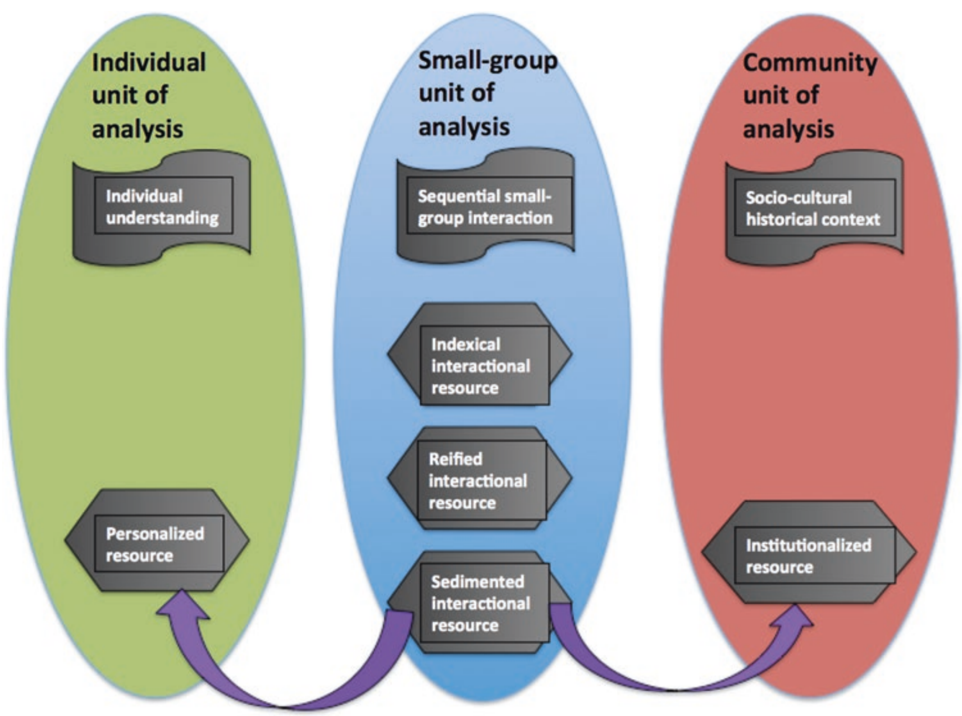

Fig. 2.2 A diagram of emergent interactional resources bridging levels of analysis

While Sawyer's analysis addresses a broad "sociology of social emergence," it can be confined and adapted to the concerns of CSCL. What is most relevant in his theory is the view of emergence arising out of the subtle complexities of language usage and small-group interaction—rather than from the law of large numbers, the interaction of simple rules or the chaotic behavior of nonlinear relationships. He thereby rejects the relevance of most popular theories of emergence for CSCL and shifts the focus to the discourse at the small-group unit of analysis. The vast variety of interactional emergents form an intermediate level of analysis between the level of individuals and that of community structures, providing a dynamic and processual understanding of social structures and infrastructures. Analysis focused on these emergent artifacts can deconstruct the reifying processes of emergence that span the group level to both the individual and the social.

The small-group interaction represented in the center of Fig. 2.2 can be theorized as being based on an "indexical ground of deictic reference" (Hanks, 1992). This means that the "common ground" (Clark & Brennan, 1991)—which forms a foundation for mutual understanding of what each other says in conversation—consists of a shared system of *indexical-reference resources*, such as deictic pronouns, which are used to point to unstated topics or resources. The coherence of the interaction and its comprehensibility to the group participants is supported by a network of references, each of which is defined indexically, that is by a pointing within the ongoing discourse context ("here," "it," "now," "that point"). Interactional resources, which can be indexically referenced in the interaction, can typically only be understood within their discourse context, but they facilitate meaning-making within that context [Investigations 5 and 19].

Interactional resources can undergo a process like Rabardel's instrumental genesis [Investigations 6 and 7]. They may initially be constituted as an object of repeated discussion—an interaction frame (Goffman, 1974)—which we might call a *reified resource*, something capable of being picked out as having at least an "ephemeral-emergent" existence. Through repetition within a group discussion, a term or the use of an object might take on a settled significance within the group's current work. Over time, continued usage can result in a *sedimented resource*, something whose existence has settled into a longer-term "stable-emergent" form, which retains its meaning across multiple group interactions.

A sedimented resource is susceptible to being taken up by a larger community as an *institutionalized resource* within a structured network of such resources, as in Latour's (2007) social-actor networks, contributing to the sociocultural-historical context surrounding the interaction. Thus, the institutional resource not only references the social context but also partially reproduces it in a dialectical relationship of mutual constitution by contributing a new element or revitalizing an old set of resources.

On the other hand, interactional resources at various degrees of reification can also be taken up into the individual understanding of community members as *personalized resources*, integrated more or less into the intrapersonal perspective of one or more group members. The personalization of previously interpersonal resources by individuals renders them into resources that can be referenced in activities of individual understanding—corresponding to processes of micro-genesis in Vygotskian internalization.

The various components of this view of interactional resources have been hinted at in previous theoretical contributions grounded in empirical examples. The progressively emergent character of resources can be seen even in fields of mathematics and science, as documented in Investigations in this volume.

The term "reification" goes back to Hegel's dialectical philosophy of mediation (Hegel, 1807). Sfard (Sfard, 2000, 2008; Sfard & Linchevski, 1994) has applied it to the formation of mathematical concepts. Husserl (1936) argued that the ideas of the early geometers became "sedimented" in the cultural heritage of the field of geometry. Livingston (1999) differentiated discovering a mathematical proof from presenting a proof; a transformational process takes place, in which the byways of exploration and possibly even the key insights are suppressed in favor of conforming to the "institutionalized" template of formal deductive reasoning. Netz (1999) (see also the review by Latour, 2008) documented the important role of a controlled (restricted and reified) vocabulary to the development, dissemination, and learning of geometry in ancient Greece. Analogously, Lemke (1993) argued that learning the vocabulary of a scientific domain such as school physics is inseparable from learning the science. Vygotsky (1930, esp. pp. 56f) noted that the micro-genetic processes of "personalizing" a group practice into part of one's individual understanding—which he conceptually collected under the title "internalization"—are lengthy, complex, nontransparent and little understood. These seminal writings name the processes of reification, sedimentation, institutionalization, and personalization of interactional resources; their empirical investigation poses a major challenge for CSCL research.

Among the theories influential in CSCL—such as activity theory (Vygotsky), distributed cognition (Hutchins) and actor-network theory (Latour)—artifacts play a central role as resources for thought and action. In the foundations of activity theory, Vygotsky (1930) conceives of artifacts as including language as well as tools. In his seminal study of distributed cognition, Hutchins (1996) analyzes how the complex of navigational tools, naval procedures for trained teams of people, and specialized language work together to accomplish cognitive tasks like ship navigation. He even analyzes data to show how an indexical phrase becomes reified within a dyad's interaction to take on significance that could have led to intrapersonal and/or institutional usage. In a witty essay, Latour (1992) shows how a common mechanical door-closer artifact can act to fill the role of an individual person (a doorman), to participate in the politics of a group, and to enforce institutional rules. He also argues (Latour, 1990) that an inscription artifact like a map on paper can traverse levels from a local discussion in ancient Asia to the social niveau of imperial Europe. However, studies like these have not often been duplicated in the CSCL literature.

Reviews of CSCL research (Arnseth & Ludvigsen, 2006; Jeong & Hmelo-Silver, 2010) show that few papers in our field have bridged multiple levels of analysis. Yet, the desired CSCL research agenda (Krange & Ludvigsen, 2008; Stahl, Koschmann, & Suthers, 2006; Suthers, 2006) calls for a study of representational artifacts and other resources that traverse between individual, small-group, and community processes to mediate meaning-making. The preceding sketch of a theory of emergent forms of evolving resources could be taken as a refinement of the research agenda for the field of CSCL: a hypothesis about how levels in the analysis of learning are connected and an agenda for exploration. A number of Investigations in this volume can be read as beginning such an undertaking. They present examples of interactional resources in small-group discussions and indicate how the resources can be seen as bridging levels of analysis.

Resources for Collaboration and for Mathematics

The idea of viewing interactional resources as central to mathematical discourse around dynamic geometry is proposed in Investigation 9, the first article in *ijCSCL* 2013 issue *8*(3). It argues that rather than focusing on the "coordination of interaction" [Interaction 12], collaborative activity should be analyzed in terms of the "coordinated use of resources." Participants rely on two major categories of resources when working on a geometry problem within a computer-based dynamic-geometry environment: (1) mathematical and tool-enabled resources (math-content-related) and (2) collaboration resources (relational or social). In Investigation 9, Öner proposes a focus on the coordination of these resources—which characterize collaborative dynamic-geometry problem-solving—for understanding what goes on in such productive math learning.

The combination of social and content resources brought to bear on geometric problem-solving often bridges levels. Social resources—such as greetings, invitations to speak, and checks on discourse direction—function to cohere the group out of its individual members, drawing upon community standards and institutional routines. Uses of math resources—such as manipulating visual representations, referencing recent findings, and expressing relationships symbolically—move fluidly between individual perceptual behavior, group problem-solving sequences, and the cultural stockpile of mathematical knowledge. Perhaps the incessant traversal of levels is particularly visible in collaborative math discourse because of its explicit use of multiple layers of reality: a physical drawing, the intended figure, a narrative description, a symbolic expression, the conceptualization, and the mathematical object.

Öner's methodological proposal is to trace both the math-content-related and the social/collaborative/relational resources used by students solving dynamic-geometry problems. Math resources may come from graphical, narrative, and symbolic representations or expressions of the math problem or from previous math knowledge of culturally transmitted concepts, theorems, procedures, symbolisms, etc. Social resources include communication practices, such as the rules of conversational discourse (transitivity, sequentiality, shared attention, argumentation, turn taking, repair, etc.).

Öner's Investigation cites a number of distinctions drawn in the CSCL literature for contrasting social/collaborative/relational resources with content-related resources:

- An interpersonal-relations space versus a content space (Barron, 2000)
- Building a joint problem space (JPS) versus solving a problem (Roschelle & Teasley, 1995)
- Temporal dimensions of the JPS versus diachronic content (Sarmiento & Stahl, 2008)
- Text chat versus shared-whiteboard graphics (Çakir, Zemel, & Stahl, 2009)
- Project discourse versus mathematical discourse (Evans, Feenstra, Ryon, & McNeill, 2011)
- Spatio-graphical observation (SG) versus technical reflection (T) (Laborde, 2004)

The "space" that a group builds up and shares is a structured set of resources gathered by the group (JPS, indexical field, common ground). The resources are "indexical" in the sense that they are only defined within (and thanks to) this constructed space of the specific problem context. Through their discourse, the group compiles these resources as potentially relevant to the problem. In turn, the resources help to define the emergent problem, dialectically.

Öner generated data to explore the interaction of the contrasting dimensions by having two people work together face-to-face in front of a shared computer on a particular dynamic-geometry problem, whose solution required a mix of spatio-graphical observation and technical reflection involving mathematical theory—a mix of SG and T resources, to use the distinction she adopts from Laborde. She uses this distinction among resources to structure her analysis. In doing so, she shows how these various resources bridge the different units of analysis. Resources of *individual* perception (during dragging of geometric objects on the computer screen) feed into the *group* problem-solving, just as do references to classical theorems passed down through *cultural* institutions. They make possible and stimulate the group interaction. This analysis provides examples of interactional resources at work in CSCL settings.

By analyzing both social and content resources, Öner shows how interrelated these can be. For instance, at one point in the data, one student says, "now two isosceles, oops, equilateral triangles are formed here." This utterance is deeply indexical. It is pointing to the "here" and "now" of the geometric construction. The student is narrating his work, intersecting two circles to locate the vertices of the desired equilateral triangle (see Fig. 2.3). The method he is using refers back over 2500 years to Euclid's first proposition, which teaches this construction. It also notes that one could use either of two potential intersections to construct alternative triangles. This leads his partner to see first one of the intersection points and then the other. Öner notes that the two students collaboratively accomplished this construction; in the doing of it, they collectively recalled the procedure, which they had

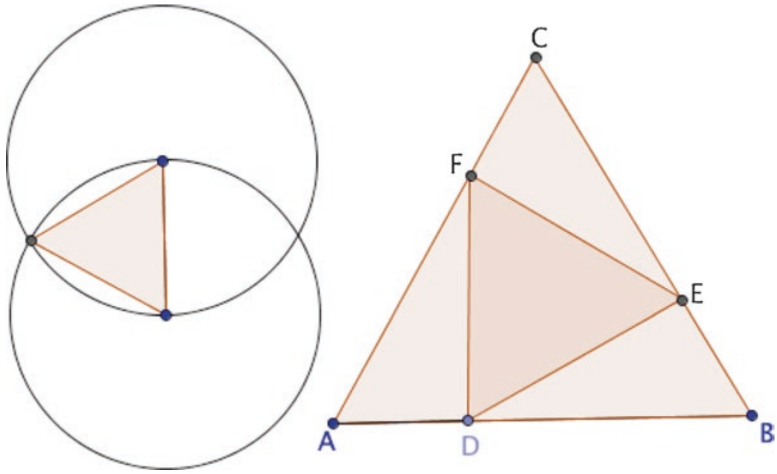

Fig. 2.3 Constructing an equilateral triangle inscribed in an equilateral triangle

performed in the past but forgotten. She also emphasizes that this utterance includes a self-repair, in which the speaker substitutes a correct term ("equilateral") for an incorrect one—a move she considers social. Repairs are conversational moves aimed at avoiding or correcting potential misunderstandings.

This raises a key theoretical point. Should this utterance be analyzed, categorized, or coded as a social resource or as a mathematical one? What is the resource here? Is it the generic conversational resource of self-repair as a "member method" (Garfinkel, 1967), or is it the word "equilateral" in the shared language, or is it the geometric concept of equilateral polygon? I.e., is it a conversational move, a linguistic term, or a mathematical concept? This is a matter of level of analysis, because one could characterize it in any of these ways. Alternatively, one could argue that the interactional resource that exists here spans multiple levels of analysis, providing an object for analysis at the conversational, linguistic, and mathematical levels of the interacting group, the speaking individual and the cultural conceptualization. In other words, such a resource can serve as a boundary object (Star, 1989), which can be discussed from different perspectives, focused on different units of analysis.

Öner succeeds in analyzing how her students collaborated on their geometry problem by focusing consistently on the interplay between social and content resources. It may be that we can often follow the movement of discourses across different levels by keeping our eyes on consequential resources. However, other CSCL researchers interpret the theme of resources differently from Öner. This leads them to different insights about their data. Perhaps we can use the concept of resource as a methodological boundary object to bring together the disparate theoretical voices. Too often, they seem to talk at cross-purposes, emphasizing differences when they might well be seeing the same phenomenon from different angles.

Scientific Representations Across Levels

Even if analysts agree in identifying a certain object as a pivotal interactional resource, that does not mean that the nature or meaning of that resource is self-evident to students using it for collaborative learning—as the second article in *ijCSCL* 8(3) by Furberg et al. (2013) makes clear. They turn to look at how students make sense of scientific diagrams to support their collaborative learning of physics. The implications of a diagram of a photoelectric cell only emerge gradually for a group of students striving to understand and explain the scientific processes represented there.

The central case study of this paper illustrates how the students gradually produce the meaning of the scientific representation. It is the sensemaking process—mediated by the representational resource—that spans levels: The individuals, each with their own approaches and each bringing in different other resources, contribute to the group's collaborative effort, resulting in a group understanding, expressed however awkwardly and partially in their written report. The representation—first from their textbook and then complemented with a second diagram from the Internet—is a contribution from the larger scientific or science-education community.

The paper characterizes the science diagram as a *structuring resource*. It argues that the representation, as it becomes meaningful to the students, structures the group's sensemaking work. The structuring takes place on various levels: Interactionally, the group uses the diagram as a deictic resource, pointing to its features either gesturally or linguistically to support the verbal accounts. Individually, the students refer to the diagrams to monitor their own understanding. At the level of science norms, the students attempt to use canonical language to express the sense they are making of the diagram.

Student discourse generally halts in articulation of an idea at the point when everyone seems to understand each other adequately for all practical purposes of the conversation. Even adding a third person to the discourse can extend the discussion somewhat, because the third person brings new questions and needs for understanding. However, when students go to write up a point, they must attain a much higher standard of articulation. They must make their written statement comprehensible and persuasive for a general audience or for people not present to indicate their understanding or agreement. This audience might, for instance, include the teacher, other students in the class, or even an audience of unknown potential readers. The audience might require a scientific formulation, using the vocabulary and stylistic genre of physics. Furthermore, since the reading audience is not co-present with the speakers, physical gestures and deictic references to times, places, people, and objects present are no longer effective. While the diagram still helps to structure their articulation of the description, the description can no longer rely so heavily on the diagram to help convey their meaning.

It is always true that there is a dialectical circularity or recursive character to the relationship of the discourse context and the utterances that are made within that context; this becomes even clearer in the relationship of the diagram as a structuring and interactional resource to the students' understanding of this resource. The (tentatively understood) diagram helps to structure the students' (increasing) understanding of the diagram itself. The paper nicely shows how the introduction of a second diagram enriches the dialectic by shedding light on the first diagram's meaning through the tension created by the differences between the two representations.

Referential Resources for a Math Problem

In the third paper of *ijCSCL* 8(3), Investigation 5 takes an ethnomethodologically informed look at the role of resources, representations, referential practices, and indexical properties in the mathematical problem-solving interactions of students within a CSCL setting. Viewed in the context of the 8(3) issue of *ijCSCL*, Investigation 5 develops further some of the central themes of the two previous papers. It concurs with the first paper on the importance of tracking the use of resources, and it further emphasizes that it is the ongoing specification-in-use that determines the significance of a given resource. It concurs with the second, in adopting a concern with representations, and it makes even more explicit the extent to which the representational practices—how the representation was built and worked with—contribute to the problem clarification and problem solution.

In theoretical terms, this paper develops the discussion of *indexical-reference resources* by Hanks (1992). It considers two groups of students who were presented with the same problem statement involving combinatorics. The two groups identified completely different sets of "indexical properties," which allowed them to formulate implicitly, share collaboratively, and solve mathematically the "same" problem, which, however, had been specified quite differently. In the first team, Bwang8 specified the stair-step pattern of squares in terms of two symmetric sets of lines. Each set of lines followed the pattern: 1, 2, 3, …, n, n. In the second team, Davidcyl specified the problem initially as "the nth pattern has n more squares than the (n-1)th pattern."

Ethnomethodologists are keen to observe the "work" that people do to accomplish what they do. Both teams engaged in intricate coordination of text understanding, sequential drawing, retroactive narrative, and symbolic manipulation to make sense of the problem statement they faced and to arrive at a mathematical solution. The work involved in this can be characterized as discovering, proposing, and negotiating successive determinations of indexical properties of the problem they were working on. The indexical properties are ways in which the team members can reference aspects of the problem, such as in terms of sets of lines arrayed in specific identifiable patterns. These indexical properties are tied to the local problem-solving context of the respective team. They specify the problem for the team in practical terms, which allow the team to make progress in both understanding and solving the problem.

This approach is appropriate for what Rittel and Webber (1984) called "wicked problems." These are nonstandard problems, for which the approach to problem-solving is not obvious and turns out to be a matter of coming to understand the problem itself. One can imagine Bwang8 entering a completely unknown territory. He was not familiar with the online environment, had never seen the kind of problem statement that was displayed, did not know the other team members, and was unclear about what was expected of him. He spotted (visually) an interesting symmetry in the problem and started by stating it as an initial specification about how to view (perceptually and conceptually) the problem. Then he started to draw the problem, so specified, on the shared whiteboard. Davidcyl entered a similarly unknown territory. He started drawing the pattern for $N = 4$, as suggested in the text. In so doing, he developed some copy-and-paste practices, which he presented (in the sequentiality of his drawing process as well as in his accompanying description) as tentatively mathematically relevant.

Starting from *individual* suggestions of indexical properties (by Bwang8 or Davidcyl, respectively), each group developed a growing shared indexical ground of deictic reference. The work of building that space of possible references led the *group* to make sense of a problem and to discover a path to a solution in mathematical terms. The ground itself is a set of shared interactional resources that allows the team to refer to its object of concern in mutually intelligible ways. By gradually moving from purely deictic terms like "it" or "this," to mathematical terms or abstract symbols, the indexical resources incorporated cultural knowledge and contributed to a less locally situated store of understanding that could be relevant in a larger classroom or *culture* of school mathematics (including standardized tests). The analysis of how these groups successively and collaboratively re-specify their referential resources suggests approaches to studying how groups make sense of problems and artifacts whose indexical properties are initially unknown or underspecified. This is a foundational concern for CSCL, as "a field of study centrally concerned with meaning and the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts" (Koschmann, 2002).

Roles as Interactional Resources for Community Meaning-Making

If the previous studies take interactional approaches, the next paper in *ijCSCL* 8(3), Hontvedt and Arnseth (2013), can be considered to be largely at the community-of-practice level. Like the apprenticeship cases of Lave and Wenger (1991), this one is concerned with how novices take on the practices of a professional community. Situated in a simulator for training Norwegian sailors, the apprentices role-play at navigating a ship. To bring a ship up the fjord to Oslo, they must bring aboard a local expert. This master pilot helps to establish the professional navigational practices with the apprentices. Interestingly, the pilot insists on using the international language of shipping, English. At times, the trainees slip into Norwegian to reflect on their role-playing, thus marking linguistically the duality of their realities. On the one hand, they are playing the roles of professional sailors interacting in English on the bridge with the local pilot; on the other, they are Norwegian students discussing their educational activities.

Through their role-playing, the participants—whether newcomers or established members of the sailing community—co-create interactionally the context of their learning. Much of the learning consists in this subtle process, which includes integrating interpersonal relations, language constructs, physical artifacts, a designed setting, and nautical tasks. Together, this constitutes what the authors call an *activity context*. Building on the theoretical framework of activity theory, an activity context is closely related to Goffman's (1974) concept of frame.

The roles taken on by the students are resources for their apprenticeship meaning-making. Like roles in a play on stage, they require a willing suspension of disbelief. The analysis in the paper nicely shows how the students fluidly move in and out of their roles and negotiate when to do so, often through code switching between the languages of the two cultures. Never taking the simulation fiction too seriously—as though it were an immutable reality—the analysis reveals how the participants themselves achieve the tenuous existence of the activity context interactionally.

The interactional resources of this learning community are ephemeral emergents—which also means they can collapse. The action can call for a role or an artifact that is missing from the simulation, resulting in improvisation, chaos, and laughter. This carries a lesson for all of us: an assemblage of resources for learning cannot foresee all uses. Even the most rehearsed experiment in complex learning is likely to run afoul of glitches. In the best cases, the participants laugh off the troubles … and the analysts discover insights in the breakdowns.

Annotations as Resources for Individual Learning

In the final paper of issue *ijCSCL 8*(3), Eryilmaz, van der Pol, Ryan, Clark and Mary (2013) take a controlled experiment approach to evaluate the effect of a promising annotation-support tool as a resource for individual learning. While acknowledging that online asynchronous discussion in a university course is a group activity in an educational social setting (with an instructor, discourse standards, canonical texts, grading, etc.), the authors systematically focus on the learning of individual students as evidenced by their individual postings and isolated pre-/posttests. In contrast to the qualitative analysis of interaction in the preceding papers, this one codes individual posts and analyzes them with a battery of quantitative methods. Even the analysis of sequentiality is done without reference to interactional context. The group and social setting are considered controlled for, and only the presence of the software function distinguishes the treatment from the control condition.

By methodologically focusing on the individual student and the individual posting as the units of analysis, this study is able to isolate and quantitatively assess the role of context on these units. For instance, the paper asserts that "collaborating students are able to use one another as a *resource for learning*" (emphasis added). That is, while learning is conceptualized as a process that primarily takes place in individual heads, it is enhanced by the interactional level of individuals formulating ideas as posted text and receiving feedback as posted responses from others. Asynchronous discussion forums seem like good media for supporting such enhancement, except that their use apparently causes excessive "cognitive load," reducing the ability to engage in the cognitive processes required for deep learning and therefore counteracting the potential benefits of social interaction.

The complex sociocultural and interactional processes analyzed in the previous papers are here viewed as likely sources of unwelcome cognitive load. In order to communicate one's ideas about a text in annotations that might make sense to other students, one must engage in the sorts of collaborative meaning-making analyzed in the other papers. For instance, one must construct explicit indexical references, such as "the third sentence in the conclusion," which can be used to coordinate co-attention.

To make it easier to establish joint reference, the authors of this study provided students with a software indexing function, which graphically connects annotations with relevant selections in the provided educational text. The treatment group uses this software tool as an *interactional resource*, which is not made available to the control group. The research then studies the effect of the resource on learning with the rigor of its chosen methodology. The study shows that the treatment group produces more posts coded as "assertions" and "conflicts." It also does better than the control on the posttest, confirming experimental hypotheses. The conclusion is that the software resource reduced the cognitive load needed to co-construct effective shared interactional resources, like indexical descriptions of target text passages. This allowed the students more cognitive ability—or perhaps just more time-on-task—to engage in interactive assertions and conflicts. So the focus on the individual unit of analysis allowed this study to evaluate interactions between individual learning, group interaction, and socio-technical setting.

Of course, one can always question a study's assumptions and operationalization. The recent findings in CSCL research about "productive failure" (Kapur & Bielaczyck, 2012; Kapur & Kinzer, 2009; Pathak, Kim, Jacobson, & Zhang, 2011) problematize the purely negative view of what is here characterized as cognitive load, as well as the way of assessing deep learning. Positive findings about productive failure suggest that group processes can underlie learning in ways that may not show up immediately. The effort (cognitive load) to build a joint problem space about a text through interpersonal interaction may confer learning benefits that are not achieved when that task is delegated to software. The benefits may also not show up in measurements taken immediately at the individual unit of analysis.

This final paper of the *ijCSCL* issue, taken together with the preceding four, illustrates how different methodologies can be adopted for analyzing resources and their relations to different levels of analysis. What can be taken as a resource for purposes of CSCL research is open to a broad range of approaches and theoretical frameworks. One can find resources for individuals, groups, and communities. Often, those resources can be seen as traversing across or mediating between levels. Analysts can fruitfully focus on one aspect or another of this; or they can strive to follow resources across multiple levels.

The CSCL Agenda on Levels of Analysis

The time has come for CSCL to address the problem of traversing levels of analysis with exacting research. Attempts to research a given level in isolation have run into fundamental limitations. Although it is clear to most researchers that the levels of individual, small-group, and community phenomena are inextricably intertwined, opinions differ on how to respond analytically. Religious wars between adherents of different methodological faiths are often based on misunderstandings: people agree on the need to comprehend the levels together but articulate that need in incommensurate-seeming locutions.

Multiple-method approaches, multilevel statistics and multivocal analyses are too limited, because they do not explicitly address the interrelationships among different levels. Some researchers claim that the apparent levels are all reducible to one fundamental level—whether individual cognition, group interaction, or the social—while others assume that they can be studied independently. Some say that there is no such thing as different levels, but only different kinds of analysis, although they generally end up talking of individual understandings, group interactions, and community practices. There are vague theories that one level is emergent from another or dialectically coupled with it, but these ties are not well worked out or evidenced with CSCL data.

The contributions in issue *ijCSCL 8*(3) provide examples of the kinds of studies and analyses that are needed. In order to comply with one or another standard of rigor, most research focuses on specific relationships within a single unit of analysis. We now also need to generate, compile, and analyze data that sheds light on relationships across levels. The idea of tracking *interactional resources* as they mediate across levels offers one suggestive approach. The different papers discussed here and other referenced theories show that there are many ways to conceptualize, analyze, and theorize resources. We do not mean to define or defend a particular tack, but to suggest interactional resources as a candidate boundary object for discussion across competing approaches. We do not claim to have proposed a consistent position, but rather to raise some questions about what can be meant by resources for computer-supported collaborative learning, in the hope of stimulating thinking for CSCL research in the future.

This Investigation has tried to prepare the way for the more detailed considerations of a theory of group cognition in this volume, especially the essays of Part III. After tracing the historical expansion of the concept of cognition—especially in twentieth-century philosophy—from individual minds to group and collective cognition, it focused on the concept of intersubjectivity as central to analyzing and designing collaborative learning. Intersubjectivity is the ability of multiple subjects to understand each other by interacting within a shared world. A number of approaches to intersubjective meaning-making were reviewed, including by CSCL researchers, philosophers, ethnomethodologists, and activity theorists. The intersubjective processes at the small-group unit of analysis were seen as intimately connected with the adoption and use of artifacts and social practices. This led to consideration of the inherent integration of multiple planes of learning and the role of resources that span the individual, group, and cultural levels. These themes are explored at length by the Investigations of Part II and Part III, which follow. They provide detailed arguments and clarifications for the vision of CSCL proposed in Investigation 1, with its theoretical, methodological, and pedagogical focus on the intersubjective small group.

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Part II

A Vision of CSCL

Investigation 3. A Relational, Indirect, Meso-level Approach to CSCL Design in the Next Decade

Chris Jones, Lone Dirckinck-Holmfeld, and Berner Lindström

Abstract

This paper reviews some foundational issues that we believe will affect the progress of CSCL over the next 10 years. In particular, we examine the terms *technology*, *affordance*, and *infrastructure*, and we propose a relational approach to their use in CSCL. Following a consideration of networks, space, and trust as conditions of productive learning, we propose an indirect approach to design in CSCL. The work supporting this theoretical paper is based on the outcomes of two European research networks: E-QUEL, a network investigating e-quality in e-learning; and Kaleidoscope, a European Union Framework 6 Network of Excellence. In arguing for a relational understanding of affordance, infrastructure, and technology, we also argue for a focus on what we describe as meso-level activity. Overall this paper does not aim to be comprehensive or summative in its review of the state of the art in CSCL but rather to provide a view of the issues currently facing CSCL from a European perspective.

Keywords

CSCL · Networked learning · Affordances · Infrastructure · Meso level · Ethics · Indirect design

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C. Jones (✉)
Educational Technology, Liverpool John Moores University, Liverpool, UK

L. Dirckinck-Holmfeld
Aalborg University, Aalborg, Denmark

B. Lindström
Gothenberg University, Gothenberg, Sweden

G. Stahl (ed.), *Theoretical Investigations*, Computer-Supported Collaborative Learning Series 18,
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Introduction

Because computer-supported collaborative learning (CSCL) is an emerging field of research and interest, it still struggles to find a provisional stability and even continues to argue over its very name (Koschmann, 1996, 2001; Strijbos, Kirschner, & Martens, 2004). However, if we think of CSCL from a sociology of knowledge perspective, we can see that CSCL has already emerged as a scientific field and a community complete with its own conferences, books, educational programs, and now a journal. The commonsense starting point in CSCL is that learning is social in nature, contextualized and situated in particular settings. The theoretical framework adopted in this paper can be described as sociocultural, in a broad sense, in that it draws on the works of Vygotsky (1978), Leontjew (1977), Engestrom (1987), Lave and Wenger (1991), Wenger (1998), Giddens (1984), Castells (1996/2000), Dewey (1916), and Negt (1975), among others. It should be noted that with regard to epistemology and methodology, these traditions are in some ways contradictory, in the relation between subject and object, the level of analysis, and the understanding of technology, for example. As a consequence, there needs to be serious reflection on the ways in which it might be possible to solve these contradictions and on the consideration of whether it's productive to try to solve them at all. Also arising from the very nature of the object of its research, the field of CSCL is interdisciplinary and naturally draws upon a variety of feeder disciplines such as education, anthropology, psychology, sociology, computer science, cognitive science, communication, media, artificial intelligence, and informatics. Studies in CSCL are diverse in their contributions dealing with analysis, theory, modelling, construction, and design. The methods applied in CSCL research stretch from controlled laboratory experiments on group collaboration to action-oriented, situated, social experiments designing for various forms of collaborative learning in a global digital networked setting. What knits the field together and what makes it special is the *integration* of the four fundamental concepts: computer, supported, collaborative, and learning.

However, in some of the recent work reflecting on CSCL, including Koschmann (2001)—one of the founding fathers of CSCL—there is a questioning of the necessity of integrating technology into CSCL:

> CSCL research has the advantage of studying learning in settings in which learning is observably and accountably embedded in collaborative activity. Our concern, therefore, is with the unfolding process of meaning-making within these settings, not so-called "learning outcomes," It is in this way that CSCL research represents a distinctive paradigm within IT. By this standard, a study that attempted to explicate how learners jointly accomplished some form of new learning would be a case of CSCL research, even if they were working in a setting that did not involve technological augmentation. On the other hand, a study that measured the effects of introducing some sort of CSCL application on learning (defined in traditional ways) would not. (ibid. p. 19)

Strijbos et al. (2004, p. 1 and p. 246) make a somewhat different point, but one that also implies a non-technological emphasis. For these authors the emphasis in CSCL is on learning and educational design. Unlike Koschmann, we think it is both necessary and challenging to keep technology within our focus. Unlike Strijbos et al., we see the technological aspect as deeply integrated in a sociocultural approach to the understanding of collaborative learning. The technology has to be taken seriously as a property, either symbolic or material—a set of tools which can afford meaning making—because this is precisely what makes this research area special. In our opinion this is where CSCL has something profound to contribute to the field of learning.

Much of the research that has taken place within CSCL has focused on the micro level of collaborative learning—on the collaborative learning taking place in single, small groups. Supplementing these approaches, we would like to argue for more focus on what we would call the meso level of collaborative learning:

- On how to design for collaborative learning at the institutional level, in organizations, in school settings, and in networked learning environments
- On what the basic conditions are that allow for collaborative learning in these settings
- On how the technology and infrastructure affords and mediates the learning taking place

The meso could be thought of as a level that was intermediate between small-scale, local interaction and large-scale policy and institutional processes. We would argue that differentiating into levels assists us in identifying the detail of what otherwise might appear as a simple or monolithic social system. We would also suggest that it is possible to use levels and the distinctions between macro, meso, and micro levels in a more analytic way. In this form, meso is an element of a relational perspective in which the levels are not abstract universal properties but descriptive of the relationships between separable elements of a social setting. The term micro identifies small group interaction with a highly local (not necessarily spatially local) setting. Meso would identify interactions in and with the settings beyond the small group, but still with a local focus that was open to routine control and intervention. Macro would identify the level of interaction beyond meso that was general in character (even if represented locally) and not open to routine control such that it could on most occasions, be treated as a given. In this sense meso points to the place of social practice as the locus in which broader social processes are located in small, local group activity (Schatzki, 1996; Schatzki, Cetina, & von Savigny, 2001). This suggested link with social practice also links the idea of a meso level of analysis with previous work in cognate research areas such as CSCW. In CSCW organizational concerns have been more generally addressed than in CSCL (e.g., Harper, Randall, & Rouncefield, 2000). The link to social practice also provides a bridge to broader concerns with organizations (e.g., Orlikowski, 2000; Wenger, McDermott, & Snyder, 2002). Such factors as we identify at the meso level have been investigated previously in CSCL research, most notably in cultural historical activity systems terms. Activity systems are not restricted to a micro level and could, in theory, apply to all of the levels we identify above (Engestrom, 1987, 1999, 2001).

Following from this approach, we would like to throw light on the field of CSCL making use of the theoretical lenses of educational research, human centered informatics, and the social sciences more generally. In doing so:

> First of all, the right vocabulary is necessary for thinking about the phenomena that occur on levels of analysis that we are not familiar with discussing. In addition, we need appropriate conceptual resources and analytic perspectives. This is what is meant here by *theory*. Philosophy used to provide such intellectual tools, but recently this has become a task for interdisciplinary sciences. (Stahl, 2006, p. 306)

In the following, we are not providing a theory, but in line with Stahl, we would like to contribute to the collaborative process of establishing a meaningful conceptual framework for the understanding of conditions for productive learning in networked learning environments. In order to understand the new emerging practices in this area and to be able to contribute to the productive development of them, we must develop conceptual tools. This is even more necessary because of the interdisciplinary nature of the field. Integrating concepts from different disciplines involves a cost in terms of the intellectual work necessary to ensure that the historically embedded meaning travels with the concepts and that the concepts are rethought and integrated in the perspective of the new practices and the insights from neighboring disciplines. We will focus on two sets of issues: technology affordances and infrastructure; and networks, space, and ethics. The first set of issues is highly general and relates to the theoretical lenses that we might adopt in relation to CSCL. It is our contention that these issues can all be understood using a relational point of view and would benefit from an explicit consideration of meso-level activity. The second set of issues moves toward the objects of research for CSCL. These have emerged in our work as being crucial to an understanding of the conditions for productive learning in networked learning environments.

Background

This paper emerges out of two European research networks, and some of the projects related to them. The first of these networks, E-QUEL, an acronym that stands for "e-quality in e-learning," aimed to develop a virtual center of excellence for innovation and research in networked learning for higher and post-compulsory education (http://www.equel.net/). The E-QUEL network brought together researchers and practitioners from 14 institutions across Europe in 6 different countries and finished its funded work in 2004. The project was organized so that each of the partners worked in plenary sessions and assigned themselves to seven different significant interest groups (SIGs), each of which reported through a position paper at the conclusion of the project and a final dissemination event held at the Networked Learning Conference held at Lancaster University, April 5–7, 2004 (http://www.shef.ac.uk/nlc2004).

The second network is called Kaleidoscope; a European Union funded Network of Excellence that aims to integrate 76 research units from across Europe (http://www.noe-kaleidoscope.org). The network was established in January 2004, and it has a funded duration extending to December 2007. This large network consisting of 23 partner countries is engaged in a wide range of activities. This article largely reflects work conducted as part of one of the network's projects: "Conditions of productive learning in networked learning environments." It is also informed by the broader work of the network, such as participation in the CSCL SIG and in the activities of the Virtual Doctoral School.

The work conducted in these two networks has informed our ideas in two separable ways. At a general level, the issues we identify arose out of the discussions that took place within the networks. At a more particular level, we illustrate some aspects of our argument with studies that were introduced as case studies by network partners. All the issues addressed here have emerged in our work as crucial to understanding the conditions for productive learning in networked learning environments.

Technology, Affordances, Institutions, and Infrastructure

We argue that the concept of technology and the relationship between the design of technology and the use of technology is a crucial issue within the CSCL community. Vygotsky's sociocultural approach, suggesting that tools fundamentally mediate higher mental functioning and human action, is a deeply accepted stance, and at times it is even taken for granted in the CSCL community (Cole, 1996; Kaptelinin, Danielsson, & Hedestig, 2004; Vygotsky, 1978). Human action employs means of mediation, and these means shape actions in crucial ways. In education it is common to focus on how information and communication technology (ICT) functions as a tool for the appropriation and understanding of conceptual knowledge (Säljö, 1999). It is not necessarily useful to categorize mediating means into external or technical tools on the one hand and internal or intellectual tools on the other. These functions and uses are in constant flux and transform as the activity unfolds (Engeström, 1999). Tools such as maps, written documents, technical drawings, etc. are not simply a mental function; they also have a clear material form. As such, they persist, continuing to exist as physical objects even when they are not incorporated into the flow of action (Wertsch, 1998). Both the material and symbolic properties of tools are seen as having important implications for understanding how internal processes come into existence and operate. Fjuk and Berge, in a case study presented as part of our Kaleidoscope activity, argue that in order to understand these processes, analysis and design must consider the individual learner in her/his concrete situation and the mediational means that are employed (2004). Fjuk and Berge argue that it is important for systems developers to understand the incorporated role of artifacts in networked learning environments. This means going beyond the operational functionality of a particular technology and considering the constellation of artifacts in relation to the specific conditions in a setting and the objectives of the activity.

The focus on social practice links this work to a similar position elaborated by Orlikowski (2000). Orlikowski suggests making an analytical distinction between the use of technology, what people actually do with technology, and its artifactual character: the bundle of material and symbolic properties packaged in some socially recognizable form, e.g., hardware, software, techniques, etc. (Orlikowski, 2000, p. 408). Through a theoretical and empirical analysis, she demonstrates that the same artifact used in different institutional contexts and by different social actors can evoke very different actions. Theoretically, these different processes are explained by Orlikowski using structuration theory (Giddens, 1984), and she makes a distinction between two discrete approaches (Orlikowski, 2000, p. 405):

(a) An approach which posits technology as embodying structures (built in by designers during technological development), which are then *appropriated* by users during their use of the technology.
(b) A practice-oriented understanding where structures are emergent. Structures grow out of recursive interactions between people, technologies, and social action in which it is not the properties of the technology, per se, which structure the practice. Rather, it is through a recurrent and situated practice over time, a process of *enactment,* that people constitute and reconstitute a structure of technology use. (Orlikowski, 2000, p. 410)

The practice-oriented structuration approach to technology presented by Orlikowski in (b) suggests that although the technology embodies particular symbolic and material properties, the technology in itself is not a structure that determines the use and the users. Rather, the opposite is true: the structure—understood as resources and rules—is instantiated and emerges through the user's responses and enactment in relation to the technological artifact. We would go on to argue, however, that Orlikowski may present too strong a contrast between the two approaches summarized in (a) and (b) above. Seen from the practice of design, technologies do indeed embody features and properties, and they also carry meaning. Having been designed with certain purposes in mind, certain understandings of communication, interaction, and collaboration were embedded in the design process. There are many examples of this within education. The design of virtual learning environments reflects certain models and understandings of communication, interaction, collaboration, teaching, and learning, and they provide particular functionalities (Tolsby, Nyvang, & Dirckinck-Holmfeld, 2002). Although these might vary in flexibility and in adaptability, the information architecture embodies particular symbolic and material properties. These properties are not determinant of the use made of them—here we agree with Orlikowski—but they make available certain features that can become affordances in use and make some kind of practice more available than others. How the technology is enacted is therefore closely related to the properties, social as well as technical, which are reified in the design (For more on this discussion, see also Stahl, 2006, esp. Chpts. 13 & 16). For CSCL it becomes an interesting research question to ask both how technologies are taken into use in ways related to what may be thought of as their technological affordances (see below) and also how they are reconfigured by users in varying situations and institutional contexts, including how users find creative ways to deal with inappropriate design.

This problem raises a question about the level of analysis being used, and it would be reasonable to ask the question: "Do meso-level processes show up in micro-level analyses?" Our answer is that, in principle, macro- and meso-level processes will be available within micro-level interaction. However, we argue that on its own, the availability for analysis of interaction related to other levels is not enough. We argue that you need a theoretical approach that explicitly takes the meso level into account, not just in terms of explanations but also to direct attention to those features of a setting that may remain invisible, while attention is focused on macro-or micro-level analysis. Therefore, analysis focused at the meso level also has to take account of both macro- and micro-level processes. Indeed, we argue that analysis at the meso level can help to link processes at the other two levels together.

Another way to deal with this question is to examine how we conceptualize technology. In her paper, Orlikowski (2000) counterposes technology thought of as:

(a) "an identifiable, relatively durable entity, a physically, economically, politically, and socially organized phenomenon in space-time"—a technological artifact.
(b) "a repeatedly experienced, personally ordered and edited version of the technological artifact"—technology in use. (Orlikowski, p. 408)

She makes it clear that this distinction is analytic rather than ontological in character, but our work leads us to question the usefulness of this distinction in relation to certain kinds of technology. In particular we wonder whether the Web or Internet can usefully be thought of as technological artifacts in relation to CSCL. We would support the general position that Orlikowski seeks to maintain, but we are concerned that conceptions that apply the metaphor of artifact to large, complex, and composite forms such as the Web and Internet are in danger of reifying a deeply reflexive phenomenon. In important ways the Web and Internet do not fully conform to Orlikowski's criteria. Though relatively durable, they are constantly in flux; though organized, they show an uncommon self-organizational capacity; they are a network form, rather than stable economic, political, and social forms. This dynamic form suggests that we cannot treat the Web or Internet as a technological artifact, but we can presume that these forms exist significantly at the macro level of analysis. That is, although deeply reflexive, they are beyond routine control or influence. At the meso level, the deployment of Web and Internet technologies in the form of intranets, virtual or managed learning environments, etc. brings these complex forms to a level in which routine control and influence may indeed be possible, and the technology is always a repeatedly experienced and edited version. At the micro level, we would point to the ways in which Web and Internet technologies become part of the local and particular interactions. At the micro level of interaction, technology is always technology in use. We suggest that the concept of technology, and in particular the concept of technological artifacts, is an area ripe for further CSCL research, especially in relation to large-scale and composite technological forms such as the Web and Internet and the way in which they impact at different levels of analysis.

Affordance

The concept of affordance has been central to thinking about technology within the CSCL tradition and beyond. The idea of affordance has been applied to technology in the sense that:

> technologies possess different affordances, and these affordances *constrain the ways that they can possibly be 'written' or 'read.'* (Hutchby, 2001, p. 447)

The concept of affordance, used in this way, allows for the possibility that technologies can have effects on users and that particular technologies can constrain users in definite ways. The idea has its origins in the work of Gibson (1977) who was interested in the psychology of perception. Gibson argued for a nondualist understanding of perception. His main interest was studying perception as an integrated or ecological activity. Affordances in Gibson's view might vary *in relation* to the nature of the user, but they were not freely variable; the affordances of a rock differed from those of a stream, even though different animals might see the affordances of each differently. Gibson's view is strongly relational and differs in significant ways from the later application of the idea of affordance by Norman (1990, 1999). Donald Norman takes an essentialist and dualist approach in which technologies possess affordances and users perceive them. Arguably, Gaver (1996) developed a position that is more aligned with Gibson's original idea, and in his 1996 paper, Gaver clearly argues for an ecological and relational perspective close to the one presented here. Nonetheless, it remains the case that Gaver argues that on the one hand, objects have affordances, and on the other, that they are made available through perception. This is a clearly dualist outlook and subsequent appreciation of his work has largely identified this aspect rather than his ecological and relational remarks. All three authors have recently been reviewed by Kirschner, Strijbos, and Martens (2004), who emphasize the distinction added by Norman between an affordance as a property possessed by an entity and an affordance as it is perceived. Kirschner et al. (2004) suggests that educational researchers and designers are not dealing with the affordances of technologies themselves; rather they are dealing with the perceptible (Gaver, 1996) or the perceived (Norman, 1990, 1999). In both Norman's and Gaver's view, the link between an affordance and action is one that relies upon the perception-action coupling.

Kirschner et al. (2004) proposed a six-stage model for a design framework based on affordances. This sophisticated and detailed model categorizes affordances as educational, social, and technological. Educational affordances are defined as "those characteristics of an artifact that determine if and how a particular learning behavior could be enacted within a given context" (Kirschner et al., 2004, p. 14). Social affordances are defined as "properties of a CSCL environment that act as social-contextual facilitators relevant for the learner's social interaction" (2004, p. 15). For technological affordances, the definition relies on Norman and technological affordances are "perceived and actual properties of a thing, primarily those fundamental properties that determine how the thing could possibly be used" (2004, p. 16). It can be seen that all three definitions rely upon an essential reading of affordance, on the *properties* and *characteristics* of CSCL environments, artifacts, and things. In all types of affordance considered by Kirschner et al., the property of having an affordance lies within the thing, environment, or artifact, even if the affordance relies on these features being perceived (2004).

The view of affordance that we have begun to consider and would propose to the CSCL community is one that returns to a Gibsonian view and extends the ecological stance found in Gaver (1996): a view that treats affordance as a *relational* property. In this view, affordance is not simply a property of an artifact alone, but it is a "real" property of the world in interaction. In this way of thinking about affordances, properties exist *in* relationships between artifacts and active agents, which would include animate actors and, following Actor-Network Theory, inanimate actants, even though there are distinctions between these different active agents in terms of intentionality. This view is nonessentialist and nondualist and does not rely on a strong notion of perception. Affordances in this view could be discerned in a relationship between different elements in a setting whether or not the potential user of an affordance perceives the affordance.

In educational settings we are likely to be concerned with reflexive social relationships. For example, in a CSCL setting, a task set for formative or summative assessment can provide the affordance of focusing group activity around which collaboration can occur. A relational view of affordance would suggest that we could analytically discern features of the setting apart from the perceptions of particular groups of users. Any actual group of users would have varied understandings and draw out different meanings from the setting, but designers can only have direct influence over those abstract elements that may become affordances in the relationship between the task and the participants. An example of such relational thinking can be found in Kreijens and Kirschner (2004). They point to the affordance of proximity in encouraging face-to-face interaction such as that associated with coffee machines/water coolers. They point to the need for teleproximity in computer networks, a simulacrum of actual proximity using designed features in digital environments. The affordances of both proximity and teleproximity rely on the relationship between participants rather than being a feature of any particular participant or a feature of the digital or physical environment.

We would argue that such a reading of affordance, alongside a view of analytic levels, allows the dynamic appropriation of artifacts in settings to be a central focus of research without losing sight of the design requirement to develop relatively fixed forms for a design, knowing that the interpretation and enactment of the design will be contingent and subject to interpretation in the interactions in any given setting.

Institutions

Implementation of CSCL in higher education is a complex task involving management, administration, and ICT support as well as teachers and learners. The environment students inhabit is now a dense interconnection between many technologies in what have been described as students' "learning nests" (Crook, 2002). The student experience is developed through activity using mobile phones, SMS and voice, instant messaging, institutional virtual learning environments (VLE), and a variety of access points for digital resources including journal articles and e-books. The practices of teaching staff are influenced in lecture theaters and classroom settings by the availability of technical resources, such as digital projectors and network links. Research in CSCL recognizes that influences on practice arise from organizational as well as pedagogical perspectives (Collis & Moonen, 2001; Dirckinck-Holmfeld & Fibiger, 2002). Despite these contributions, however, the implications beyond the practice of the individual teacher or small groups of teachers are still relatively vague. Change nevertheless involves processes well beyond the individual or small group.

In a recent case study of a Masters-level program developed as part of our work, Jones (2004b) argues that obtaining a single login to enable all students in a distance-education program to access library-like digital resources is a multilevel problem. Jones (2004b) argues that the technology does not present itself as a simple technological artifact; rather the technology is immediately a socially mediated form. At a macro level the required digital resources are enmeshed in a legal framework of ownership concerned with property rights. Access to the materials and resources available for teaching and learning is not a simple matter as some of the materials that appear freely on the web are ephemeral with links moving or disappearing on a regular basis. Secure resources have to be embedded in an institutional and organizational infrastructure that takes on some of the roles, such as preservation, that libraries have hitherto fulfilled. This institutional support may be external to the university and even the educational sector, as with materials supplied by government, NGOs, and corporations. When resources become organizationally supported, they often disappear from the Web's open access behind password protection. The creation of a single log-on authentication for staff and students and a public "commons" for educational materials is a political, legal, and social process well beyond the control of single educational programs. The significance of meso-level activity, focusing on organization and technical provision in departments, faculties, and entire universities in this multilevel process, is very high and conditions the range of choices available at a micro level.

Infrastructure

In common usage, infrastructure refers to the generally subordinate and relatively permanent parts of an undertaking. In a city we might think of roads, the sewage system, the water supply, the electricity or gas utilities, and the communications systems such as telephone lines. Infrastructures for CSCL, and learning more generally, might include the provision of ICT as it is closely related to the organizational and institutional factors mentioned above. In a sense, the infrastructures are the working out of institutional processes in relation to available technologies. Earlier we noted that it was difficult to consider technological forms such as the Internet and Web as artifacts. We would suggest that one way of considering such amalgams, such composites of technologies, is as infrastructures. Recently the notion of a "learning oriented" infrastructure has been introduced, relating more general ideas of technological infrastructures to the specific practices of learning (Lipponen & Lallimo, 2004).

Nyvang and Bygholm (2004), in a case study of a campus-based networked learning environment developed for presentation in the Kaleidoscope network, draw on the works of Star and Ruhleder (1994, 1996). They suggest that we interpret ICT in use as infrastructures that both shape and are shaped by practice. They go on to propose that we understand infrastructure as a relational concept. "Thus we ask, when—not what—is an infrastructure" (Star & Ruhleder, 1996, p. 113). This understanding of infrastructure has strong resonance with the earlier accounts of technology and affordance, and we would suggest that the infrastructure for CSCL is a location in which these general issues find focus for research. Infrastructures are concerned with the design of complex environments rather than singular tools or artifacts, environments that are informed by pedagogical and organizational understandings of practice. We return to the issue of design when we discuss the issue of design in relation to space and place. Our argument here, following work by Guribye (Guribye, 2005; Guribye, Andreassen, & Wasson, 2003), is that infrastructure can best be understood in a similar way to that suggested for affordance: as relational and ecological.

We have argued that technology, affordance, institution, and infrastructure are terms that the CSCL community may need to revisit. We have suggested that all four may be better understood using a relational perspective. We have also set out a number of ways in which we think this approach may lead to new research directions. The idea of technology and, in particular, the idea of technological artifacts are an area ripe for further CSCL research. We argue that technology and the affordances that may emerge in its use are factors that require investigation at a more meso level than has been usual in CSCL.

Conditions for Productive Learning: Networks, Places, and Ethics

This section examines three issues as examples of areas that need further research in CSCL from different levels of analysis. The first examines the capacity that networks have at a general level to influence learning. We suggest that networks are implicated in the patterning of forms related to digital technologies—the Web and Internet, for example—with embedded features linking individuals, groups, and institutions across time and space in ways that influence the broad conditions for learning. The second issue examines questions related to design in such environments. Design in this sense concerns both task and spatial design and, using the example of space and place in networked settings, argues for the appropriateness of an indirect notion of design for networked learning. Finally we examine the question of ethics. This discussion focuses on the social dimension of activity in networks and relates to the discussion of the meaning of collaboration and communities of practice.

Networks and Networked Learning

Castells (1996, 2000) writes about inclusion/exclusion in networks and the architecture of relationships between networks, enacted by information technologies, which configure the dominant processes and functions in our societies. Castells, following Wellman (Wellman et al., 2003), has described the form of sociality in network society as one of "networked individualism" (Castells, 2001, p. 129 ff). On the one hand, the new economy is organized around global networks of capital, management, and information, whose access to technological know-how is at the root of productivity and competitiveness:

> Business firms and, increasingly, organizations and institutions are organized in networks of variable geometry whose intertwining supersedes the traditional distinction between corporations and small business, cutting across sectors, and spreading along different geographical clusters of economic units. (Castells, 1996, p. 502)

On the other hand, he claims that the work process is increasingly individualized:

> Labour is disaggregated in its performance, and reintegrated in its outcome through a multiplicity of interconnected tasks in different sites, ushering in a new division of labour based on the attributes/capacities of each worker rather than the organization of the task. (1996, p. 502)

This overall trend in societal development raises fundamental questions about the relationships between the networked society and the organization of learning environments within formal education. The term networked individualism suggests that it is possible to take a critical approach to theories of community based on consensus, without ruling out the possibility of communication and dialogue. In particular, "networked individualism" suggests that it is possible for subjects to communicate from their own unique, socially situated positions. It also suggests that a community is reconfigured in networks so that different aspects of the community are supplemented, while others are decreased. It is an interesting research question whether the Internet will help foster more densely knit communities or whether it will encourage sparser, loose-knit formations. We believe it is a significant question for CSCL whether the designs of networked learning environments have to, or perhaps should, reflect the trend toward "networked individualism" or, on the other hand, whether CSCL could serve as a counter practice offering opportunities for developing collaborative dependencies in networked learning environments.

The idea of networked learning has developed some force within European research, expressed in a number of publications and a series of international conferences. One definition of network learning from this tradition is that:

> Networked learning is learning in which information and communication technology (ICT) is used to promote connections: between one learner and other learners, between learners and tutors; between a learning community and its learning resources. (Jones, 2004b, p. 1)

The central term in this definition is *connections.* This definition takes a relational stance in which learning takes place in relation to others and also in relation to learning resources. Networked learning differs in this way from CSCL and Communities of Practice in that it does not privilege strong relationships, such as cooperation and collaboration, or the close relations of community and unity of purpose. Unlike CSCL and Communities of Practice, this definition of networked learning draws particular attention to the place of learning resources and peer learners in relational terms (for further elaboration of this view see Jones, 2004a, 2004c; Jones & Esnault, 2004).

European research and practice has been heavily influenced by Communities of Practice thinking, and other learning environments for professionals have built more explicitly on ideas of Communities of Practice and the pedagogical principles of collaborative learning. This trend is evident, for instance, in the form of problem- and project-based learning: encouraging and expecting students to work together and to rely on interdependencies among students (see, e.g., Dirckinck-Holmfeld, 2002; Fjuk & Dirckinck-Holmfeld, 1997). The concept of Communities of Practice has developed from the apprenticeship model proposed by Brown, Collins, and Duguid (1989) and is most commonly associated with the work of Etienne Wenger (1998).

For Wenger, networks are not necessarily in opposition to the ideas of Communities of Practice. Wenger suggests that a network with strong ties resembles a community:

> Communities of practice could in fact be viewed as nodes of 'strong ties' in interpersonal networks. (1998, p. 283)

However, he also stresses the difference in purpose:

> …but again the emphasis is different. What is of interest for me is not so much the nature of interpersonal relationships through which information flows as the nature of what is shared and learned and becomes a source of cohesion—that is, the structure and content of practice. (1998, p. 283)

In other words, Wenger is not only concerned with the flow of information between nodes, he also emphasizes the differences in what flows across the network. Communities of Practice are characterized by three related structural properties—a shared enterprise, mutual engagement, and a shared repertoire (Wenger, 1998, p. 72)—while networks are characterized as interconnected nodes (Castells, 1996/2000), or the *connections* between learners, learners and tutors, and between a learning community and its resources (Jones, 2004b, p. 1). As such, networked learning is concerned with establishing connections and relationships, whereas a learning environment based on Communities of Practice is concerned with the establishment of a shared practice. An area of common ground between network analysis and Communities of Practice may be found in the idea of networks of practice, proposed by Brown and Duguid (2001) to deal with relationships that are too broad and diffuse to be considered Communities of Practice.

The case studies we drew upon in our work provided contrasting examples. In some learning environments, this issue is dealt with by a combination of the networked perspective alongside a community of practice, in the sense that the individual learner is supported in relating learning to his/her work practices, which are seen as the primary community of practice (Jones, 2004b). In other learning environments, however, different means are used, such as team-based project work in order to not only design for and facilitate connections between students and between facilitators and their learning resources but also to establish true interdependencies and mutual engagement between all participants, such as peer students, teachers, and facilitators (Dirckinck-Holmfeld, Sorensen, Ryberg, & Buus, 2004).

The notion of networked learning and the practical application of the design of networked learning environments raise several questions:

- Should researchers, in CSCL and education more generally, serve as critical opponents to the overall trends in the networked society as expressed by Castells (1996, 2000) and stand up against "networked individualism," or should the design of CSCL and education reflect these trends?
- Which models—networked or community of practice models—are more productive with respect to the learning of the individual participant, and under what conditions? Is it, for example, more productive for busy professionals to be organized through a pedagogical model based on relatively weak ties among the participants, or is it more productive to be organized in accordance with a pedagogical model facilitating the development of the strong ties in a community of practice?

The theoretical approach based on the metaphor of networks is one that has a strong resonance with the relational approach suggested earlier.

Space and Place in Networked Environments

Several authors have in recent years pointed to the need to distinguish between space and place in computer networked environments (see, e.g., Goodyear, Jones, Asensio, Hodgson, & Steeples, 2001; Jamieson, Taylor, Fisher, Trevitt, & Gilding, 2000; Ryberg & Ponti, 2004). Goodyear et al. (2001, Part 8) claim that we should not try to design the elements that are most closely involved in learning itself. In Fig. 3.1, Goodyear et al. suggest that designers can design for organizations, tasks, and spaces, but it is participants who make them into communities, activities, and places. Perhaps even more importantly, the figure suggests no known link to learning itself, either for the designer or the participant. The authors suggest that the learners themselves should have some capacity to adapt and reconfigure what teachers and designers create for them. They argue that it is appropriate to try to design learning spaces (the physical learning environment, including all the artifacts which embody “content”), but they point out that we should expect students to customize these designed learning spaces and make their own “local habitations” or “nests” (Crook, 2002; Nardi & O’Day, 1999). More generally, they argue for a distinction to be made between space, understood as a relatively stable and potentially designed environment, and place, understood as contingent and locally inhabited.

The distinction between space and place is connected in significant ways to the earlier discussions of technology, affordance, and networks. Participants in a computer network are simultaneously situated at a real point in time and space and displaced from that point in a space configured through the network. Ryberg and Ponti (2004), writing from within the Kaleidoscope project, are interested in the development of social context in networked environments. They comment on Lash (2001) who argues that networks are non-places:

> Technological forms of life are disembedded, they are somehow lifted out. As lifted out, they take on increasingly less and less the characteristic of any particular place, and can be anyplace or indeed no place. This lifted-out space of placelessness is a generic space… It is not any particular space, but a generic space. Its context is no context at all. Its difference is indifference… The Internet is a generic space. It is no particular space. Indeed, networks are themselves by definition lifted-out spaces. (Lash, 2001, p. 113)

Ryberg and Ponti ask the question:

> If networks are non-places, with no context at all, how can we create a social context to support interaction and sociability? Ryberg and Ponti (2004, p. 2)

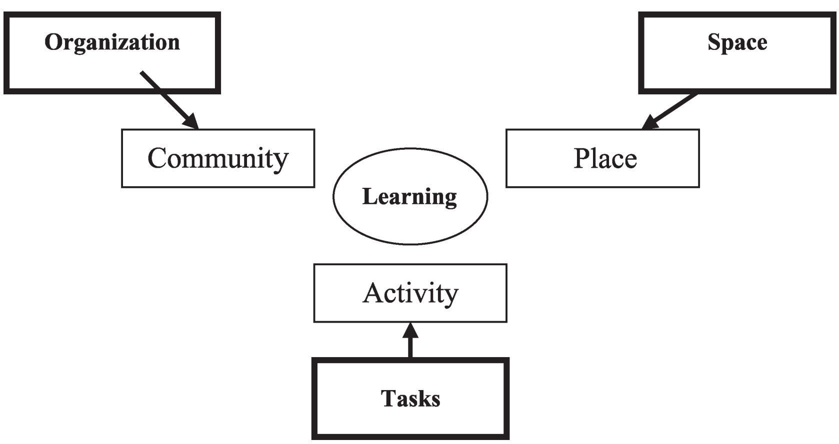

Fig. 3.1 Design, an indirect approach. From Goodyear et al. (2001)

Drawing a distinction between space and place, Ryberg and Ponti quote Harrison and Dourish (1996) “space is the opportunity, place is the understood reality.”

The distinction between space and place is fundamentally rooted in the shift toward networked environments and is one example of the set of problems in which designers only have an indirect control over the intended outcomes of their design. Indeed, we argue that this fundamental design problem could be useful in specifying a more general case for the ways in which design can be thought of in CSCL. It is also related to the notion of space as produced through interactions between individuals and institutions, rather than thinking of space as simply given. This point would be true of *all* spaces and would not simply apply to virtual spaces (see, e.g., Lefebre, 1991; Urry, 2000). Overall, we argue that the notion of space and place is a problem area that could have significance for CSCL in its own right as well as practical implications in terms of design in that it illustrates a wider point with major significance concerning the indirect nature of design in networked learning environments and the dependencies of design on social context, types of organization, and enacted practice.

Ethical Issues in CSCL

Collaboration is not simply a technical, pedagogic, or pragmatic concern. Collaboration includes an ethical dimension, both in terms of the rationale for its use and in terms of the conditions for its success. The question “Why collaborate?” cannot simply be answered by measures of success such as learning outcomes or considerations of alignment with effective learning goals. Collaboration has an ethical dimension that speaks to the ways in which we choose to structure our social lives. Too often collaboration is reduced to narrow concerns that ignore this ethical choice. This can lead to those involved in a CSCL environment to not appreciate the rationale behind activity and compare it unfavorably with individualized and transmissive methods that flow from different ethical positions.

In terms of the considerations for the successful use of CSCL, the question of trust is central. Trust has been identified as an ethical question at the heart of communication:

> Regardless of how varied the communication between persons may be, it always involves the risk of one person daring to lay him or herself open to the other in the hope of a response. This is the essence of communication and it is the fundamental phenomenon of ethical life. (Løgstrup, 1997, p. 17)

In work related to the Kaleidoscope network, Rasmussen (2004) has argued from this position that this:

> …is not a question of a concept of trust which stands or falls on whether or not it is honoured. It is a matter of the simple form of trust expressed by the fact that we cannot avoid surrendering to each other. (Rasmussen, 2004, p. 4)

CSCL and collaborative activity more generally is a public and an accountable activity in which those active are potentially subject to surveillance (see below), and as such the issue of trust becomes central.

Furthermore, Rasmussen argues that this ethical demand can only be honored spontaneously. As soon as we begin to think about whether we are really acting as we ought, the focus moves toward ourselves and away from acting exclusively in relation to the other person. This ethical requirement for spontaneity can come into conflict with the modern demand for self-reflection. In educational terms, we often require our students to be critically reflective in relation to their own work and the work of others. The question then arises as to how this might affect trust in CSCL environments. Insofar as we require actions which are engaged in as a duty, these actions may lose in spontaneity and in trustworthiness, elements that are central to trust and, as a consequence, to collaboration. Also, if free communication relies upon spontaneous action and the ability to lay oneself open to others, how much does the planned nature of many CSCL environments and the pedagogic requirement for reflection affect collaboration and communication, and how might we design CSCL environments to reflect this ethical concern?

A second area of ethical issues, arising out of the social and collaborative issue of trust and affecting the conditions for productive learning, concerns surveillance and control. Writers from the tradition of Foucault point to CSCL environments as environments in which participants are aware that their actions are under surveillance (see, e.g., Land & Bayne, 2005; and Rasmussen, 2004). Surveillance comes from other participants in an equal power situation and often from others who are in a position of actual or potential control (e.g., teachers or managers of the teaching program). Land and Bayne point out that for the tutor, as constituted in the discourse and practices of computer-mediated environments, they are both "seers" of their students and "seen" by their managers in an increasing process of accountability in education (2005). This would suggest that participants would generally conduct themselves in accordance with the perceived norms of the environment and attempt to conceal actions that step outside of the accepted norms.

An example of how issues of trust impact on learning in networked environments can be found in the work done by the moderator in networked learning environments. Salmon argues that successful learning is the result of networking, but it is crucial that networking occur within a safe space:

> [s]uccess in using CMC seems to come where most networking occurs and where there is openness and freedom to explore with little risk attached. (Salmon, 2000)

Part of the moderator's role, according to Salmon, is the creation of this safe space and to address any concerns or fears that the learners may have. Trust is a central element in the provision of both a safe environment for learners and the conditions for communication and collaboration. An interesting research question for CSCL might be how the condition of trust affects different types of relationships. It is by no means obvious that the weak links identified in network analysis are any less dependent upon trust. Indeed, the maintenance of weak links may require a high degree of trust just as much as the strong links of community and collaboration. The ethical question of trust may, however, be in tension with Castell's notion of networked individualism. The ethical confrontation (and ethical practice) as embedded in computer-supported collaborative learning is an overlooked feature, which we argue should receive greater attention.

A Relational Approach and Indirect Design

Throughout this article we have argued for what we refer to as a relational approach. This argument has been developed in relation to the uses of the terms technology and affordance in particular. At this point we wish to clarify what a relational approach might involve and how it might result in a research agenda for CSCL. At a general level, the key to the position we argue is that it is a nondualist understanding of technologies and their affordances. This approach is not in itself novel and builds, as we noted in the introduction, upon the broad sociocultural tradition. We do not believe that we can think of technologies as being artifacts in any normal sense of the word. An artifact distinguishes those features of the world that are the products of human activity from those that are naturally occurring. We are interested in a different distinction: that between things, conceived of as facts external to human interpretation and the nature of those features of the world that are always subject to interpretation. A dualist approach suggests that technologies exist separately from interpretations of them and that such technologies possess affordances. The other aspect of this dualism is that the technology or affordance has to be brought into the human mind through perception. An alternative to this view could be a radical social constructivism and relativism that claimed that all features of the world have to be constructed by an active human engagement with them and that there are no definite and discernable features fixed in the world beyond human thought. The position we argue for is one that adopts a relational view, a view that neither accepts external features in the world as fixed nor adopts relativism. A relational view suggests that technology and its affordances exist in the relationships between people and the material world. Technologies do not have affordance within them, affordances occur *in* relationships with active agents or actants.

The implications of this dualism for research in the CSCL tradition are to extend and deepen aspects that are already present rather than to present a unique approach. The two key areas we point to are the idea of a meso-level approach to research and an indirect approach to design. We argue that while in principle, all levels that can be distinguished analytically will be present in observed social interaction, being present is not sufficient to make them available for research. We noted earlier that macro- and meso-level processes will be available within micro-level interaction. The point we make is that while they are available, they have to be made visible within a research framework. Making the meso level visible, we suggest, is particularly important at this point in the development of the CSCL tradition because of the increasing importance of the technological and social infrastructure in which CSCL activity is embedded. This point came out clearly from the case studies presented in the Kaleidoscope project. For example:

> ICT in itself is thus not sufficient for an infrastructure-it has to be integrated in and support practice. The findings we have discussed in this paper show challenges to the emergence of an educational infrastructure. As for the solution and further work with the concrete problems elucidated in this study we would like to stress the importance of organizational structures that support not only the use of the infrastructure, but also the discussion about the proper use of the system in the context and the discussion about the goals and values. (Nyvang & Bygholm, 2004)

Other case studies identified different aspects of infrastructure concerned, for example, the delivery of online digital resources (Jones, 2004b) and the provision of videoconferencing (Kaptelinin & Hedestig, 2004). In both of these cases, infrastructure was not simply the technology; it concerned organizational support and changes in local practice. The case study by Kaptelinin and Hedestig explicitly raises the issue of the invisibility of some aspects of the setting (2004). The level of analysis of infrastructure was beyond the micro in situ activity of learners and CSCL groups, and it was more localized and open to influence than macro-level features.

The approach to technology outlined above points to the need for what we label *indirect* design, so that we can design *for* learning. This stands in distinction from those who argue that we can design learning and learning environments directly. The relational view we have of technology and its affordances suggests that designers have limited direct control over how their designs are enacted. How learners respond to, understand, and enact in relation to any design is a complex structuration process that has to be studied in practice. Examples of such studies have been given throughout this article, and they draw on a wider range of cases developed as part of our work that includes Fjuk and Berge (2004), Pilkington and Guldberg (2004), Johnsson, Vigmo, Peterson, and Bergviken-Rensfeldt (2004), and Bernsteiner and Lehner-Wieternik (2004). In our review of the case studies and theoretical work, we had undertaken it became clear that there was an underlying common theme in relation to design. In order to plan and design for learning in CSCL environments, some degree of predictability of response to the design is required. Our research showed how contingent factors necessarily reduced design capacity in this critical regard. We focused on exactly what we understood to be available in terms of design as predictable aspects for planning. We suggest that designers within CSCL need to concentrate less on the material aspects of the designed artifact and more on the relationships that surround the enactment of the design and the mobilization of technologies and artifacts in that enactment along with a basic understanding of the role that the technology or infrastructure play in the teaching and learning process. This approach might also suggest a flexible approach to design in which designed artifacts are thought of as shells, plastic forms that incline users to some uses in particular but are available to be taken up in a variety of ways and for which the enactment of preferred forms depends upon the relationships developed in relation to learning. This may also point toward user-centered design methodologies, where designers and users collaborate closely in the design process (Kaptelinin & Hedestig, 2004).

Future Perspectives for CSCL

Throughout this paper we have tried to indicate where we believe our reflections point us in terms of future topics and issues for CSCL research. Overall we have argued for a relational approach to our understanding of technology, affordances, and infrastructure, and we wonder if a network metaphor and an ethical dimension to our approach may be necessary. We indicated that the question of how technologies simultaneously embed constraining features and express relatively fixed properties—including design intentions—and are also brought into use contingently in ways related to and reconfigured by users with differing intentions in a variety of settings draws us toward what we describe as a relational approach to technology and its affordances and an indirect notion of design. Technology within the CSCL tradition has had a relatively narrow focus that places in the background issues concerning the politics, policies, institutions, and infrastructures in which the processes of CSCL take place. We would argue for a greater focus on what we call the meso level of collaborative learning. We would include in this the way in which many of the aspects of the settings in which CSCL is enacted are beyond the direct control of the individuals and groups involved. Such areas might include the way institutions select and implement infrastructures within which CSCL will take place, including the use of open-source software (Nyvang & Bygholm, 2004; Svendsen et al. 2004). We suggest that the concept of technology itself, in particular the use of the term "technological artifact," is an area that requires further attention in CSCL research. We point in particular to the Web and Internet as large-scale and composite technological forms through and in relation to which CSCL now takes place. The past 10 years have seen CSCL move from an environment in which the Internet was a minority concern and the Web only an emerging form to a time when the Internet is becoming ubiquitous and the Web a basic platform.

Our research points us to a number of ethical questions related to our approach to technology. We point to how the condition of trust affects different types of relationships, including the weak links identified in network analysis and the strong links of community and collaboration. We argue that it is a significant question for CSCL whether the designs of networked learning environments have to reflect the trend toward "networked individualism" or whether CSCL researchers might choose to act as a counter practice by offering opportunities for the development of collaborative practices. We ask whether CSCL, and education more generally perhaps, can or should act as a critical opponent to some of the trends identified in the networked society and stand up against "networked individualism." We ask whether CSCL should privilege certain models of learning—for example, networked learning or Communities of Practice—and whether such models are more productive with respect to learning and under what conditions that might occur. We use the example of the continuing professional development of busy professionals and wonder if organization through a pedagogical model based on relatively weak ties or one based on the strong ties in a community of practice is more appropriate. We argue that these are choices that need to be made on the basis of CSCL research, which can provide good criteria for selection.

In this article we have proposed a deepening of approaches already found in CSCL, which emphasize a nondualist and relational approach to understanding technologies and their affordances.

We have linked this to what we have called a meso-level approach that explicitly addresses issues that arise beyond small group interaction but sufficiently close to that setting for the features to be open to influence and control. We go on to suggest that this approach leads on to an indirect approach to design. In our introduction we took issue with recent work in CSCL that downplayed the role of technology. In this article we have begun to articulate an approach to technology that places technology in a central position but interprets it in a particular way. Throughout this article we have not aimed to offer a fully developed theory as our thinking is still at a formative stage. Rather, our intention has been to identify issues and to begin a process that we believe might lead to answers and more fully developed theoretical approaches. We think this approach is in keeping with the exploratory and innovative field of CSCL.

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Investigation 4. Technology Affordances for Intersubjective Meaning Making: A Research Agenda for CSCL

Daniel D. Suthers

Abstract

Now well into its second decade, the field of computer-supported collaborative learning (CSCL) appears healthy, encompassing a diversity of topics of study, methodologies, and representatives of various research communities. It is an appropriate time to ask: what central questions can integrate our work into a coherent field? This chapter proposes the study of technology affordances for intersubjective meaning making as an integrating research agenda for CSCL. A brief survey of epistemologies of collaborative learning and forms of computer support for that learning characterize the field to be integrated and motivate the proposal. A hybrid of experimental, descriptive, and design methodologies is proposed in support of this agenda. A working definition of intersubjective meaning making as joint composition of interpretations of a dynamically evolving context is provided and used to propose a framework around which dialogue between analytic approaches can take place.

Keywords

CSCL research agenda · Intersubjective meaning making · Representational guidance · Technology affordances

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D. D. Suthers (✉)
Department of Information and Computer Sciences, University of Hawaii, Honolulu, HI, USA
e-mail: suthers@hawaii.edu

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Introduction

Computer-supported collaborative learning (CSCL) has been active for over a decade since the 1995 conference in Bloomington and is entering its second decade with the founding of a journal dedicated to the field. The primary purpose of this chapter is to offer a research agenda for this second decade, an agenda that is one among many, but is proposed as particularly paradigmatic for CSCL in terms of the problems that the field now needs to address and is perhaps most uniquely ready to address. Koschmann (2002) has characterized CSCL as "a field centrally concerned with meaning and practices of meaning making in the context of joint activity and the ways in which these practices are mediated through designed artifacts." The proposed agenda accepts, but elaborates on Koschmann's definition. This chapter is organized according to constituents of the definition: collaborative learning as meaning making, approaches to mediation through designed artifacts, and methodologies for the study of these two facets of CSCL. Although the range of current theory and practice within CSCL is discussed, the argument is analytic rather than empirical, making a case for what should be the thematic focus of CSCL based on identification of those problems in the nexus of computer mediation and collaborative learning that are our special concern.

CL: Learning and Meaning Making

What is the central phenomenon of interest for CSCL? Since "computer supported" is an adjunct to "collaborative learning," let us begin by looking more closely at what we mean by the latter.

Epistemologies for Collaborative Learning

Any CSCL research agenda will be based on assumptions, implicit or explicit, concerning what it means to learn in collaborative settings. This section identifies epistemologies common in CSCL in order to understand the range of phenomena we are trying to support and to prepare for subsequent discussion. For purposes of brief exposition, the epistemologies will be presented in terms of their most distinguishing commitments, so they are necessarily oversimplified. Broadly speaking, there are two kinds of accounts. In *individual epistemologies*, the individual is the learning agent, who may benefit from the collaborative situation. In *intersubjective epistemologies*, the group is the learning agent, within which individual participation may change. Between these extremes, one can postulate that learning is a group activity that results in individual changes, which we also call "learning."

Although not an epistemology of *collaborative* learning, constructivism (Piaget, 1976; von Glasersfeld, 1995) is frequently cited as a motivating theory in CSCL literature and underlies some collaborative epistemologies. It is therefore a useful starting point for discussion. A *constructivist epistemology* emphasizes the agency of the learner in the learning process. Learning can only happen through the learner's efforts at meaning making (making sense of the world), although a mentor might arrange for the learner to have challenging experiences in order to accelerate the change process. Computer support motivated by this epistemology includes simulations and "microworlds" (Rieber, 2004). All knowledge is acquired by being constructed by the learner; therefore, from the standpoint of the learner, learning necessarily means constructing new knowledge. CSCL researchers rarely take this view to its solipsistic extreme. Instead, constructivism takes the form of "collaborative knowledge construction" (Stahl, 2000), implying an interactional constructivist epistemology. This brings us to the question of how interaction between people leads to learning.

We begin with individual epistemologies in which the individual is the unit and agent of learning. Since we are concerned with collaborative learning, we focus on such learning that takes place "in the *context* of joint activity" (Koschmann, 2002; emphasis added). In an individual epistemology, collaboration provides the conditions and support for learning, but is not intrinsic to the learning itself. A social-as-context view might maintain that learning remains fundamentally a process within individual minds, yet this process can be enhanced through contacts with other minds. Cognitive dissonance theory (Festinger, 1957) and socio-cognitive conflict theory (Doise & Mugny, 1984) can be read this way.

A *knowledge-communication epistemology* (Wenger, 1987) is common in the CSCL literature (e.g., Bromme, Hesse, & Spada, 2005). Knowledge communication is "the ability to cause and/or support the acquisition of one's knowledge by someone else, via a restricted set of communication operations" (Wenger, 1987, p. 7). Research conducted under this epistemology examines how to more effectively present knowledge in some medium or how to otherwise generate or facilitate communications that "cause and/or support" the desired acquisition of knowledge. Although work that takes a knowledge transfer view of knowledge communication continues to be published, the trend within the knowledge communication tradition is toward more constructivist and more interactional views.

Many CSCL authors (e.g., Baker, Hansen, Joiner, & Traum, 1999; Rummel & Spada, 2005; van der Pol, Admiraal, & Simons, 2003) build their interactionism on the metaphor of "common ground" from Clark's contribution theory (Clark & Brennan, 1991). Pfister (2005) proposes that adding knowledge to common ground "is the gist of cooperative learning: going from unshared to shared information." This conception of "cooperative learning" has its merits. It attributes learning to group interaction rather than to a unidirectional transfer of information between individuals. It relies on an influential model of communication that bridges psycholinguistic and social perspectives and thereby offers CSCL a substantial research literature to draw upon. Yet, in focusing on the sharing of information (which was held, presumably, by a subset of the participants), it does not explain how knowledge that did not predate the communication is jointly constructed within the communication process. See also Koschmann and LeBaron (2003) for a critique of the concept of "common ground" as a "place with no place" that is only an approximation to contingently changing interpretations.

A more radically interactional epistemology, which for now will be called *intersubjective learning*, goes beyond an information sharing conception of collaborative learning in two ways. First, interpretations can be *jointly created* through interaction in addition to being formed by individuals before they are offered to the group. Cognitive activities underlying learning can be distributed across individuals and information artifacts through and with which they interact (Hollan, Hutchins, & Kirsh, 2002). In the most extreme version of this epistemology, learning is not only accomplished through the interactions of the participants, but also *consists of* those interactions (Koschmann et al., 2005). (This concept of learning as activity will be discussed later.) Second, *intersubjectivity* is to be understood in a participatory sense: it is a simultaneous process of mutual constitution that may involve disagreement as well as agreement about shared information (Matusov, 1996) within a "polyphonic nonharmonious concert characterized by synchronic movements, as well as by distinct, conflicting, and dissonant voices" (Smolka, De Goes, & Pino, 1995; see also Wegerif, 2006). An intersubjective epistemology is distinguished from common ground by assuming a participatory process within which beliefs are enacted (and in this sense are shared from the outset) without necessarily being mutually accepted.

In addition to intersubjectivity on the interpersonal level, we find within CSCL intersubjective epistemologies that address learning at the community level. A *participatory* epistemology conceives of learning as a process of "legitimate peripheral participation" in the practices of a community (Lave & Wenger, 1991). It is possible to read participatory accounts from an individual epistemological perspective: one becomes a member of a community by *acquiring* that community's cultural practices and worldview through apprenticeship. A related concept is that of *internalization:* developmental learning through social interaction can be understood as the internalization of interpersonal processes as intrapersonal processes (Vygotsky, 1978). However, more radical participatory epistemologies dispense with notions of acquisition or internalization and treat learning *as* participation (Rogoff, 1995). In this view, "learning is an integral part of generative social practice in the lived-in world" (Lave & Wenger, 1991, p. 35)—a process that constructs personal identity, entwining individual learning with group practices that themselves can change. Although social systems are organized to replicate themselves, they can "learn" when local innovations undertaken in response to internal tensions and external disturbances redistribute activity across the system (Engeström, 2001). The new practices can be reflected in concomitant creation of novel artifacts that support and help to replicate these practices (Wartofsky, 1979).

Another community-level epistemology is *knowledge building*, which should not be confused with the linguistically similar *knowledge construction.* Knowledge building is a collective version of Scardamalia and Bereiter's (1991) *intentional learning*. The difference is described by the Institute for Knowledge Innovation and Technology (http://ikit.org/kb.html; accessed August 31, 2004) as follows:

> To understand knowledge building it is essential to distinguish learning—the process through which the cultural capital of a society is made available to successive generations—from knowledge building—the deliberate effort to increase the cultural capital.

Scardamalia and Bereiter have worked extensively within primary school classrooms, some of which they describe as instances of "knowledge-building communities." Whether knowledge is "new" is relative to the cultural capital of the community undertaking the activity, such as the knowledge available to the children in a primary school class. The essential difference between knowledge building and other forms of learning is that members of a knowledge-building community expand the boundaries of their knowledge through their own collective agency by periodically reflecting on the limits of their understanding and choosing actions that address these limitations.

For simplicity, the remainder of this chapter will use *collaborative learning* to encompass all socially contextualized forms of learning, although it should be noted that a distinction between *cooperative learning* as parallel coordinated activity and *collaborative learning* as an effort to maintain a joint conception is made in the literature (Dillenbourg, 1999; Roschelle & Teasley, 1995). The other phrases are layered in the following manner: *knowledge construction* recognizes that individuals create meaning for themselves rather than just receiving it preformed from others; *collaborative knowledge construction* more specifically locates this meaning making in a group context; *intersubjective learning* further specifies that the process of meaning making is itself constituted of social interactions; and *knowledge building* requires that this group-based meaning making is being done to intentionally extend knowledge.

The Case for Studying Intersubjective Learning

Koschmann's definition of CSCL as being concerned with the "practices of meaning-making in the context of joint activity" can be understood under many of the epistemologies previously discussed. Like the Hindu parable in which several blind men feel an elephant and each describe it differently, all are describing some aspect of the truth: learning happens in many ways. However, the question we face is how to most productively focus our research efforts: which aspect of the elephant do we now most need to understand?

The first major claim of this chapter is that we most need to understand those processes of learning highlighted by *intersubjective epistemologies*, at both the interpersonal and community levels.

Intersubjective learning is an *appropriate* topic for CSCL because it is more uniquely suited to a field that conceives of itself as being concerned with collaborative learning than the other epistemologies. There has been substantial work on how the cognitive processes of participants are influenced by social interaction, and others will continue this work. The study of individual learning that is merely stimulated by a social context does not distinguish CSCL as strongly from other fields that study learning.

The study of intersubjective learning is *interesting* because it gives rise to questions that are among the most challenging facing any social-behavioral science and even touches upon our nature as conscious beings. Do cognitive phenomena exist transpersonally? How is it possible for learning, usually conceived of as a cognitive function, to be distributed across people and artifacts (Salomon, 1993)? Can we understand knowledge as accomplished practice rather than as a substance or even predisposition? Yet we need not leave individual learning behind. In support of this research agenda, cognitivists can ask: What is the relationship of the change process we call "individual learning" to that individual's participation in socially accomplished learning?

The study of intersubjective learning is *timely* because the composition of the CSCL community is becoming increasingly well equipped to address this topic. We find among those who count themselves as members of the CSCL community people who are accomplished in various relevant disciplines and research traditions.

Finally, a call for the study of intersubjective learning is *needed* because it is currently not prominent as a topic of study in our field: it is surprisingly difficult to find research publications within CSCL that directly address this epistemology. (Exceptions will be noted shortly.) Even where process data is examined in detail, the analysis typically counts features that are essentially proxies for interactive accomplishment of learning (e.g., the number of utterances of a given type) rather than exposing collaborative knowledge construction in action. The author needs to go no further than his own work to illustrate this point (e.g., Suthers & Hundhausen, 2003).

Learning as a Scientific Concept

The foregoing sections surveyed a variety of accounts of collaborative learning and concluded that while all provide some insight into learning, CSCL needs to study the intersubjective processes of learning. Following Garfinkel, Koschmann et al. (2005) argue for the study of "member's methods" of meaning making: "how participants … actually go about *doing* learning" (emphasis in original). Yet, learning was never defined. Various theories about how learning happens in group settings were discussed, but these are theories to be tested, not definitions. By what definition can we recognize that participants are "doing" learning?

The agenda outlined in this chapter is deliberately designed to avoid depending on a particular definition of learning. Learning takes place within a huge diversity of activities and situations: learning is ubiquitous. Any attempt to write a single definition that covers this diversity would risk producing a concept too undiscriminating to be a productive basis for a research program, while more discriminating definitions might exclude potentially productive lines of work. The strategy taken in this chapter is to integrate the field of CSCL by providing a basis for dialogue between researchers following multiple conceptions of learning and methodological traditions—a basis to be developed in this and later sections. Yet, some comments on what would count as a suitable definition of "learning" and the role of that concept in analysis may help to motivate the proposal.

If we are going to study how people go about doing learning in practice, then in order to avoid circularity in the research agenda we need an operational definition of learning that allows learning to be identified without presupposing that a particular kind of practice constitutes learning. The definition of learning taken at the outset cannot be written in terms of properties of the episodes of practice to be studied. (In contrast, an empirically derived *account* of learning should specify properties of practice related to learning, but this account is a product of the research program, not a definition that enables the program to be undertaken.) Therefore, a scientifically useful definition of learning is forced "outside" the episode, as it were, and must take the form of a post hoc or retrospective judgment about consequences of the episode. Various definitions of learning already in use meet this requirement, including learning as (1) gains from pretest to posttest scores, (2) transfer of problem-solving success to similar tasks, (3) an individual's attribution of an experience as having been valuable, and (4) a community's acceptance of a new member. From the standpoint of the criterion just expressed, any of these definitions are acceptable for a CSCL research agenda. All of these definitions have the property that some community makes a judgment about the consequences of an activity. No commitment to what form the post hoc judgment takes or who makes that judgment is necessary to continue the following argument.

"Learning" is not a concept that can be productively applied to an analysis of interaction that seeks to understand how learning is accomplished. This is because learning is ubiquitous; it is found in diverse activities and situations. We need a definition of learning that is independent of that which the research program seeks to uncover. It is a category mistake to set out to study "how people go about doing learning" in any sense that tries to interpret the actions as *learning actions*. We cannot say, *"That* was a learning act." We *can* say, "That act is more likely to lead to a particular learning accomplishment," but this is an empirically grounded description of contingencies, not a direct identification of learning itself.

Intersubjective Meaning Making

In order to understand learning, we must examine what participants are doing when they engage in an activity that leads to learning. In many of the situations from which learning can result, participants may not be engaged in an intentional effort to learn, but rather are trying to make sense of a situation (Dervin, 2003). They do so at multiple levels: solving a problem, maintaining interpersonal relationships, and/or affirming their identity in a community (Bronckart, 1995). A common denominator is the attempt to make a situation meaningful. The second major claim of this chapter asks that our analysis of activity stay true to this common denominator of meaning making:

> To study the *accomplishment* (a post hoc judgment) of intersubjective learning we must necessarily study the *practices* (the activity itself) of *intersubjective meaning-making:* how people in groups make sense of situations and of each other.

As previously noted, few studies published in the CSCL literature have addressed intersubjective meaning making directly. Exceptions include Koschmann et al. (2003), Koschmann et al. (2005), Roschelle (1994), and Stahl (2004). Koschmann's work has generally focused on participants' methods of *problematization:* identifying a situation as problematic and requiring further analysis, possibly leading to a change of conception. Further work should identify methods for resolving the problematized issue. These will include methods for argumentation and for negotiation of meaning (Baker, 2003).

This author's own analytic stance is that *meaning making* is accomplished (and evidenced) by the *composition of interpretations of a dynamically changing context.* Interpretations are enacted in human cognitive and social activity. *Interpretation* can be understood in terms of the participation/reification duality (Wenger, 1998). An interpretation takes a reification as having a given significance for ongoing participation, thus, in effect, forming a new reification. Interpretation functions as much on moment-to-moment ephemeral reifications such as thoughts, utterances, facial expressions, and gestures as on persistent inscriptions and artifacts. An act of interpretation may take the form of predications, commentary, restatements, or expressions of attitude (for example), expressed verbally, gesturally, or through manipulations of representations, and may also be "represented" when participants invoke inscriptions in the medium as evoking such interpretations. The perceptual environment and accumulated history of interpretations provides a rich context that participants may selectively choose to further interpret. "Composition" is used in analogy to the mathematical concept of composition of functions in order to highlight that interpretations act upon the images of previous interpretations. *Intersubjective meaning making* takes place when multiple participants contribute to a composition of interrelated interpretations. In other words, *the joint composition of interpretations is the gist of intersubjective meaning making.* This conception provides an alternative to "going from unshared to shared information" as the gist of cooperative learning. No commitment to mutual beliefs residing in some platonic realm is necessary; the physical and historical context available to participants is the field upon which intersubjectivity plays.

Clarifications and Implications

The claim that it is now time for CSCL to focus on practices of intersubjective meaning making is offered as a strategic choice. Others may choose to prioritize different directions for the field. On the other hand, the claim that it is inappropriate to use "learning" as an analytic concept in understanding "how people go about doing learning" is offered as an absolute claim, independently of the foregoing strategic choice. The claim that members' methods of intersubjective meaning making is the appropriate analytic concept is more agnostic concerning epistemology than it might seem. Learning can still be conceived of as individual internalization that results from a social activity of meaning making (including Vygotskian internalization of the social activity of meaning making itself). One can equally take the opposing view that "… orienting our inquiry by focusing on how people participate in sociocultural activity and how they change their participation demystifies the processes of learning and development" by eliminating the need to search for "the nature of internalization as a conduit" (Rogoff, 1995). In advocating an intersubjective stance as a strategic choice, this chapter does not reject the cognitive agenda, but rather asks that all paradigms focus on intersubjective meaning making as a shared object of contemplation—a "boundary object" (Star, 1990) that will give the field the basis for coherence through dialogue between traditions.

Practices of intersubjective meaning making are found in potentially any and every kind of joint human activity. One might object that the proposal requires that we attempt to understand all of human collaborative activity, and CSCL would have lost its focus. The objection is partially sustained. CSCL is indeed potentially concerned with all of human collaborative activity (learning as a consequence of activity is always a possibility), but there is still a focus to CSCL's learning science agenda. The focus is not defined by limiting consideration to certain kinds of activity (e.g., activities in institutionally sanctioned learning settings such as "schooling" or, more generally, situations in which there is the intention to learn or to teach). Rather, the focus is defined by what aspect of human collaborative activity we examine and try to make sense of: intersubjective meaning making.

This view of the scope of CSCL elevates the potential impact of the field. CSCL need not be conceived of as merely a subfield of a subfield (e.g., a specialization of collaborative learning within educational psychology). If we succeed in shedding light on intersubjective meaning making, it can inform many fields of inquiry. Because of the potential for misunderstandings, it should be emphasized that the author is strongly supportive of the study of learning. The call to replace learning with meaning making as an *analytic concept* in understanding learning is done out of necessity. If we are to serve learning well, we must grapple with intersubjective meaning making, and in so doing will be achieving something larger as well, whether we wish to or not. Therefore, we might as well accept this larger agenda and celebrate the relevance and longevity of our field that it portends.

CS: Computer "Support" or Mediation

Let us now add computers to the mix. In what ways can we bring technology to bear on the problem of supporting collaborative learning as it is variously conceived and in particular intersubjective meaning making? This section identifies two distinct ways in which technology is applied to support collaborative learning—as *medium* and as *constraint*—and then proposes a synthesis. [See also Hansen, Dirckinck-Holmfeld, Lewis, and Rugelj (1999) for a synthesis of "compensating" and "facilitating" and Jermann, Soller, and Lesgold (2004) for "structuring" and "regulating."] The prior discussion is relevant because our choice of an epistemology of collaborative learning can affect how we approach the design of computer mediation and what questions we ask in our research. For example, under a knowledge communication model, we might think about the information technologies we are designing as communication channels, focusing on the ease with which one can move information between participants. Under an intersubjective meaning making model, we might design information technologies as forums within which new ideas can be jointly formed—or discovered—and evaluated. However, it is also possible to support collaboration without making any particular commitment to a theory of collaborative learning. We first consider an approach that minimizes its epistemological commitment.

Technology as Interaction Medium

Some approaches to computer support treat technology as a communication channel in a manner that is neutral to learning. Computer support enables interaction (and perhaps collaboration); learning is left as incidental or up to the participants to achieve.

People often resort to computer-mediated communication (CMC) as a substitute for face-to-face (FTF) interaction in order to make interaction possible between people at different locations (synchronous distance interaction) or at different times (asynchronous interaction). It is not surprising that FTF interaction would then be taken as the standard against which CMC is evaluated (Olson & Olson, 2000). Research in this tradition tries to improve the bandwidth and multimodality of CMC technology and fine-tune its design to match the characteristics of FTF. For example, gaze and gesture are demonstrably vital cues in FTF interaction, so some researchers study how to arrange cameras such that the remote image of a person gives a more accurate indication of where they are looking or pointing (e.g., Kato et al., 2001). Without denying that face-to-face interaction has great value, it is instructive to consider why technology-oriented research in CSCL should not be conceived of as merely seeking online replication of the multimodality of FTF learning. Four reasons are offered.

First, CSCL does not necessarily replace FTF interaction. Computational artifacts can also augment spoken and gestural communication between copresent collaborators (Roschelle, 1994; Suthers & Hundhausen, 2003) and be embedded in classrooms where much of the interaction is FTF (Lingnau, Hoppe, & Mannhaupt, 2003; Scardamalia & Bereiter, 1991; Toth, Suthers, & Lesgold, 2002).

Second, although further progress can be made, ultimately the goal of replicating FTF interaction online may not be achievable. “Distance matters” (Olson & Olson, 2000) in many subtle ways when collaborating through technology. Even with extremely high bandwidth communication in multiple modalities, some advantages of spatial co-location will be difficult to replicate online, such as access to implicit contextual information, unconstrained gaze and gesture as cues for identifying deictic referents, and the use of interpersonal space to coordinate action.

Third, it is not sufficient for CSCL to merely replicate FTF interaction. As Pfister (2005) puts it “even if virtual reality is achieved… genuine learning discourse is not supported. It is completely up to the participants… how to structure the learning process.” Rather than leaving efficient learning up to the learners, CSCL has an obligation to design technology that supports effective collaborative learning. In order to do so, some commitment to an epistemology is necessary.

Fourth, CSCL can explore the advantages of going “beyond being there” (Hollan & Stornetta, 1992): ways in which CMC is actually *better* than FTF. An obvious example is that CMC “turns communication into substance” (Dillenbourg, 2005), providing additional resources for learning. The record of contributions and shared representations that are manipulated during communication provide a shared persistent information base that enables the community of collaborators to reflect and act on its own state of understanding—to reinterpret, find connections between, refine, and expand information and ideas explored over time.

Research that focuses primarily on supporting collaboration through CMC, but does not necessarily directly address issues of learning, might be considered peripheral to CSCL. However, under the proposed agenda, understanding the affordances technology offers for intersubjective meaning making is as foundational to CSCL as understanding learning. (Although “affordances” originated with Gibson (1977), in this chapter, the term is used in Norman’s (1999) sense of “perceived affordances,” widely adopted in the human-computer interaction literature.) Much further work is needed to answer questions such as: What strategies do people use to manage collaboration and meaning making via artifact mediation? How are the affordances of various media (including, but not limited to, information technologies) appropriated to carry out these strategies? How then can we design information technologies to provide functionally equivalent affordances with the most natural match to the observed strategies? (Dwyer & Suthers, 2005).

Technology as Constraint and Guide

Computational technologies, as well as other information technologies such as paper-based instructional materials, are often applied to education as means to limit the options available to learners. Although it sounds negative, this is sometimes a useful strategy, for two major reasons: reducing socio-cognitive load and implementing a learning agenda.

Properly applied, constraints on activity can resolve a paradox of collaborative learning. Collaboration imposes an additional task on the learners: in addition to choosing actions within the problem domain and evaluating the consequences of those actions, they must also manage interpersonal relations and group functioning (Whitworth, Gallupe, & McQueen, 2000). Learning may be reduced if cognitive resources are diverted from the primary task (Sweller, van Merriënboer, & Paas, 1998). However, if learners can help each other with different parts of the problem, collaboration can reduce task load. Furthermore, collaboration can increase learning effectiveness through activities that are more difficult to do alone, such as argumentation, explanation, and reflection (Andriessen, Baker, & Suthers, 2003; Slavin, 1995). To resolve this paradox, instructional technology is often designed to structure part of the activity, “offloading” work onto the technology so that learners can focus their cognitive and social resources on other relevant aspects of the learning activity. The technology support can take different forms, such as full automatization of the offloaded task, constraining actions to reduce the need to make decisions while executing the task, or nonmandatory guides such as coaching agents or representational guidance. Whatever form it takes, this support might be subsequently removed (the "scaffolding" "fades" in this mixed metaphor) as learners internalize the guidance it provided. This strategy is called a reduction of *socio-cognitive load* strategy, expanding on Sweller et al.'s (1998) concept of cognitive load, because the strategy addresses the capacity of the group, not just individuals, to manage multiple task demands at once. Important research topics include determining what to scaffold (Weinberger, Reiserer, Ertl, Fischer, & Mandl, 2005), comparing the effectiveness of different forms of scaffolding (Rummel & Spada, 2005), optimizing fading strategies, and exploring whether the answers to these questions generalize in any predictable ways across task domains.

Technology constraints can also be used to implement a learning agenda. Analysis of the learning task may reveal prerequisites or uncover difficulties that are best left for after fundamental skills are learned. Then, guidance is applied via any of the methods previously listed (automatization, interface constraints, coaches, representational guidance) to ensure that skills are acquired or new challenges are taken on in an optimal order. Choices of what parts of the task to "scaffold" and how to sequence "fading" can be effective ways to implement a learning agenda. Similarly, constraints can be used to enforce a collaboration protocol, perhaps one based on an epistemological commitment as to what constitutes learning through collaboration (e.g., Jermann & Dillenbourg, 2003; Weinberger et al., 2005). For example, some researchers have identified collections of conversational moves that they believe are necessary for an effective learning dialogue and implemented these moves as mandatory sentence openers in a communication interface (e.g., Baker & Lund, 1997; Robertson, Good, & Pain, 1998).

Some ways in which technology can be used to guide and support collaborative learning are not intrinsic to the technology itself. For example, consider scripting and role-playing. We might prompt participants to go through phases of collaboration or provide protocols for making and evaluating proposals. These interventions could just as well be done with paper or even verbal instructions. There are clear advantages to using computational technology, such as support for distance interaction and automated prompting, but the primary variable being studied is not itself a property of computational technology (see also Dillenbourg, 2002).

From the point of view of theories that claim to be able to prescribe activities for learners, technology as constraint has great value. Indeed, domain-specific (Shulman, 1987) and even problem-specific (Anderson, Corbett, Koedinger, & Pelletier, 1995) guidance is seen as critical to learning success. However, domain-specific guidance is more of a problem for instructional design than one specific to the unique concerns of CSCL. Also, the use of technology as guide and constraint risks inflexibility and may be inappropriate for learner-driven epistemologies such as intersubjective meaning making and knowledge building. Under these epistemologies, we do not want to limit the potential meanings that can be expressed or trajectories of joint action through which a group approaches a problem. Rather, we want to uncover and exploit affordances to make these easier.

Technology Affordances for Intersubjective Meaning Making

In order to serve the intersubjective meaning making agenda, a selective synthesis of the two uses of technology mediation just discussed is needed. Richer communication media are needed, particularly with respect to supporting the indexical nature of human communication (Nunberg, 1993). Guidance for a learning agenda is needed for both discipline-specific practices and learning trajectories and for processes of intersubjective meaning making, but without limiting creativity by excessively rigid scripting of action. In order to achieve advancements in these forms of support, we need to better understand "the ways in which these practices [meaning-making in the context of joint activity] are mediated through designed artifacts" (the second half of Koschmann's definition of CSCL). The third major claim of this chapter follows:

> The technology side of the CSCL agenda should focus on the design and study of *fundamentally social technologies* that are *informed by the affordances and limitations of those technologies for mediating intersubjective meaning making.*

CSCL systems should be fundamentally social because interactional and especially intersubjective epistemologies of learning require this. To be fundamentally social means that the technology should be designed specifically to mediate and encourage acts of *intersubjective* meaning making. To be informed by the affordances and limitations of a technology means that the design attempts to leverage the unique opportunities provided by the technology rather than replicating support for learning that could be done through other means or (worse) trying to force the technology to be something for which it is not well suited.

The research agenda surrounding technology affordances for intersubjectivity is rich. We first need to understand what collaborative strategies people use when communicating via information artifacts of all types. Human communication and the use of representational resources in its service are flexible: we cannot specify meanings or communicative functions for those resources in advance. Instead, CSCL research should identify how collaborators appropriate perceived affordances of media (Norman, 1999) and explore how notational properties (e.g., Blackwell & Green, 2003) of media influence the course of collaboration. Interactional strategies that recur across a variety of media are likely to be essential (Dwyer & Suthers, 2005). People will try to find a way to apply them regardless of how viscous the medium is with respect to those strategies. Our job as designers is to find more natural mappings, offering collections of affordances that support participants' strategies while providing flexible forms of guidance (see also Kirschner, Martens, & Strijbos, 2004). The remainder of this section discusses some unique opportunities computational technology provides for intersubjective meaning making, suggesting specific lines of investigation for the proposed research agenda.

(Im)mutable Mobiles

As a notational medium, the computational medium is reconfigurable and replicable. It is easy to manipulate digital objects and to replicate actions and objects elsewhere: one can bridge time and space. The mobility of digital inscriptions—both mutable and immutable—provides opportunities for recruitment of partners in the sense-making process (Latour, 1990) and supports continued engagement in that process. How can we exploit this property of technology for its potential to make new social alignments and their interactions possible?

Negotiation Potentials

Any medium offers certain potentials for action. To the extent that inscriptions within the medium are socially shared (e.g., representations of problem solutions in a synchronized workspace), participants may feel an obligation to obtain agreement on modifications to those inscriptions. The potentials for action offered by the medium can therefore guide interactions toward ideas associated with the afforded actions (Suthers & Hundhausen, 2003). An analysis can begin by asking: what constructive actions does the medium enable? Which possibilities for action are most salient (i.e., are *perceived* affordances)? What decisions must be made to choose and carry out one of these actions? If participants negotiate these decisions, will their interactions be productive for learning according to the epistemology guiding the design? Design can apply this analysis in reverse: if we would like users of our technology medium to focus on particular aspects of a problem, how can the medium be designed to prompt for actions that require negotiation of these aspects?

Referential Resource

Jointly constructed representations become imbued with meanings for the participants by virtue of having been produced through a process of negotiation. These representational constituents then enable reference to prior interpretations with deictic reference (through gesture or language) or by direct manipulation (Suthers, Girardeau, & Hundhausen, 2003). In this manner, collaboratively constructed external representations facilitate subsequent negotiations, increasing the conceptual complexity that can be handled in group interactions and facilitating elaboration on previous conceptions. The expressive and indexical affordances of a medium will affect its value as a referential resource. Therefore we might consider how to make salient that which we would like our technology users to elaborate on and relate to new information or ideas. What interpretations (e.g., ideas or elements of the argumentation or problem solution) do participants tend to assign to representational proxies? How can the indexicality necessary for subsequent interpretive acts be accomplished in our technology-mediated settings?

Similarly, disciplinary representations such as models, simulations, and visualizations also offer negotiation potentials and serve as resources for conversation. Rather than being vehicles for communicating expert knowledge, such representations become objects about which learners engage in sense-making conversations (Roschelle, 1994) and can be designed to lead to productive conversation.

Integration

Inscriptions in the computational medium can be persistent. A record of activity and its products can be kept, replayed, and modified. This property can be selectively exploited to leverage prior activity as a learning resource, enabling compositions of interpretations that transcend distribution across time and individuals. We should explore how a persistent record of interaction and collaboration can serve as a resource for intersubjective meaning making through reflection on prior activity. How can representational artifacts be designed to foster appropriate awareness of prior conceptions and the means to reference these in subsequent interactions so that they may be integrated with new information and ideas?

Trajectories of Participation

What are the social affordances of technologies for patterns of participation over larger spans of time and collections of actors? In what ways and at what scales can multiple transformations of representations distributed across individuals and time be collectively understood as a joint meaning-making process? Can we encourage productive entanglement of multiple individual trajectories of participation by selectively making their reifications salient, and hence available, for subsequent interpretation by others?

Adaptiveness

A computational medium can analyze workspace state and interaction sequences and reconfigure itself or generate prompts according to features of either. We should explore the potential of conditional dynamism as an influence on the course of intersubjective processes. We need not anthropomorphize the medium to take advantage of its ability to prompt, analyze, and selectively respond.

Reflector of Subjectivity

Computational media can be designed to foster group awareness (e.g., Kreijns & Kirschner, 2004). The mere awareness that others are present and will evaluate one's actions may influence one's choice of actions (Erickson & Kellogg, 2000). Information about the attentional status of group members and their attitudes toward previously proposed ideas may influence the actions of individuals in the group. Visualizations of conflict or agreement between members may lead to further argumentation or reaching of consensus (Jermann & Dillenbourg, 2003). Technology can enhance intersubjective meaning making by projecting representations of self into a social representation (Kaput & Hegedus, 2002) or embedding the physical self in a social simulation (Colella, 2002). In what specific ways can we design technology to mediate intersubjectivity by reflecting activity, subjectivity, and identity?

All of these questions of how the properties of technology cannot only enable but also be appropriated for intersubjective learning are concerned with social technology affordances. The study of technology affordances should be undertaken with constant reference to the activity to be supported: intersubjective meaning making and its consequences for learning.

Methodological Considerations

What methodological approach is most suited for the proposed study of technology mediation of intersubjective meaning making? This section first considers the major methodological traditions of CSCL and the granularities at which they may be applied and then offers a framework for multivocal analysis that is motivated by the definition of intersubjective meaning making previously advanced.

Methodological Diversity and Synthesis

CSCL can presently be characterized as consisting of three methodological traditions: iterative design, experimental, and descriptive.

The *iterative design* tradition is exemplified by Barab and Squire (2004), Fischer and Ostwald (2005), Guzdial et al. (1997), and Lingnau et al. (2003). Design-oriented researchers continuously improve artifacts intended to mediate learning and collaboration, driven by the dialectic between theory and informal observations and engaging stakeholders in the process. Their research might best be understood as "quisitive" (Goldman, Crosby, Swan, & Shea, 2004) rather than qualitative versus quantitative. Exploring design is a valuable component of the overall CSCL portfolio of research strategies. We are trying to uncover the potential affordances of information technologies, so we need to explore the "space" of possible designs, pushing into new areas and identifying promising features. However, iterative design alone lacks methods for predicting the implications of its design choices. We look to another tradition for the establishment of dependencies between interventions and outcomes.

Many *empirical studies* follow the dominant experimental paradigm that compares an intervention to a control condition in terms of one or more variables (e.g., Baker & Lund, 1997; Rummel & Spada, 2005; Suthers & Hundhausen, 2003; van der Pol et al., 2003; Weinberger et al., 2005). Data analysis in most of these studies is undertaken by "coding and counting": interactions are categorized and learning outcomes measured, and group means are compared through statistical methods in order to draw generalizable conclusions about the effects of the manipulated variables on aggregate (average) group behavior. Typical studies do not directly analyze the accomplishment of intersubjective meaning making. Such an analysis must examine the structure of specific cases of interaction rather than categorize and aggregate single contributions. Therefore, experimental studies have been criticized for missing the point, although this limitation is not intrinsic to the experimental approach, but rather to the methods of analysis used. Another critique concerns the weak external (ecological) validity of studies based on contrived situations.

Descriptive research addresses these concerns through methods that are more suited for understanding authentic practice through case studies. These include conversation analysis (Sacks, Schegloff, & Jefferson, 1974), interaction analysis (Jordan & Henderson, 1995), grounded theory (Glaser & Strauss, 1967), and narrative analysis (Hermann, 2003). Descriptive methods are exemplified in CSCL by Baker (2003), Roschelle (1994), Koschmann et al. (2003, 2005), and Yukawa (2006). Typically, video or transcripts of activity in "natural" settings are studied to uncover the methods by which participants accomplish learning. The approach is data driven, seeking to discover patterns in the data rather than imposing theoretical categories. Some descriptive methods such as conversation analysis are microanalytic, examining brief episodes in great detail, but others such as narrative analysis address phenomena at a larger scale. Descriptive methodologies are well suited to existentially quantified claims (e.g., that a community sometimes engages in a given practice). Yet, as scientists and designers we would like to make predictive generalizations about the effects of design choices. Descriptive methodologies are less suited for claiming that an intervention has an effect, the province of experimental methodology.

If we focus on finding examples of how members accomplish learning, we may miss abundant examples of how they also fail to do so. Yet in order to find that something is not there, we need to have an idea of what we are looking for. A purely data-driven approach that derives but never applies theory does not complete the job. An iterative comparative approach can be applied to address this need. Common patterns found in successful learning episodes subsequently become the theoretical categories we look for elsewhere and perhaps do not find in instances of unsuccessful collaboration. Having identified where the successful methods were *not* applied, we can then examine the situation to determine what contingency was missing or responsible.

Care should be taken, however, to make sure that in finding case examples where the interactional accomplishment of learning as we define it is absent, we do not fail to notice where something else of value to the participants *is* being accomplished! For example, establishment and maintenance of individual and group identity are also worthwhile accomplishments as far as the participants are concerned (Whitworth et al., 2000) and indeed are a form of learning, whether or not they are aligned with researchers' or institutionally sanctioned learning objectives.

The foregoing discussion of complementary traits suggests that we explore mixed and hybrid research methodologies, drawing upon the strengths of each (Cresswell, 2003; Häkkinen, Järvelä, & Mäkitalo, 2003; Johnson & Onwuegbuzie, 2004). Multiple forms of mixed-method research are possible. Cresswell (2003) discusses various sequential and concurrent strategies. In a *sequential* strategy, one method is used to locate portions of the data to be analyzed by other methods. For example, traditional quantitative analyses, including coding and counting of interaction categories and measures of learning outcomes, might be used to obtain quick indicators of where more detailed descriptive analyses are merited, thereby focusing the time-consuming work. Conversely, descriptive analyses can be used to identify the affordances of designed artifacts that seem to be correlated with effective learning episodes, thereby isolating variables that can be explored systematically in experimental designs.

Concurrent triangulation strategies apply multiple methods independently of each other in order to obtain a consistency check (if they are addressing the same aspect of the phenomenon) or to obtain a richer understanding of the phenomenon from different perspectives (if they address different aspects). For example, Koschmann, Stahl, and Zemel (2004) suggest that ethnomethodology be applied to understand practice in the context of design-based research.

Concurrent nested strategies combine multiple methods into a single analysis. For example, experimental designs can compare interventions in terms of descriptive analyses of how the features of information technology influence and are appropriated for members' methods of joint meaning making. This fusion raises the level of experimental "coding and counting" to patterns of meaning making that are less subject to the critique of missing the point while providing the descriptive methodology with systematically varied contexts that sanction correspondingly systematic generalizations. Such analyses are time intensive: researchers will need instrumentation of learning environments and automated visualization and querying of interaction logs as research aids. In each of these examples, the synthesis need not relegate either family of methodologies to subservient roles. For example, a conversation between the theoretical assumptions of ethnomethodology and those of design can lead to a "technomethodology" that changes the very objectives of design (Button & Dourish, 1996).

Unit of Study

Stahl (2006) argues that small groups are the most fruitful unit of study, for two reasons. Most simply, small groups are where members' methods for intersubjective meaning making can be observed. Groups of several members allow the full range of social interactions to play out, but are not so large that participants and researchers alike lose track of what is going on. More interestingly, small groups lie at the boundary of and mediate between individuals and a community. The knowledge building that takes place within small groups becomes "internalized by their members as individual learning and externalized in their communities as certifiable knowledge" (Stahl, 2006, p. 16). However, small groups should not be the only social granularity studied. For example, understanding the emergence of social and knowledge capital in a community of practice may require tracing out the evolution of relationships and the formation and spread of ideas in networks of individuals larger than the small group (Resnick, 2002; Wenger, McDermott, & Snyder, 2002). Analysis of large-scale changes in communities and organizations may lead to understanding of emergent social learning phenomena (Engeström, 2001) as well as elucidate the role of embedded groups in driving these changes. At the other extreme, Shaffer and Clinton (2005) argue that even the interaction between an individual and technology can be understood as collaborative.

Eclectic Analysis of Uptake

In the proposal under consideration, multiple theoretical and methodological traditions are brought to bear on the problem of understanding technology-mediated intersubjective meaning making. This final section proposes a framework for eclectic analysis.

Intersubjective meaning making requires interactions between participants (interpretations of reifications of actions of another participant). Any analysis of intersubjective meaning making, whether microanalytic or concerned with the dynamics of the community or culture evolving through time, must begin by identifying *uptake* acts in which one participant takes up another's contribution and does something further with it. Contributions may include attentional orientation, information, or expressions of attitude, reified as media affordances allow. Examples of uptake include "A has expressed proposition P(α), B expresses Q(α), or Q(P(α))," "A says P and B expresses (dis)agreement," "A makes object O available, and B attends to O," "A has created object O1; B has changed it to O2," "A has created O1 and B has created O2; now A combines O1 and O2 in such a manner," etc.

In order to begin with a defensible starting point for analysis, we consider only uptake relations that are evidenced by the observable dependence of an act on others or their products. Inferences that require further theoretical commitments are left for subsequent analysis. In order to support analysis of both personal and group processes and how the two are intertwined, both intra- and intersubjective uptake relations are included. The resulting collection of uptake relations may be conceived of as a directed acyclic graph (embedded in a temporally continuous process) consisting of arcs between points at which we have evidence (grounded in use of media affordances) of perceptions and/or expressions of attention, attitudes, and conceptions.

Once we have identified a portion of this uptake structure, we need to recognize what the participants have accomplished through sequences or compositions of uptakes, and we need to identify the potential influence or utilization of technology affordances in this accomplishment. What do we look for in order to identify the acts of interpretation and meaning making accomplished through the uptake? Different analytic approaches offer different answers to this question (Suthers, 2006). The uptake graph becomes a boundary object toward which theoretical and methodological discourse between these analytic approaches may be directed. We can layer interpretations on this graph, working from the physical actions and their interdependencies to inferences concerning participants' personal and intersubjective meaning-making processes. Multiple interpretations can be juxtaposed and compared. There will always be multiple interpretations because an action can be understood simultaneously as an act on the objective world, an attempt to conform to behavioral norms, and a way of constructing one's identity in the social world (Bronckart, 1995); participation in a community can be understood on three "planes" (Rogoff, 1995). Also, collaborative knowledge construction involves multiple processes (see figure 9.1 of Stahl, 2006, p. 203). An eclectic approach that "triangulates" from multiple theoretical perspectives is necessary due to the complexity of the problem we are tackling. We can draw upon various theories for insights on what count as interpretive acts and what those acts mean for the learning of individuals and groups.

This framework was applied in an analysis of participant's manipulations of a shared workspace during synchronous online collaboration in order to determine whether and how such actions can be understood as accomplishing collaborative knowledge construction (Suthers, 2006). The analysis explored the potential contribution of different theoretical stances, including contribution theory, socio-cognitive theories, distributed cognition, and activity theory. There are other theories that can be applied to the process of generating researchers' interpretations of uptake relations as evidence of participants' composition of interpretations of their dynamically evolving context. The challenge is to take the step from affordances defined in terms of features of representations to the social level and make predictions of the opportunities the technology provides for discovering affinities with others, orienting attention, expressing viewpoints, exposing conflict and consensus, and supporting debate and negotiation. We have at our disposal a powerful repertoire of theories of learning and social interaction and have not yet fully explored the analytic power of this repertoire. Incompatibilities between the fundamental worldviews of proponents of these theories do exist, but this does not prevent those of us who are open to a multivocal understanding of the phenomena we study from appropriating the insights of each theory and applying them toward achieving this understanding.

Conclusions

CSCL is a field that is establishing basic yet sometimes peripheral findings as it seeks its center. Work currently being done in the field is undertaken through diverse methods, encompasses several epistemologies of collaborative learning, and leverages information technology as communication medium and as a constraining and guiding medium. However, there is an emerging awareness that we need to grapple with the central and most unique problem of CSCL: processes of intersubjective meaning making and how technological affordances mediate or support such processes.

Research methodology in CSCL is largely trichotomized between experimental, descriptive, and iterative design approaches. Although sometimes combined within a single research project, the methodologies are even then typically kept separate in companion studies or separate analyses of a single study. This situation can be productive for a little longer, as the experimentalists continue to identify variables that affect general parameters of collaborative behavior, while the ethnomethodologists identify patterns of joint activity that are essential to the meaning making and learning we all seek to support. However, very soon CSCL needs experimentalists to study dependent variables that directly reflect the phenomenon of interest, the ethnomethodologists to look for *predictive* regularities in technology-mediated meaning making that can inform design, and the designers to generate and assess promising new technology affordances in terms of the meaning-making activities they enable. Mutual assistance is possible through sequentially and concurrently hybrid methodologies and through computer support for our own meaning-making activities as researchers. A common focus on intersubjective meaning making will serve to increase the dialogue between subcommunities of CSCL.

A framework for analysis was offered in which inter- and intra-subjective "uptakes" grounded in observed uses of media affordances are identified, forming a graph that serves as a common starting point for multiple analyses exploring participants' personal and intersubjective meaning-making processes, and as a boundary object for discourse between the theoretical traditions that inform these analyses. This chapter is offered in hopes of accelerating an impending shift in our field toward the study of practices of intersubjective meaning making and how these practices are mediated by technology affordances.

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Investigation 5. Recalibrating Reference Within a Dual-Space Interaction Environment

Alan Zemel and Timothy Koschmann

Abstract
In this paper we examine how two groups of middle school students arrive at shared understandings of and solutions to mathematical problems. Our data consists of logs of student participation in the Virtual Math Teams (VMT) system as they work on math problems. The project supports interaction both through chat and through a virtual whiteboard. We have examined in detail the sequential work these students do to constitute and specify "the problem" on which they are working in the ways they produce whiteboard objects and text postings. Solutions emerge as students come to understand the problem on which they are working. This understanding is achieved through gradual respecification of the math problem on which they are working.

Keywords
Indexicality · Referential practices · Problem-solving · CSCL · Ethnomethodology

Introduction

Collaborative math problem-solving in online chat environments can be a tricky business. Students coming together in a CSCL environment to work on a math problem must figure out what problem they are working on and what they are referring to along the way as they communicate in the CSCL environment.

When students work together collaboratively in online environments, they tend to organize themselves to accomplish a shared understanding of the problem on which they are working. When a group of students is confronted with a problem-solving task, they must be able to (a) represent and refer to "relevant" parts of the problem on which they are working and (b) know that everyone understands at

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A. Zemel (✉)
Department of Communication, University at Albany SUNY, Albany, NY, USA
e-mail: azemel@albany.edu

T. Koschmann
Department of Medical Education, Southern Illinois University School of Medicine, Springfield, IL, USA
e-mail: tkoschmann@siumed.edu

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least to some degree that which is being referenced (Parnafes, 2010). The problem that students face is that they cannot know in advance of their engagement with problem resources and each other what counts as "relevant" (Macbeth, 2011). Much of the interactional work that students do in collaborative problem-solving involves specifying the problem. This involves identifying, representing, referring to, and recognizing what become the problem's relevant constituent elements and properties in different semiotic modalities (online chat and whiteboard).

To get a sense of the issues that students face when working collaboratively on a math problem, consider that when a student attempts to convey to others a possible solution to the problem, all parties in the interaction must work out locally and in very practical terms how to actually refer to "the problem" and how to formulate what "the solution" might be. Referential practices, understood here as the ways that actors refer to and represent problems and solutions, are at the heart of the matter (Koschmann & Zemel, 2009). In our view, students work to arrive at agreed-upon representations of relevant elements of the math problem on which they are working. The kinds of representations they use and the uses to which those representations are put constitute and constrain the trajectory of their engagement with and understanding of the problem on which they are working.

Any reference whose sense is dependent on the context of its use can be characterized as an indexical referent.[1] We align with ethnomethodological perspectives that hold that *all* references, expressions, accounts, and the like are indexical (Garfinkel, 1967; Garfinkel & Sacks, 1970), that is, dependent on the circumstances of their occurrence for their local sense or meaning. We refer to the myriad ways in which they point to or index the context of their production as their "indexical properties." Thus math problems are indexical phenomena that can be "indexed" in various ways. Students constitute the problem on which they are working by indexing it, pointing to it, referring to its constituent properties, elements, and features in particular ways. The more refined their referential work, viz., the more they recalibrate their referential practices to finer granularity of reference, the more refined their understanding of the problem.

In so-called "dual-space" interaction environments, those that offer both chat interaction and sketching on a virtual whiteboard, it is necessary that others understand how the posting and the whiteboard object mutually constitute their sense and meaning (Cakir, 2009; Cakir, Zemel, & Stahl, 2009; Lonchamp, 2009, 2011; Mühlpfordt, 2006). Actors will routinely label, highlight, point to, or otherwise specify the object or matter of interest; but even then, confusions and misunderstandings may arise. Anticipating, encountering, and remedying these confusions involves an ongoing process of identifying, recognizing, and reporting on properties of the object or matter in question as referentially relevant (Cakir et al., 2009; Mühlpfordt & Wessner, 2009). If some object or matter is something students communicate about and work with, they must have a set of shared interactional resources that allow them to refer to that object or matter in mutually intelligible ways.

Representation has been a topic of considerable interest to scholars of mathematics and science education. Studies have examined representations produced and/or used by students engaged in problem-solving work in classroom contexts (Azevedo, diSessa, & Sherin, 2012; Danish & Enyedy, 2007; Danish & Phelps, 2011; diSessa, 2004; diSessa & Sherin, 2000; Hall, 1996; Medina & Suthers, 2008; Parnafes, 2010). In much of this literature, representations are routinely treated as artifacts with particular properties, the usefulness of which depends upon their design features. While the uses of representations are concerns that drive design considerations, representations themselves are treated as distinct from the referential uses to which they are put.

In CSCL settings, the issue of representation has been examined in terms of the design of external representational resources as well as the production and use of representations by students in terms of

[1] "Indexicals are sometimes defined simply as expressions that change reference from one context to the next" (Nunberg, 1993, p. 2).

the affordances of the computer systems they use (Beers, Boshuizen, Kirschner, & Gijselaers, 2005; Fischer & Mandl, 2005; Kirschner & Van Bruggen, 2004; Lonchamp, 2011; Medina & Suthers, 2008; Suthers, 2005; Suthers, Girardeau, & Hundhausen, 2003; Van Bruggen & Kirschner, 2003; Van Bruggen, Kirschner, & Jochems, 2002; White & Pea, 2011). As with mathematics and science education, the approach frequently taken presumes that representations are phenomenal objects that, in their design and organization rather than their use, index cognitive and other phenomena (Vergnaud, 1998). Roschelle's work on the Envisioning Machine (Roschelle, 1996; Roschelle & Teasley, 1995) examined how students work with external representations of physics concepts and the referential challenges they faced. Representational and referential concerns also arise when students try to produce, understand, and share arguments or patterns of reasoning (Van Bruggen et al., 2002; van Drie, van Boxtel, Jaspers, & Kanselaar, 2005).

In dual-space, online CSCL systems, students routinely display their reasoning by sequentially producing objects on a whiteboard or posting arguments in a chat area as though they are meaningfully connected by a set of shared reasoning practices (Cakir et al., 2009). It is often the case that students produce these sequences without much elaboration because they assume others can and will infer the reasoning steps involved from the sequential juxtaposition of relevant objects. To complicate matters, when students want to use the whiteboard to illustrate arguments they have made in the chat area, they are faced with the technical constraints of being able to work in only one area at a time (Mühlpfordt, 2006; Mühlpfordt & Wessner, 2009). This can make it difficult for some participants to know what object in the whiteboard is being referenced by some part of a chat posting.

Ethnomethodological studies of mathematical and scientific practice offer an alternative orientation (Garfinkel, Lynch, & Livingston, 1981; Greiffenhagen & Sharrock, 2005; Hester & Hester, 2010; Koschmann & Zemel, 2009; Livingston, 1986; Lynch, 1985, 1994, 2011; Psathas, 2007; Schegloff, 2000; Sharrock & Anderson, 2011; Suchman, 1988, 2006; Woolgar, 1988). From this perspective, representations are materially manifest as particular kinds of referential practices by which actors come to specify and refer to the indexical properties of phenomena. We take an ethnomethodological perspective and see representation as a very particular form of "objects-in-use." Objects, be they drawings, gestures, graphs, texts, formulae, etc., are not themselves representations. We hold that representations are these objects *and* the way they are used in referential work. This makes representations referential resources used in the pursuit of interactional goals or outcomes that achieve their meaning through their referential use. In our view, no object is inherently representational in and of itself. It is only when that object is placed in the service of referring to the indexical properties of a phenomenon that it becomes a representation. According to Lynch (1994), "Wittgenstein and ethnomethodology inform us that the extent to which expressions and texts take on referential functions may owe less to the intrinsic properties of representational items than to the deeds performed when those items are embedded in action" (p. 5).

In this paper, we extend the research traditions of CSCL concerned with representation by treating it as a feature of referential practice. We examine how the indexical properties of underspecified objects emerge in the way that representations of these objects are sequentially accomplished and used in interaction. We look at how two groups of students build a problem by working out its referential properties. Specifically, we examine two cases in which a mathematical "problem" and its "solution" emerge as a recalibration of the referential properties of an emerging representation of the "problem." In doing so, students come to a shared, common understanding of these problems and their solutions. Students do so using the affordances of the system, resources in the problem statement sheet (an "external representation" available on a wiki page), and a shared set of referential practices. It is up to the students themselves to identify in their reading of the problem statement's formulations and directives what the math problem is *for them* and then to work together to identify what *for them* might count as a solution to that problem. As we will see in the analysis that follows, this involves engaging in a process of calibrating and recalibrating reference to and representation of the relevant indexical properties of the problem and its solution in a way that achieves shared understanding.

Virtual Math Teams

The materials to be discussed come from a corpus assembled at the Math Forum at Drexel University. The Virtual Math Teams (VMT) Project, established in 2003, is one of a variety of programs conducted under the auspices of the Math Forum. In this project, teams of geographically dispersed students use an integrated suite of web-based software tools to explore proposed mathematics topics (Stahl, 2009; Stahl, Zhou, & Toledo, 2006). VMT sessions are run as an enrichment activity conducted outside of the regular school curriculum. Students are recruited through their math teachers at their home schools.

The VMT environment is a multimodal environment consisting primarily of a chat area and a shared whiteboard area (Mühlpfordt, 2006; Mühlpfordt & Wessner, 2005, 2009). Students interact by posting text to the chat area and by drawing figures or placing text in the whiteboard area (see Fig. 5.1). The system offers a number of affordances. Each participant is assigned a color in the chat area. Whiteboard actions appear in the whiteboard and are indexed by color-coded squares in the chat area that correspond to participants performing the whiteboard actions. Participants can “point” back to prior chat postings or to areas of the whiteboard using an indexing tool provided by the system.

The VMT system offers certain analytical tools as well. It captures all actions performed by actors or by the system in a log file that can be used in a “playback” technology that allows analysts to repro-

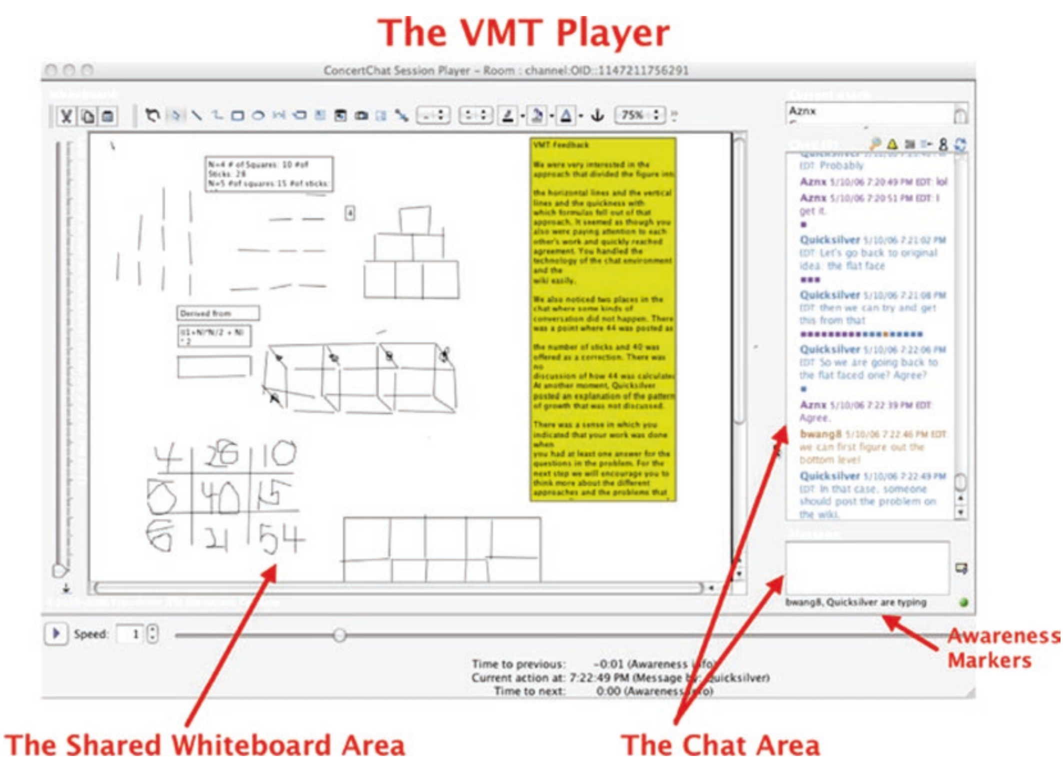


Fig. 5.1 The VMT player

duce a display of the interactional environment of the VMT system. Postings and whiteboard actions can be played back in a way that shows exactly what an observer of the actual chat session would have seen as it occurred. This provides an analytical environment for investigating how the participants interacted using this online system.

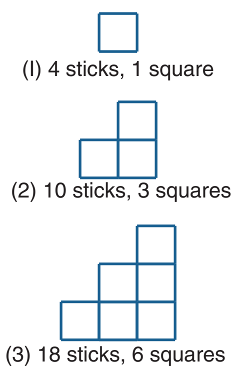
In the spring of 2006, four teams of middle school students were recruited from around the country to participate in Spring Fest 2006. The team that displayed the best collaboration in approaching and coming up with a set of mathematical problems would receive an iPod as a prize. Members of the VMT staff monitored the teams, provided feedback, and assisted with technical questions about the VMT software. For the first session, the VMT staff provided resources on a wiki site for the teams to constitute for themselves a problem to solve (see Fig. 5.2).

This "View Topic" wiki page makes available certain resources to the team for the purposes of beginning their participating in the VMT Spring Fest 2006. While one might be tempted to consider the contents of this page a "statement of the problem" for the students, it is only in the way that the assembled students orient to and organize their activities with respect to these resources that they come to discover what is for them the problem on which they will work. In short, through their reading practices and their online interaction, they work to constitute these resources into a problem to which they can give their attention and on which they can work.

It is also up to the students to produce a solution strategy, a solution, and a report of that solution they are to post on a wiki. We selected two teams, team B and team C, to investigate. We examine how team members organize themselves and their analytical work to identify the problem they are working on and what might stand as a solution to that problem. We treat the work these students do as a form

VMT Spring Fest

Here are the first few examples of a particular pattern or sequence, which is made using sticks to form connected squares:



N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...	...	...
N	?	?

Session I

1. Draw the pattern for N=4, N=5, and N=6 in the whiteboard. Discuss as a group: How does the graphic pattern grow?

2. Fill in the cells of the table for sticks and squares in rows N=4, N=5, and N=6. Once you agree on these results, post them on the VMT wiki

3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the VMT wiki

Fig. 5.2 The View Topic wiki page

of "discovering work" (Garfinkel et al., 1981). This perhaps stretches the notion of discovery a bit, but we feel it is in keeping with the ordinary sense the participants have of (a) "figuring out" what the problem is and (b) "finding" the answer to that problem. For our students then, discovery involves a set of practices by which they orient to and acknowledge, as a discoverable phenomenon, a problem, and a solution that are for them underspecified and are therefore subject to referential practices that allow the students as "members" (Garfinkel & Sacks, 1970) to speak of, orient to, report on, and account for the underspecified problem and its under-specified solution as discoverable matters.

It is well recognized that talk-in-interaction and text/graphics-in-interaction are different modalities of interaction that offer significantly different affordances for sensemaking and communication by and among actors (Garcia & Jacobs, 1999; Greiffenhagen, 2008; Schönfeldt & Golato, 2003; Zemel & Cakir 2009). What we see in the VMT environment is that actors engaged in chat through VMT contend with the same set of concerns about referring to underspecified phenomena that actors in face-to-face interaction have. We also see that online chat affords different opportunities and resources for dealing with these concerns. For example, in the VMT environment, actors frequently use text-based referential terms in concert with whiteboard demonstrations in ways that differ significantly from how a speaker might talk during and in relation to the construction of a graphical display in a face-to-face interaction. Unlike a mathematician presenting a proof at the blackboard (Greiffenhagen & Sharrock, 2005), who can both talk and point at the same time, VMT participants can type in the chat window or draw on the whiteboard, but not both simultaneously because of practical constraints imposed by the computer interface. Thus online chat participants must organize the production of their textual and graphical postings in a serial sequence. In other words, a graphical demonstration can be constructed first followed by a text-based set of explanations, references, glosses, etc., or text-based explanations, references, glosses, etc., can be produced in the chat environment first which are then followed by graphical demonstrations on the whiteboard. They cannot happen simultaneously. Thus, online interactions can present participants with an interesting set of procedural concerns involving how reference and specification of relevant matters is achieved.

The online activities we examine are "reflexive, self-organizing, organized entirely in situ, locally" (Livingston, 1987, p. 10). As such, they are available to an ethnomethodologically informed study. In practical terms, that means we are trying to understand the observable practices people perform from moment to moment to get things done in an organized, meaningful, and accountable manner (Livingston, 1987, 1999). In our examination of the VMT data, we investigate the students' mathematical reasoning as a set of accomplished referential and representational practices. The evidence suggests that, whatever else "arriving-at-an-understanding" might be, it is most intimately bound up with the emergent and shared use of a set of referential practices by which "experience, its retrieval in memory, and its shaping in discourse are designed by reference to context, co-participants, stance, the realization of action, and the trajectories of activity in which it is embedded" (Schegloff, 2000, p. 718).

The Calibration of Reference as Problem-Solving in VMT

In the Spring Fest 2006 session data, actors rarely just presented completed solutions to the problems for ratification by others during their work sessions. The usual approach involved offering up displays and descriptions of their reasoning, grounded in the directives found in the resources found on the View Topic page, as a way of eliciting recipient participation in the discovery of a problem's solution. This reasoning was often achieved as the sequential display of text postings and graphical objects that were designed to allow presenter and recipients to identify and reference more general mathematical representations of the specific examples or instances on which they were working.

In this analysis, we focus on two cases in which students use particular referential and representational practices to sequentially specify the problem on which they are working and its solution. Rather than distinguish between reference and representation as distinct phenomena, we see them as different aspects of a discovery and design process by which the relevant indexical properties of some under-specified object or matter are discovered and made available for referential use. As a practical matter, a representation becomes useful only when its indexical properties, the properties that allow for reference, are adequately specified and shared with other actors (Hanks, 1992, 1996, 2000). We focus here on what Hanks (1990) termed *referential practices*. Thus, in the VMT system, when a student builds a "representation" of a problem in a particular manner using some combination of text and graphics, it is not the "representation" per se but the work of building the representation and working with it in a way that allows for the selection and identification of its relevant indexical properties that constitute the work of problem-solving.

Team B: "You can divide the thing into two parts"

In their first meeting, members of team B (Bwang8, Aznx, and Quicksilver) took up the problem of working out the pattern of growth in the number of sticks and squares in the figures shown on the View Topic page (see Fig. 5.2). After familiarizing themselves with the features of the VMT system, Bwang8 posts the following text: "you can divide the thing into two parts" (see Fig. 5.3, 6:32:05 PM; or Appendix 1, line 52)[2]. This is a puzzle because two seemingly important elements of Bwang8's post are underspecified. There is no indication of (a) what "thing" refers to or (b) what "divide… into two parts" could mean. His

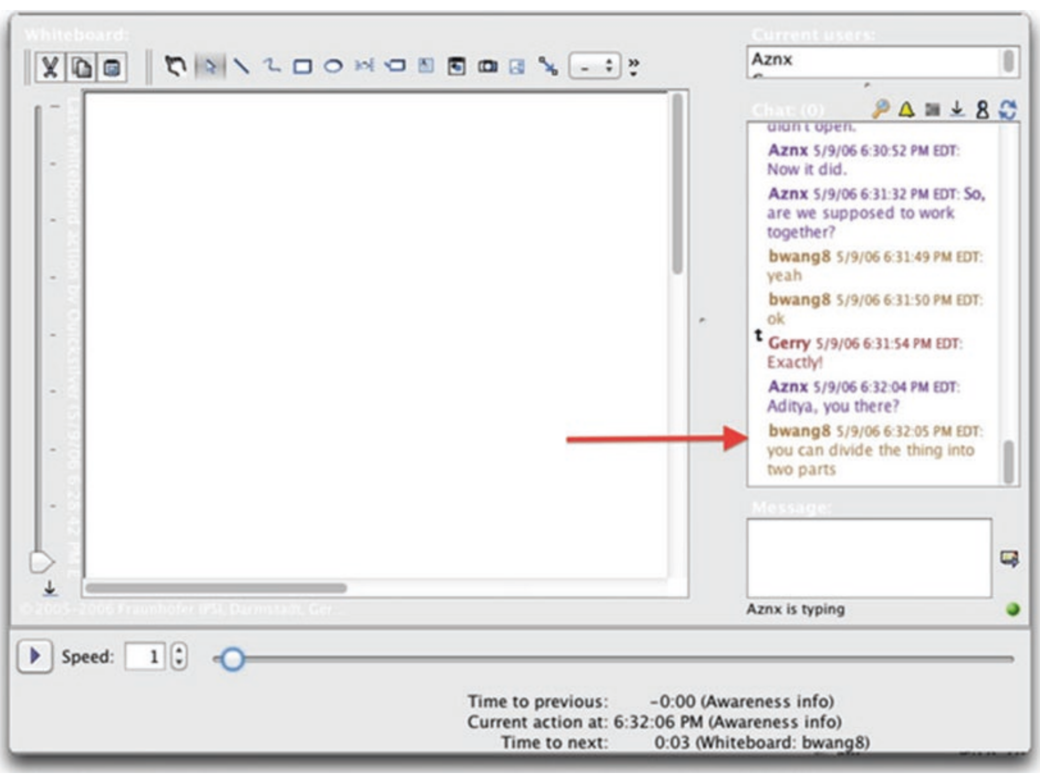


Fig. 5.3 Bwang8's noticing

[2]Transcripts of the text postings for teams B and C are available in Appendix 1 and 2, respectively.

statement, however, supplies an interpretative framing through which his subsequent actions on the whiteboard become meaningful. Bwang8 works on the whiteboard immediately after posting his text, which suggests the possibility that his whiteboard actions are to be seen as providing some kind of elaboration of the evidently vague and underspecified set of mathematical actions proposed in his text posting.

Rather than identify in any explicit way what that "thing" is to which he refers, how it might be divided, or even its relation to the problem, Bwang8 proceeds to systematically produce a set of unelaborated whiteboard objects that, by virtue of being unelaborated, project the expectation that both Quicksilver and Aznx can or should be able to identify "the thing" to which Bwang8 referred in his post.

The systematic manner with which Bwang8 produces the whiteboard objects (see Fig. 5.4) suggests that he is producing a "representation" of the "thing" to which he had referred. The representation is built

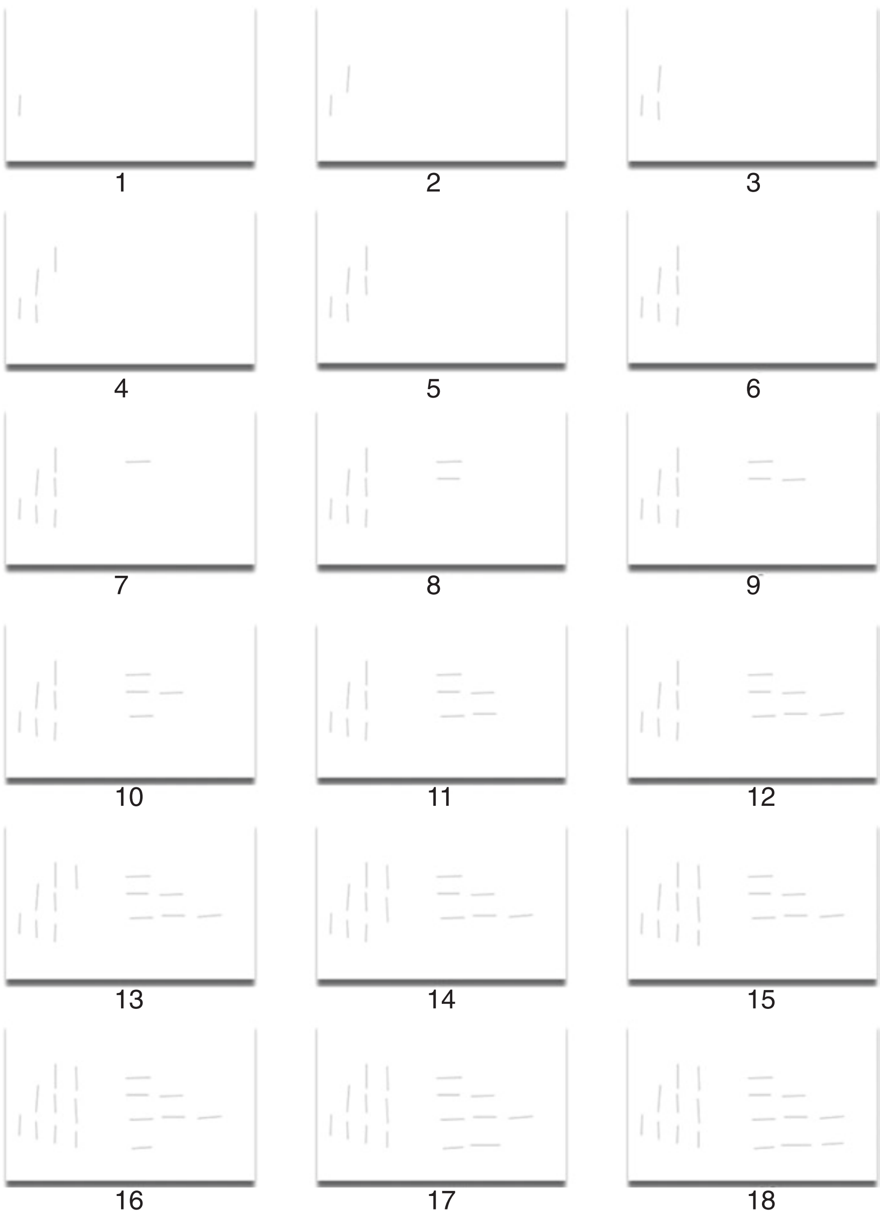


Fig. 5.4 Production of Bwang8's "thing"

line by line, as an emergent phenomenon. Bwang8's actions over time ultimately provide the indexical resources for identifying the object he is producing and demonstrates the nature of the division of that "thing" to which he has referred. The emergence of the "thing" through its systematic production on the whiteboard appears designed to make it possible for Aznx and Quicksilver to discover by witnessing Bwang8's blackboard work that the divisible object Bwang8 is producing corresponds to the $N = 3$ stage object with 18 sticks and 6 squares shown on the View Topic page. What Bwang8 produces is not the same object, however. Bwang8's design work in producing these objects is systematically organized to make recognizable two mirror-image sets of lines, one horizontal and the other vertical, that in the order of their production and in their shape and distribution on the whiteboard display how the $N = 3$ stage figure viewable on the View Topic page can be divided into two parts. For Aznx and Quicksilver to recognize this object as the $N = 3$ stage figure divided in two parts, they need to identify the relevant indexical properties of the graphical representation as related to the figure on the View Topic page.

However, as Bwang8 completes his whiteboard figures, Quicksilver, who had been resolving a problem with his computer, asks, "what are the lines for?" (see Fig. 5.5, 6:32:58 PM; or Appendix 1, line 56). Quicksilver's question suggests that he does not "see" the connection between Bwang8's initial posting, his whiteboard actions, and the problem on which they are working. Aznx advises Quicksilver to review the View Topic page to allow Quicksilver to see the figures shown there as representations in relation to Bwang8's graphical objects. Aznx's response to Quicksilver does not actually answer Quicksilver's query but points him to the indexical resources necessary for recognizing what Bwang8's lines could be. This suggests that Aznx recognizes in Bwang8's referential and representational work a connection between the completed figure and the diagram on the View Topic page.

Upon completing his whiteboard objects, Bwang8 posts the following text in the chat area: "so you can see we only need to figure one out to get the total stick" (see Fig. 5.6, 6:33:05 PM; or Appendix

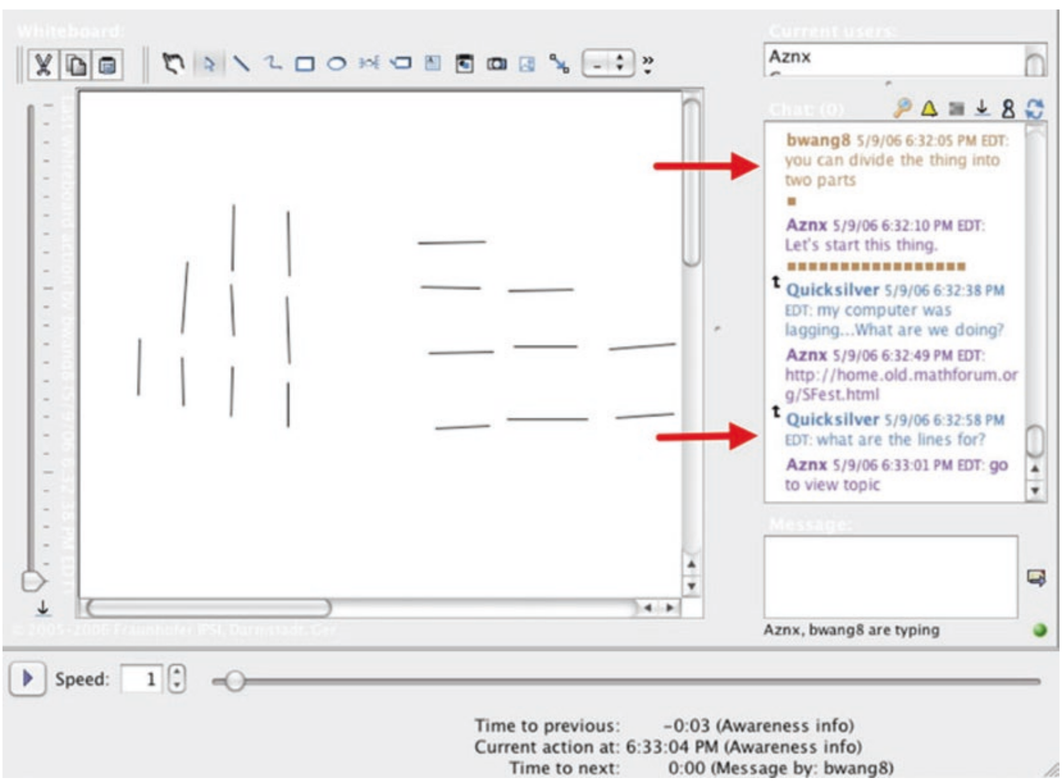


Fig. 5.5 The "thing" divided in half

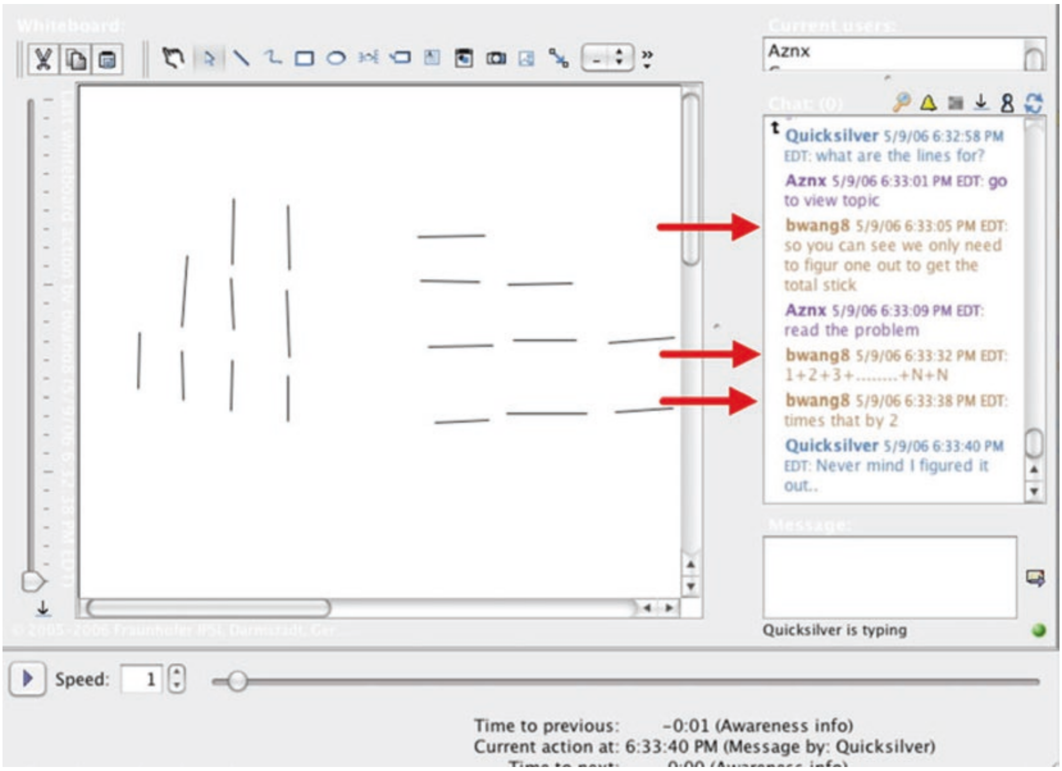


Fig. 5.6 Bwang8 specifies a solution strategy

1, line 58). While not explicitly saying so, Bwang8 relies on Quicksilver and Aznx (a) to have witnessed the production and distribution of two symmetrical objects, one with horizontal lines and the other with vertical lines, and (b) to have treated the production of these objects and their symmetry as consequential for the mathematical formulation of a solution to the problem. In fact, Bwang8 treats the whiteboard object and the procedure of its production as the solution to the problem. All that remains is to "represent" those objects and the procedures of their production into what is for them a suitable mathematical form. Bwang8 achieves this by respecifying the specific $N = 3$ case as a more general algebraic formulation of the problem solution, "1+2+3 + … + N+N" (see Fig. 5.6, 6:33:32 PM; or Appendix 1, line 60) and "times that by 2" (see Fig. 5.6, 6:33:38 PM; or Appendix 1, line 62).

Though Bwang8 has produced a mathematical formulation of the procedure he used to produce the whiteboard object, it was necessary to bring the other students to an understanding of his representation of the problem and its solution. Quicksilver had encountered technical difficulties as Bwang8 produced his whiteboard work and had not necessarily followed the way the whiteboard objects had been produced. Aznx on the other hand appears to have been following Bwang8's work and responds to the initial formulation of the solution represented in algebraic form by recommending further algebraic simplification (Appendix 1, lines 63, 64 and 66). Bwang8 accepts the recommendation and offers such a simplification, "((1 + N)*N/2 + N)*2" (Appendix 1, line 67), followed by a confirmation request (Appendix 1, line 68). Because the simplification was unelaborated, Bwang8 apparently presumed that the other participants would recognize his initial algebraic representation of his solution procedure (as worked out graphically on the whiteboard) as a Gaussian summation. Aznx calls for a derivation (Appendix 1, line 69). Bwang8 identifies his simplification as "a common formual (formula)" (Appendix 1, lines 71 and 72). What we see happening here is work between Bwang8 and Aznx to work out the relevant indexical properties of the proposed formulation, using the formulation itself to accomplish the referential work.

Taking stock, we see that Bwang8 began with an underspecified text version of a solution strategy. His first text posting, while built to be recognizable as a possible solution strategy, did not specify what was meant by such key terms as “thing” and “divide.” In producing this post, Bwang8 was making reference to what were then for him evidently vague properties of the problem and its solution. While it is clear that Quicksilver and Aznx did not immediately know what Bwang8 was referring to as “the thing,” Bwang8’s whiteboard work (Fig. 5.4) made it possible for him to demonstrate through its construction the “thing” divided in two parts. The enacted production of the divided object provided a basis for describing his procedure in a more precise and generalizable mathematical form, as “1+2 + 3 + … + N+ N” (see Fig. 5.6, 6:33:32 PM; or Appendix 1, line 60) times two, or subsequently in its reduced form as “((1 + N)*N/2 + N)*2” (Appendix 1, line 67). While Quicksilver struggles to “catch up” with his partners, Aznx works to understand the references Bwang8 has made. Whether Bwang8 had the final version “in mind” from the outset or “discovered” it as he produced more specific mathematical versions of the solution based on the solution procedure he had enacted cannot be definitively established from the data. However the data clearly shows Bwang8 “recalibrating” his presentation by successively producing and introducing a richer set of indexical resources for specifying both the problem and its solution.

Team C: “Okay I’ve drawn *n*=4,5,6”

As the members of team B were coming to terms with Bwang8’s “solution” to the problem, members of team C (Davidcyl, 137, Jason, and Ssnish) were taking up the same problem but in a slightly different way. In team C’s case, the production of whiteboard objects preceded the posting of text in the chat area of the VMT system. Unlike team B, where Bwang8’s proleptic “You can divide the thing into two parts” creates a context for subsequent board work, Davidcyl begins without any chat posting and instead sequentially produces a figure on the whiteboard.

Davidcyl is the first team member to begin the session after the moderator’s greeting. Rather than posting a text, or even responding to the moderator’s greeting, Davidcyl produces a whiteboard object (see Fig. 5.7; note that the marker in the chat area indicates a whiteboard action has been performed). Davidcyl then proceeds to produce a series of squares and form them into first one object, then a second, and, finally, a third, adding squares in a systematic manner to each successive object produced. The work consists of (1) building an initial object consisting of ten squares (steps 1 through 10), (2) duplicating that object (steps 11 and 12), (3) duplicating the squares from the longest edge and positioning them along that edge (steps 13 and 14), and (4) then adding a square to that edge (steps 15 and 16). A third object is constructed from the second object in a similar manner (steps 17 through 24). This is shown in Fig. 5.8.

Davidcyl’s whiteboard work presents recipients with the problem of recognizing the relation between the sequentially unfolding design and production of representations on the whiteboard and some aspect of the problem presentation available on the View Topic page. Though members of team C have access to the View Topic page with its diagrams and text, there is no explicit work done by any of the participants to indicate a link between Davidcyl’s whiteboard work and the content of the View Topic page. In fact, as Davidcyl methodically produces his objects, 137 engages in some “doodling” on the whiteboard that, by taking no particular care with regard to Davidcyl’s activity, treats Davidcyl’s objects as a form of doodling as well (see panels 11 and12 in Fig. 5.8). Davidcyl explicitly directs 137 to stop (Appendix 2, line 14), suggesting by this intervention that his whiteboard work is or will become consequential for their problem-solving work. From that point forward, only Davidcyl works on the whiteboard until he announces the completion of his work, “okay i’ve drawn *n*=4,5,6” (see Fig. 5.9, 6:26:26:25 PM; or Appendix 2, line 22).

The intelligibility and significance of Davidcyl’s whiteboard work has not been explicitly described prior to the sequential production of those objects. Participants are faced with the problem of sorting out the indexical properties of the objects Davidcyl has produced without any explicit indication of the significance of those objects. Jason started his own work in the text area while 137 began doo-

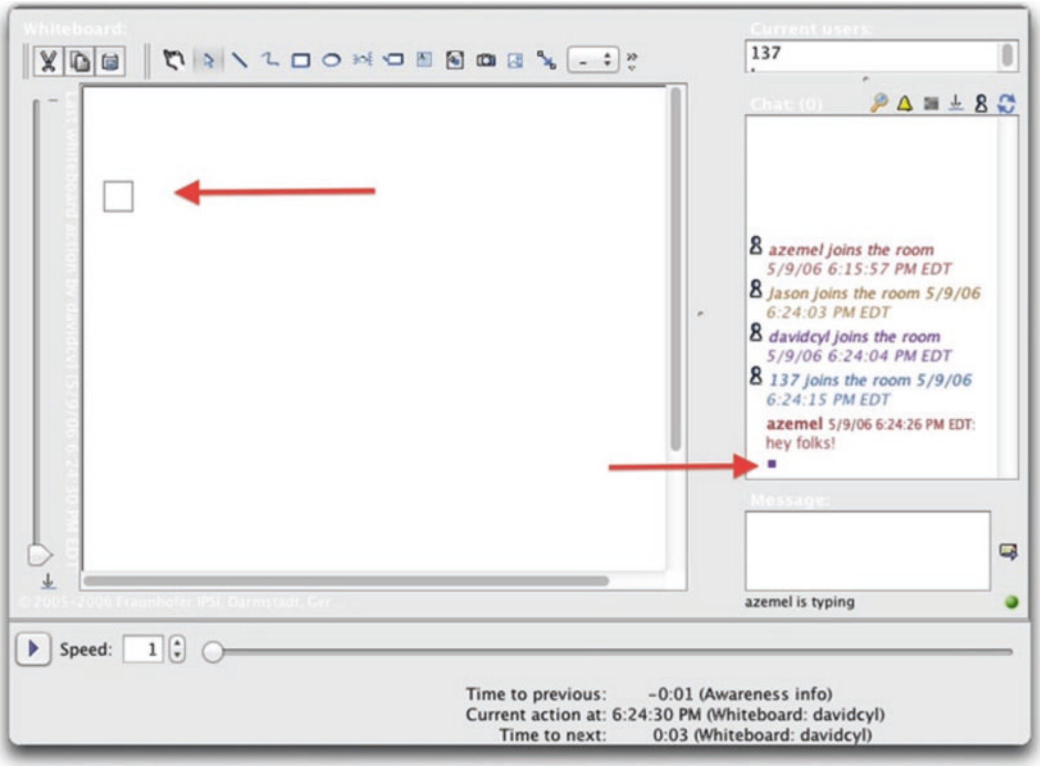


Fig. 5.7 Davidcyl's first move

dling. By declaring "okay i've drawn $n = 4,5,6$," Davidcyl references resources from the View Topic page, resources with which other participants are presumed to be familiar, to indicate that (1) he has completed his whiteboard work and (2) the three completed whiteboard objects are in response to the first problem task listed on the View Topic page, "Draw the pattern for $N = 4$, $N = 5$, and $N = 6$ in the whiteboard" (see Fig. 2). By themselves and without Davidcyl's post, "okay i've drawn $n = 4,5,6$," it is not obvious to the participants what the figures are, their possible or intended use, or their relationship to the problem. By producing a text posting upon completing the figures, Davidcyl is offering an account of these objects that indexes the shared problem resources available to them.

As it turns out, it is not simply the three figures that matter for their work. The way these figures were produced is consequential for the formulation of the mathematical reasoning that will turn out to be the solution to the problem. However, before Davidcyl can produce this formulation, Jason offers up text postings with regard to the issue of the sequential growth of the number of squares. Simply identifying the figures as "$n = 4,5,6$" does not appear to reveal the sense of the objects to the other recipients, who continue to pursue other ways of specifying the problem (Appendix 2, lines 23, 24, and 25).

As Jason presents his own reasoning with regard to their task (see Fig. 5.10), Davidcyl rearranges the figures on the whiteboard. He appears to take no notice of Jason's immediately subsequent text postings and instead produces his own post in which he reports, "the nth pattern has n more squares than the (n-1) th pattern" (see Fig. 5.10, 6:27:32; or Appendix 2, line 26). Davidcyl then formulates this description in more mathematically specific representation in the next post: "basically it's $1+2+\ldots+(n-1)+n$ for the number of squares in the nth pattern" (Appendix 2, line 27). An algebraic variable is the ultimate indexical, one that holds its object of reference as open. Here, the variable n achieves its denotational sense, both in terms of Davidcyl's use of "$n = 4,5,6$," as a descriptor for what he has drawn and because of the use of "N" in the original task description. In response to Davidcyl's mathematicized formulation of the

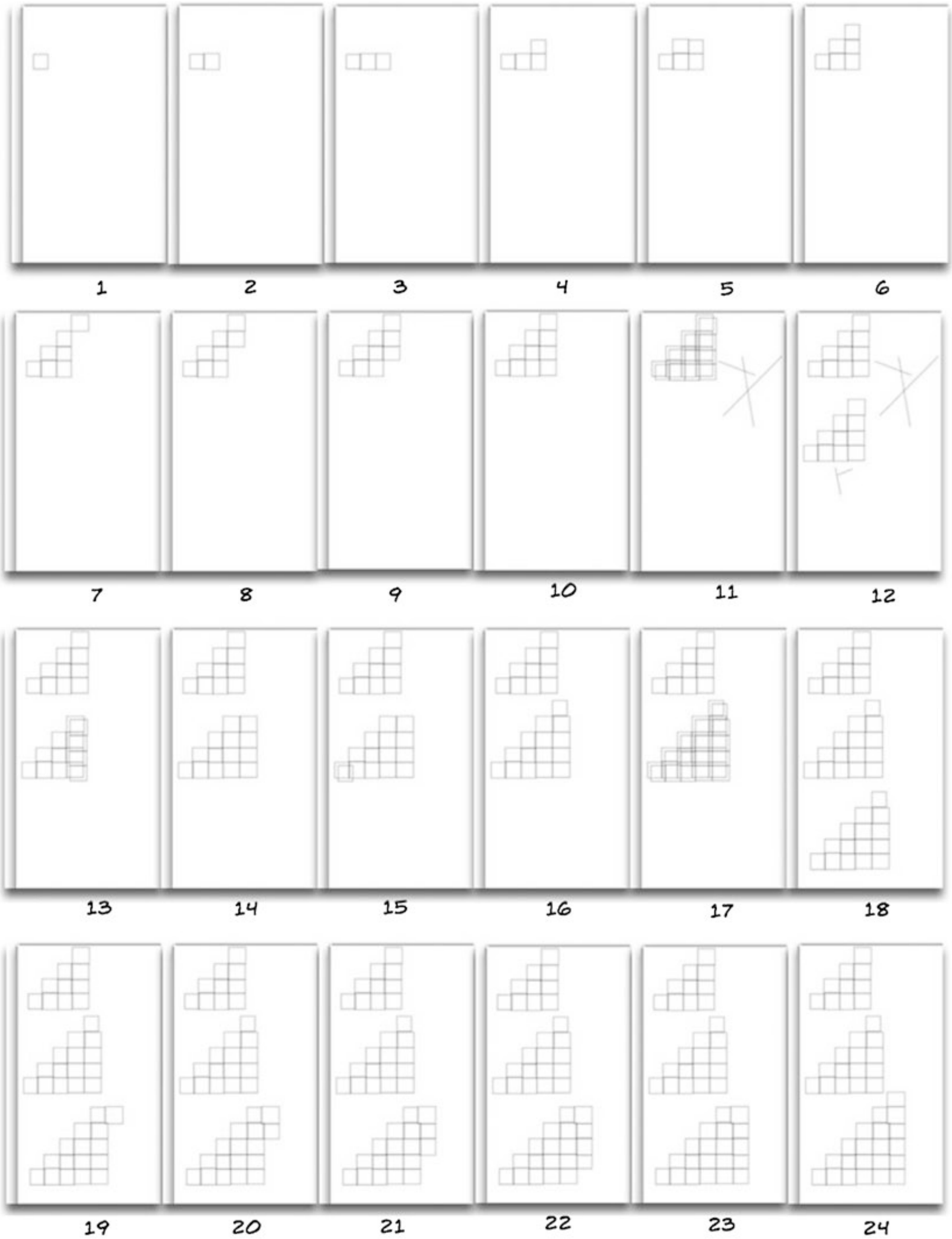


Fig. 5.8 Performing the squares problem

procedure by which the whiteboard objects were constituted, 137 responds with "so *n(n* + 1)/2" (Appendix 2, line 28), extending Davidcyl's work to give the simplified version of the Gaussian sum. As 137 is composing his response to Davidcyl, Davidcyl is preparing a follow-up: "and we an use the Gaussian sum to determine the sume: *n*(1 +*n*)/2" (Appendix 2, line 29). It is at this point that both 137

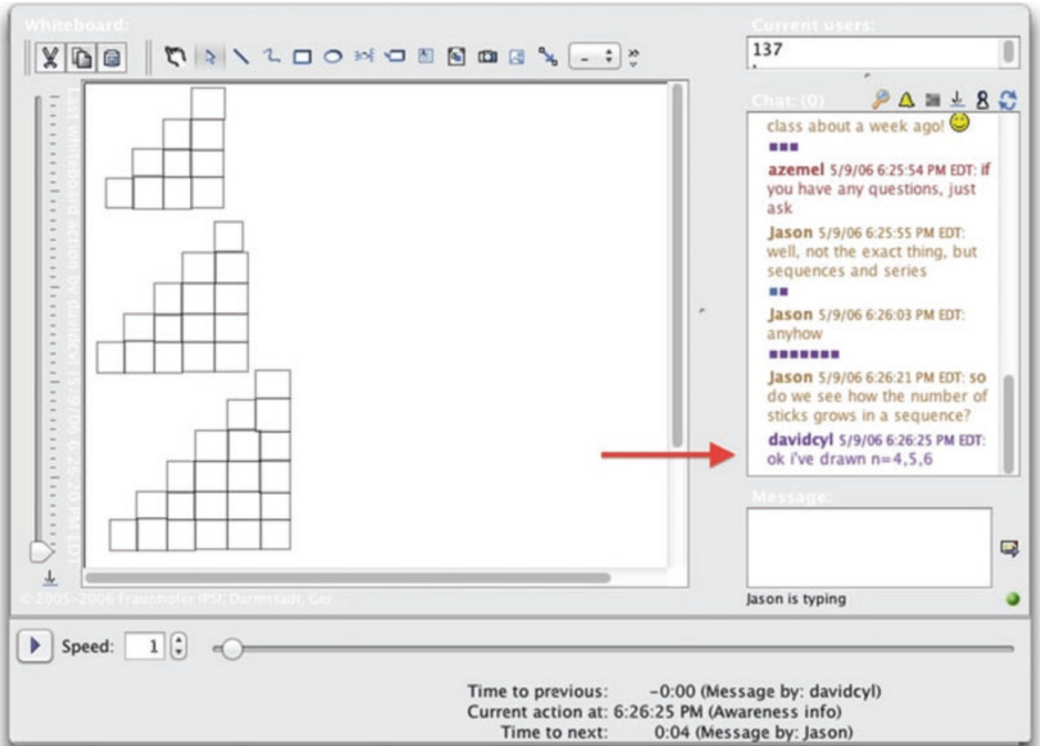


Fig. 5.9 Davidcyl completes the objects

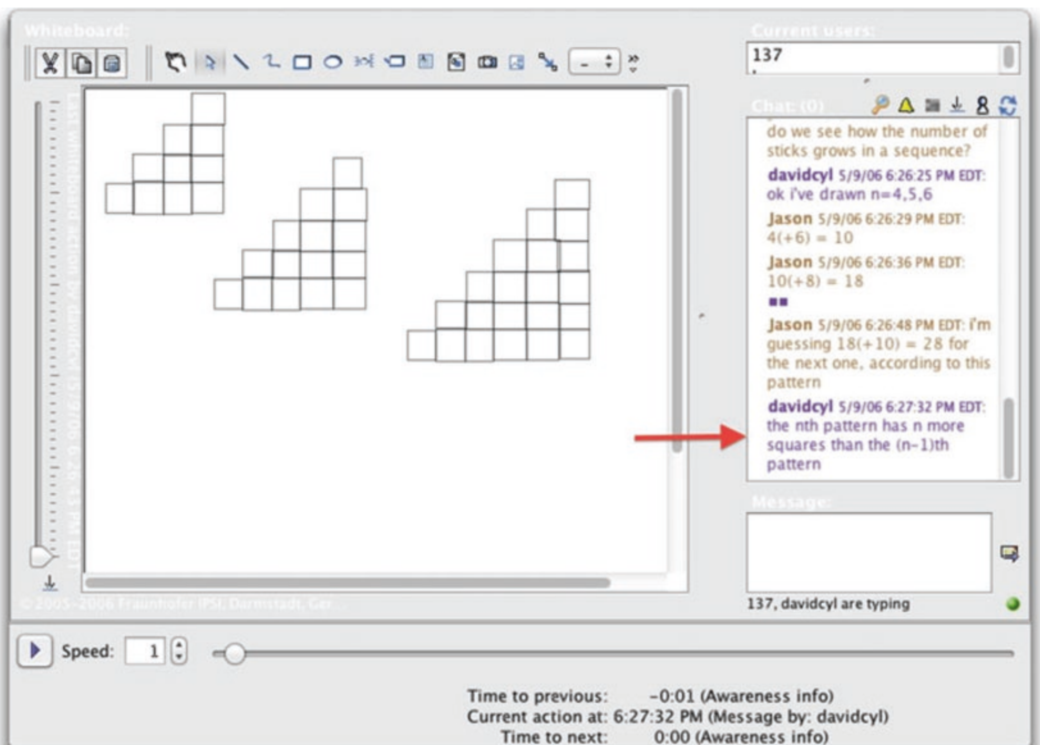


Fig. 5.10 Davidcyl formulates the sequence

and Davidcyl have achieved a shared understanding of the problem and its solution. Davidcyl remarks, “137 got it” (Appendix 2, line 30).

Specifying the Sense of Objects and Texts as a Sequential Achievement

The work Davidcyl did in team C contrasts with and complements the work Bwang8 did in team B. In both cases, participants relied on and utilized the contents of the View Topic page as referential resources in producing and interpreting the respective representations of problem solutions. The sense of these resources, however, emerges only through the situated, local, and sequential production of the whiteboard objects and text postings. In the first case, Bwang8 produced an underspecified text posting whose sense was elaborated in the procedure he used subsequently to constitute the whiteboard objects that demonstrated how to understand the underspecified indexical terms “thing” and “divide… in half”. Davidcyl, on the other hand, produced objects and a procedure for their production to which he could make reference in his subsequent text postings (“$n = 4,5,6$,” “pattern,” and “squares”). The semiotic resources of the View Topic page, the whiteboard representations produced and the procedure of their production on the whiteboard, and the text postings with their indexical terms provided both teams with the resources required to discover the problem being solved and its solution.

Because one cannot produce texts that simultaneously narrate the production of whiteboard objects in the VMT environment, how actors accomplish the production of texts and objects is consequential for their intelligibility. In both cases we examined, the actors exploited this as an affordance of the VMT system, making it possible for both the objects produced and the sequential organization of their production to contribute to the specific sense of prior text posting in team B’s case and subsequent text postings in team C’s case. Thus it was the way that Bwang8 produced the line objects that made evident what he was referring to in his post when he wrote, “you can divide the thing into two parts.” Likewise, it was the way that Davidcyl constructed each successive “pyramid” as a copy of a prior figure to which were added an increasing but specific number of additional squares in a particular way that provided for his formulation of the sequence in mathematical terms, “the nth pattern has *n* more squares than the (n-1)th pattern.” While we only examined these two cases, this suggests that the emergent recalibration and specification of the indexical properties of the problem constitute the conceptual achievement of the students.

Recalibration of Reference as Discovering Work in VMT

In a landmark ethnomethodological study of how people do mathematical proof, Eric Livingston (2000) wrote:

> [P]rovers while engaged in the work of proving, are hunting for proofs in that work. The conception of proofs and their associated theorems as discrete entities, somehow separated from provers continual, omnipresent engagement in the activity of proving, is simply false. *From within proving’s work, the prover seeks to ‘pair’ a written description with a discovered, and often quite nonlinear, gestalt of reasoning.* (p. 265, emphasis added)

We too are interested in the lived work of mathematics as a kind of discovery. Like Livingston, we are interested in the local and situated practices and procedures by which actors refine and specify the indexical properties of an emergent math problem on which they are working. We are not dealing with mathematicians well-versed and trained in the referential and representation practices of professional mathematics, but middle school students engaged in mathematical problem-solving. These students, like their professional counterparts, are engaged in the lived work of understanding the problems on which they are working. In our approach, we recognize that understanding is accomplished and shared in the referential practices by which actors constitute their emerging representations of the problems they face. We build on earlier research (Koschmann & Zemel, 2009, 2011) that explores the nature of discovery in broader terms. In that earlier work, we argued that "discovering work" (Garfinkel et al., 1981) consists of the work that actors do to specify relevant properties of some noticed matter, viz., its indexical properties, in a way that allows others to refer to those properties as well. In other words, discovering work involves recalibrating referential practices that consist of the pursuit and production of greater referential specificity or granularity (Schegloff, 2000) using natural language and/or other semiotic resources with regard to an underspecified "object-of-sorts with neither demonstrable sense nor reference" (Garfinkel et al., 1981, p. 135). The concerted work of this kind of specification is part of how underspecified but noticeable features of the phenomenal world, including math problems and their solutions, become known and available as social facts.

So, how can the work of Bwang8 and Davidcyl be seen as discovering work rather than just the production of a demonstration of an already-achieved solution to the problem? We cannot know definitively, but these two cases suggest that by looking at referential practices, we might be able to point toward an answer. Had this been a demonstration of an already-achieved solution, the indexical properties of the problem would have already been worked out by the presenters, Davidcyl and Bwang8, and made available to the other participants. However, for both Bwang8 and Davidcyl, the referential and representational resources and practices they came to use emerged as constituent features of their presentations. Neither Bwang8 nor Davidcyl presented a set of terms, features, assumptions, or any other such mathematical specifications (other than those resources available in the problem statement) prior to the demonstrations by which recipients might have been able to follow the reasoning in either the text-based work or the whiteboard work. No explicit explanations of objects, terms, or reasoning were produced as they might be when instructing others to recognize an already-worked-out solution. Instead, it seems that they were working out these matters as they came to recognize them during the sequential production of their whiteboard objects and text postings. The specific indexical or referential properties of the problem emerge in the way the whiteboard objects and text postings were sequentially produced in relation to each other. The work done by Davidcyl and Bwang8 involves producing greater specification of texts and objects in the VMT system through the sequential production of objects and texts as mutually referential and constitutive domains of interaction.

The emergent nature of the indexical properties of the text and objects these students work on/with is highlighted by the fact that the VMT environment, by virtue of its technical affordances, does not allow participants to "narrate" the production of whiteboard figures as one might do while drawing on a chalkboard in a classroom full of students. Instead, VMT participants are constrained to (1) produce a text posting in advance of their whiteboard work that prepares recipients for the whiteboard work that is to be done or (2) produce whiteboard figures first and then account for the production of these figures after they have been produced. This means that whenever actors seek to mutually constitute the sense of texts and objects, recipients either must await the appearance of the object after the production of a text and then discover how the indexical properties of the text map onto the whiteboard object or they must await the appearance of a text after the production of a whiteboard object and discover how the indexical properties of that object map onto the text. In short, greater specification of texts and objects in the VMT system is achieved in the sequential production of objects and texts as mutually referential domains of interaction. Actors exploit the design features of any system to identify what they can accomplish with that system (Hutchby, 2001). Not only are design recommendations difficult to identify as a result, they are beyond the scope of this paper.

The emphasis in this paper has been on the ways that individual actors produce greater referential specificity regarding the indexical properties of the mathematical problems on which they are working. We saw that recipients of these recalibrating references oriented to or took up these recalibrations in their recognition of when to examine the problem statement page on the VMT wiki and in their assessment of the various proffered solution formulations. While it remains to be seen what happens when the work of recalibration is interactionally problematic, these examples show that the achievement of the problem, not just the solution, arises from the ways that actors calibrate their representations of and references to problem elements in increasingly specific ways.

This leads us to the broader question we consider in this paper: How do interlocutors refer to and represent unknown, underspecified, or poorly understood matters? It is clearly the case that people routinely do refer to, discuss, represent, and specify matters that they do not fully understand, that are unknown to them, or that are in relevant ways underspecified[3]. In order to engage in interaction with regard to such underspecified matters, actors attempt to specify noticed features of that underspecified matter, viz., its indexical properties, in ways that allow others to refer to that object and its indexical properties. In such circumstances, the distinction between representation and referential practice effectively collapses. In order to refer to an underspecified matter, actors must identify or discover its indexical properties, properties that through their specification, articulation, and formulation become, for the purposes at hand, both a representation of the matter and the means by which it is referenced (cf. Koschmann & Zemel, 2009; Zemel, Koschmann, LeBaron, & Feltovich, 2008). It is precisely this work of specifying the indexical properties of unknown things that allows what was previously unknown to become known.

Appendices

Appendix 1 (Log 5.1)

Log 5.1 Team B Chat log

Chat Index	Time of Posting	Author	Content
52	06.32.05 PM	bwang8	You can divide the thing into two parts
53	06.32.10 PM	Aznx	Let's start this thing.
54	06.32.38 PM	Quicksilver	My computer was lagging … What are we doing?
55	06.32.49 PM	Aznx	http://home.old.mathforum.org/SFest.html
56	06.32.58 PM	Quicksilver	What are the lines for?
57	06.33.01 PM	Aznx	Go to view topic
58	06.33.05 PM	bwang8	So you can see we only need to figure one out to get the total stick
59	06.33.09 PM	Aznx	Read the problem
60	06.33.32 PM	bwang8	$1 + 2 + 3+ \ldots + N + N$
61	06.33.38 PM	bwang8	Times that by 2
62	06.33.40 PM	Quicksilver	Never mind I figured it out
63	06.34.01 PM	Aznx	Can we collaborate this answer even more?
64	06.34.05 PM	Aznx	To make it even simpler?
65	06.34.15 PM	bwang8	ok
66	06.34.16 PM	Aznx	Because I think we can
67	06.34.50 PM	bwang8	((1 + N)*N/2 + N)*2
68	06.34.58 PM	bwang8	That' s the formula, right?
69	06.35.15 PM	Aznx	How did you come up with it?
70	06.35.16 PM	bwang8	For total sticks
71	06.35.34 PM	bwang8	Is a common formual
72	06.35.40 PM	bwang8	Formula
73	06.35.46 PM	Aznx	Yeah, I know
74	06.35.59 PM	bwang8	And just slightly modify it to get this
75	06.36.31 PM	Aznx	Aditya, you get this right?
76	06.37.45 PM	Quicksilver	What does the n represent?
77	06.37.57 PM	bwang8	The given
78	06.37.58 PM	bwang8	N
79	06.38.02 PM	Aznx	Yeah
80	06.38.05 PM	Aznx	In the problem
81	06.38.37 PM	Quicksilver	Oh
82	06.38.38 PM	bwang8	The number of squares is just (1 + N)*N/2
83	06.38.50 PM	Quicksilver	We need that as well

[3] Garfinkel et al. refer to these as "object [s]-of-sorts with neither demonstrable sense nor reference" (1981, p. 135).

Appendix 2 (Log 5.2)

Log 5.2 Team C Chat log

Chat Index	Time of Posting	Author	Contentee we only need to figure one out to gm
1	06:15:57 PM	Azemel	Joins the room
2	06:24:03 PM	Jason	Joins the room
3	06:24:04 PM	Davidcyl	Joins the room
4	06:24:15 PM	137	Joins the room
5	06:24:26 PM	Azemel	Hey folks!
6	06:24:39 PM	Azemel	Is everyone here?
7	06:24:42 PM	Jason	
8	06:24:44 PM	Davidcyl	Yeaqh
9	06:24:45 PM	137	YA.
10	06:24:46 PM	Jason	4 people
11	06:24:52 PM	Azemel	Great!
12	06:25:03 PM	Azemel	Be sure to click on the view topic button
13	06:25:18 PM	Azemel	Up at the top of the vmt screen
14	06:25:22 PM	Davidcyl	137 stop
15	06:25:29 PM	137	Oops.
16	06:25:37 PM	Davidcyl	Np
17	06:25:44 PM	Jason	Ooh we just did this in math class about a week ago!:-)
18	06:25:54 PM	Azemel	If you have any questions, just ask
19	06:25:55 PM	Jason	Well, not the exact thing, but sequences and series
20	06:26:03 PM	Jason	Anyhow
21	06:26:21 PM	Jason	So do we see how the number of sticks grows in a sequence?
22	06:26:25 PM	Davidcyl	Ok i've drawn $n = 4,5,6$
23	06:26:29 PM	Jason	4(+6) = 10
24	06:26:36 PM	Jason	10(+8) = 18
25	06:26:48 PM	Jason	i'm guessing 18(+10) = 28 for the next one, according to this pattern
26	06:27:32 PM	Davidcyl	The nth pattern has n more squares than the (n−1)th pattern
27	06:27:55 PM	Davidcyl	Basically it's$1 + 2 + \ldots + (n - 1) + n$ for the number of squares in the nth pattern
28	06:28:16 PM	137	So $n(n + 1)/2$
29	06:28:24 PM	Davidcyl	And we can use the gaussian sum to determine the sum: $\mathrm{n}(1 + n)/2$
30	06:28:36 PM	Davidcyl	137 got it

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Investigation 6. How to Bring a Technical Artifact into Use: A Micro-developmental Perspective

Maarten Overdijk, Wouter van Diggelen, Jerry Andriessen, and Paul A. Kirschner

Abstract

In order to understand how technical artifacts are attuned to, interacted with, and shaped in various and varied classrooms, it is necessary to construct detailed accounts of the use of particular artifacts in particular classrooms. This paper presents a descriptive account of how a shared workspace was brought into use by a student pair in a face-to-face planning task. A micro-developmental perspective was adopted to describe how the pair established a purposeful connection with this unfamiliar artifact over a relatively short time frame. This appropriation was examined against the background of their regular planning practice. We describe how situational resources present in the classroom—norms, practices, and artifacts—frame possible action, and how these possibilities are enacted by the pair. Analysis shows that the association of norms and practices with the technical artifact leads to a contradiction that surfaced as resistance experienced from the artifact. This resistance played an important part in the appropriation process of the pair. It signaled tension in the activity, triggered reflection on the interaction with the artifact, and had a coordinative function. The absence of resistance was equally important. It allowed the pair to transpose or depart from regular procedure without reflection.

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M. Overdijk (✉)
Department of Educational Sciences, Utrecht University, Utrecht, The Netherlands

W. van Diggelen
Department of Education, Da Vinci College, Dordrecht, The Netherlands

J. Andriessen
Wise and Munro Learning Research,
The Hague, The Netherlands

P. A. Kirschner
Centre for Learning Sciences and Technologies (CELSTEC), Open University,
Heerlen, The Netherlands

G. Stahl (ed.), *Theoretical Investigations*, Computer-Supported Collaborative Learning Series 18,
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Appropriation · Enactment · Resistance · Plan construction · Shared workspace

Introduction

Recently, there has been increased consideration in CSCL for the propositional nature of technical artifacts (ijCSCL Volume 7, Issue 2) in that technical artifacts make opportunities available for collaboration and learning that suggest a certain use but do not causally determine learning activities or outcomes. It is argued that technology is a composite of the technical artifact and the practical actions of its users. Underpinning the argument is the assumption that a technical artifact itself is underdetermined and that its use and effect as a technology take shape when brought into use in particular activity contexts (either by an individual user or in collaboration). It is maintained that a technical artifact carries a potential for action that becomes available when learner(s) and artifact connect and that the availability and realization of this potential is relative to the one(s) who interact(s) with the artifact and to the sociocultural context in which this takes place (Overdijk, van Diggelen, Kirschner, & Baker 2012). This is not simply saying that learners do different things with artifacts or that they may do things differently. Underlying this is a more fundamental concern: There is agency present in both the learners and the technical artifacts they are presented with (Pickering, 1993). The artifact-in-use, consequently, is contingent on the interaction of these agents, and it is—to a greater or lesser extent—shaped by both of them.

The task that lies ahead is to further detail how technical artifacts are brought into use, or rather, how they are attuned to, interacted with, and shaped in various and varied educational practices. It is necessary, we argue, to give precise accounts of how the uses and effects of particular technical artifacts are constructed within the contexts of particular classrooms. This is important also because classrooms—such as the one in this study—are increasingly open and heterogeneous environments, wherein learning is often no longer centrally arranged. Instead, the learners themselves are at the center of their own learning process and are expected to shape their own learning activities in a trajectory that fits with their personal abilities, knowledge, and needs. To adapt to these new kinds of pedagogies, the current breed of technical artifacts shows increased flexibility.

In this paper we adopt a micro-developmental perspective on the use and effect of artifacts (Engeström, 1987; Rabardel & Bourmaud, 2003). We maintain that use and effect are constructed within situated classroom practices, involving multiple resources that are drawn from and integrated interactionally (Danish & Enyedy, 2006; Enyedy, 2005; Stahl, 2013). In order to understand how a technical artifact is brought into use, we examine how these multiple situational resources frame possible action and how the learners enact these possibilities.

Goal and Relevance of This Study

The goal of this study is to provide a descriptive account of how a technical artifact is introduced and brought into use in an existing classroom practice. In specific terms, we address the appropriation of a digital shared workspace by a student pair who works jointly on the construction of a project plan. We examine how this shared workspace is brought into use against the background of their regular planning practice. Appropriation, as we understand it in this context, implies a tension between the artifact-as-used and the intentions invested in the artifact by its designers (Carroll, Howard, Vetere, Peck, & Murphy, 2002; DeSanctis & Poole, 1994; Dourish, 2001; MacKay & Gillespie, 1992; Norman, 1988; Orlikowski, 2000; Overdijk, 2009; Pinch & Bijker, 1987). In this paper we present some insights on the way in which this tension comes to arise, how it develops within a small time frame in the context of joint activity, and how it is eventually resolved through a complex set of negotiations.

Theoretical Perspectives

From Artifact to Artifact-in-Use

Technology does not exist independent of its use, instead it takes shape when used in particular activity contexts. This idea is not new to CSCL (see LeBaron, 2002), and it has been pursued in sociology (Bijker, Hughes, & Pinch, 1987; MacKenzie & Wacjman, 1985) and organizational sciences (Orlikowski, 1992, 2000) since the 1980s. It rests on the assumption that technology is a composite entity that consists of technical artifact(s) and practical knowledge and action, as instantiated in activity. It assumes that technology is the result of an association of the two—human action and artifact—wherein both may exercise agency: Human agency, the intentions of the users of the artifact, and material agency, the intentions of the designers invested in the artifact. The challenge is to account for both, without unnecessarily prioritizing one over the other. One could rephrase this as follows: CSCL technology results from an interaction of the intentions that are invested in the artifact by instructional designers and the intentions of the learners that perform actions upon the artifact. In this way, utilization of a technical artifact can be seen as a process of social construction that is generated from a dialectic of resistance and accommodation between human agency and material agency (Pickering, 1993).

How do the learners and the artifact become purposefully connected? A useful starting point is the affordance (Gibson, 1979; e.g., Kreijns & Kirschner, 2001; Suthers, 2006). This concept proposes that an artifact carries a potential for action that becomes available when learners connect with it. The particular opportunities that become available are commonly assumed to be relative to the needs and abilities of the learners. Learners enact the opportunities they perceive and thereby realize part of the action potential that is carried by the artifact. The affordance is appealing because it underscores personalized perspectives on CSCL and an active role of learners in working with technology. However, in the context of appropriation of new and unfamiliar technology, its explanatory value is limited (Overdijk et al. 2012) because it does not capture development.

Instrumental Genesis

A framework that is more elaborate with respect to appropriation, and compatible with the affordance, is brought forward with the theory of instrumental genesis (Lonchamp, 2012; Rabardel, 1995; Ritella & Hakkarainen, 2012). Here, the artifact-in-use is a heterogeneous entity—referred to as instrument—that emerges from the interaction of the learners with those artifacts. The use and effect of the artifact result from the interaction and (gradual) association of the two. The process by which an artifact is brought into use as the development of a hierarchical activity system (Rabardel & Bourmaud, 2003; Rabardel). During this development the artifact and relevant (cognitive) utilization schemes become associated with each other and form a functional system (Kaptelinin & Nardi, 2006). An instrument consists of an association of an artifactual component—an artifact, a fraction of an artifact, or a group of artifacts—and a scheme component (in the Piagetian sense of the term: Piaget, 1964). Rabardel and Bourmaud suggest that when agents bring an artifact into use, they call upon sets of routines and procedures that have developed around previous use of the specific artifact at hand, or, when the artifact is unfamiliar to them, upon those that are associated with similar or otherwise related task-artifact configurations (Rabardel & Bourmaud, 2003; Rabardel, 1995). For example, in the case of planning, some of the routines and procedures that have developed around paper-and-pencil plan construction may also apply to plan construction with another, new type of representational artifact, depending on the similarities and differences between that particular artifact and the paper-and-pencil situation. According to Rabardel and Bourmaud, the new representational artifact is either (partly) operated from a preexisting set of utilization schemes or when these do not apply, from an adapted version of the existing set. This transposition of utilization schemes, when successful, allows for the generalization of "ways of doing" from one task-artifact configuration to another. If such transposition is not possible, utilization schemes are adapted, or the artifact itself is adapted.

Instrumental genesis is seen as a progressive movement along hierarchically organized, interrelated dimensions. On a personal dimension, the physical connection that each single learner entertains with the artifact, and the ability to act consciously on the basis of personal needs, goals, and expectations. On a collective dimension, the coordination and fine-tuning of the interaction with the artifact between multiple learners in order to achieve a common goal. It suggests furthermore that the object of activity, or in Rabardel's terms "the orientation of mediation," may shift throughout the development from artifact to artifact-in-use.

The theory predicts that when learners are confronted with a new artifact, they initially focus on the interaction with the artifact in order to perform basic acts. In activity terms, their action is oriented toward entertaining a physical connection with the artifact and toward manipulation of its interface, whereby the artifact itself is the object of activity, and knowing how to produce basic acts is the motive. Once a leaner has mastered sufficient basic acts, that is, knows how to manipulate the interface, his or her attention shifts toward the object for which the artifact is a means of performance. It shifts, in other words, from mastery to utilization. This is when basic acts are coupled to a purpose, aimed at the fulfillment of a task-related motive (what Rabardel and Bourmaud have termed the establishment of "an instrumental act"). In this process there are potential sources of conflict and tension. Different learners, when confronted with the same artifact, may perceive and enact different opportunities. In order to collaborate, they will have to arrive at a mutually agreed use. Coordination and mutual fine-tuning is then crucial to achieve a common goal. Another potential source of conflict and tension is the transposition of ways of doing from one task-artifact configuration to another. Existing routines and procedures can be in conflict with the "spirit" of the artifact (a term coined by DeSanctis & Poole, 1994)—the intentions that are invested in it by its designers—and may be counterproductive.

Classroom Practice and Situational Resources

When an artifact is introduced in the context of existing activity, then this context is important to understand how the artifact is brought into use. The use of artifacts is situated in practices (Enyedy, 2005; Hall, 1996) and motivated by routines and procedures that are part of those practices (Cobb, Stephan, McClain, & Gravemeijer, 2001). Classroom studies indicate that the use of an artifact is an interactional achievement, whereby learners draw on and integrate multiple situational mediators (Danish & Enyedy, 2006; Enyedy; Goodwin, 2000; Medina & Suthers, 2012; Roth, 1996; Streeck, Goodwin, & LeBaron, 2011). These mediators, some of which are material and some immaterial, elaborate each other and are interpreted in relation to each other (Roth; Goodwin). They include resources for communication as well as classroom norms, procedures, and available (technical) artifacts. The practical knowledge part of these resources could perhaps be traced back to Rabardel and Bourmaud's cognitive scheme components, but these schemes are not available to us as researchers. Following the study by Cobb et al., three elements of classroom culture are likely to frame the learner's situated actions (Greeno, 1998; Suchman, 1987): The social norms of the classroom, the social norms that are specific to the task at hand, and the practices that have formed around this task. Applied to our context of plan construction, these three mediating factors can be described as follows: Social norms refer to taken-as-shared ways of interacting and participating within the classroom, such as the need to justify solutions or accepted modes of collaboration. Socio-planning norms refer to those norms that are specific to plan construction, such as what counts as a valid simulation of a planning decision. Finally, planning practices refer to specific ways in which procedures and artifacts are used to achieve planning goals (after Cobb et al.). Together, these norms and practices contribute to the frame from which the technical artifact is enacted.

Through enactment the use and effect of the artifact take shape. The term enactment emphasizes that people respond to the environment they face, and at the same time, through their performance produces part of the environment (see, e.g., Bansler & Havn, 2003; Orlikowski, 2000; Weick, 1995). Enactment, as Weick (ibid.) has put it, has a reactive and a proactive dimension. Reactive in the sense that human action is framed within the constraining and enabling conditions of the environment, and proactive in the sense that through their actions, humans produce new conditions for future action. Although it is not our aim to band with Weick's theory, we use the term "enactment" with a similar intention: Learners' practical actions are framed within the constraining and enabling conditions set by situational resources, while with their performance, learners produce new conditions and resources that shape future actions (Overdijk & Van Diggelen, 2008).

Plan

A digital shared workspace is introduced to support joint plan construction. We address the appropriation of this artifact as a relatively short-term situational process—a micro-development (Engeström, 1987; Rabardel & Bourmaud, 2003). We assume that the learners' practical actions are framed within the constraining and enabling conditions that are set by the artifact as well as by the norms and practices of the classroom. We take it that the learners draw from these situational resources through enactment. Since the artifact is introduced into a preexisting planning practice, it is possible and likely that existing norms and practical procedures become associated with the artifact and influence the way it is brought into use. It is also possible that transposition of norms and practices lead to tension and that those new practical procedures have to be invented.

We approach appropriation as micro-development by pursuing these questions: What is the nature of the norms and practices of regular planning? To what extent and how do these norms and practices become associated with the artifact? How does this develop over a relatively short time span?

Methods

A case study approach (Yin, 2003) was chosen as the most appropriate research method, given the need for in-depth understanding and the explorative character of the study.

Educational Context

The case study was carried out within a secondary vocational school. The school management had initiated a pilot program that induced a transition from a more traditional form of education to a form in which learners perform project work in pairs, relatively independent of the teacher. This new form contained far less structure than the traditional way of working. In the pilot program, the students had to plan, carry out, and evaluate their project themselves. The school was exploring artifacts that could fit with the program, and in this context, they introduced the shared workspace as a planning aid. At our point of entry, the pilot program was running for approximately 4 months. Our study began one project (for 2 weeks) before the introduction of the shared workspace in the classroom. We examined the two consecutive projects, one in which students were engaged in regular plan construction (the Flower Project) and one in which the shared workspace was introduced to support the planning process (the Kitchen Project).

Participants and Course

The class that participated in our study consisted of 12 students (6 pairs) aged 14–15 years at the third year level. Over the duration of the school year, they had to complete several projects. Each project lasted 2 weeks, and every 2 weeks, a new project began. The projects addressed different themes but always covered the domains communication, technology, and civics. With each project the pairs were presented with a syllabus that contained a series of assignments organized by domain (see Appendix 1). At the start of each project, the pairs were expected to construct a plan that described in detail the tasks that had to be carried out for each day of the project.

The Planning Problem

The planning problem requires that the students identify task requirements, sub-tasks, and external constraints that could influence their plan and to translate this problem representation into an ordered set of planning decisions. The translation from problem representation to plan construction requires, among other things, projection of the consequences of particular planning decisions (Pea, 1982). For example, students had to make estimates of the time that would be needed to complete a particular part of the plan and had to take into account interdependencies between different parts. Plan construction also requires critical evaluation and possibly revision of these decisions (Pea). The planning problem is organized around some form of shared representation—either on paper or on-screen. This representation should enable the students to discuss the problem and should capture their planning decisions in terms of tasks, sub-tasks, duration, and the order of implementation.

Methodological Approach

We chose to zoom in on the appropriation process of one pair. We used a qualitative descriptive method to construct a case study, in which we combined several sources of data. A case was defined as the activities and products of the pair during the planning phase of the two consecutive projects. The first part of a case pertains to the regular mode of plan construction (first project), and the second part pertains to plan construction with the shared workspace (second project).

Data

In the first part of our study, we collected data about the norms and practices of regular planning via interview, observation, and a completed project plan. Prior to our entry in the classroom, we interviewed the teacher. At entry, we observed the planning session and made field notes of our observations. We also collected the project syllabus that contained the description and assignments of the project. In the second part of our study, we were present in the classroom when the shared workspace was introduced and brought into use. Again we observed the planning session and made field notes of it. We collected the syllabus and the final plan. In addition, we made audio recordings of the pair, and we saved a replay of their actions in the workspace. Finally, we interviewed the pair about their experience (this interview was also an important source of information about the norms and practices of regular planning).

Analytic Approach

The two parts of the case were subjected to a descriptive analysis. The analysis of the first part serves to contextualize the second part. The first part focuses on identification of norms and practices (Cobb et al., 2001) that were established in the classroom with respect to planning. We identified planning practices through observation, via the interviews with the student pair and the teacher, and through the constructed project plan. The teacher interview and the constructed plan were our sources of information about social planning norms.

The second part of the case focuses on how the workspace was brought into use. Analysis here has a dual focus. First, it examines representational actions, defined here as the observable acts in the workspace that learners engage in as they are creating their project plan (e.g., placing a line or adding a feature). Complementary to this it examines those aspects of the learners' talk that were oriented toward a purposeful and coordinated use of the workspace. In practice, this talk and representational actions overlap and mutually elaborate one another.

We analyzed the data in three steps. In the first step, we transcribed the audio recordings of the pairs into a protocol that included all utterances, the time of the utterance, and the speaker. With aid of the replay, we then added the actions that took place in the workspace onto the timeline. The replay gives a time-stamped, frame-by-frame representation of the actions that took place in the workspace (notably, our transcription did not take overlap of talk and action into account). We used the first step to organize the data and to take a first pass at understanding what was going on. In step two we selected relevant episodes for further analysis. An episode corresponds to a duration of coherent activity demarcated by the students' own behavior (Roschelle, 1992). We selected all episodes that contained talk and/or actions oriented toward construction of the project plan. In the third step, we constructed a qualitative description of the selected episodes.

Analyses

In the first part of this section, we examine the norms and practices of regular planning with the Flower Project. In part two we examine how the shared workspace is brought into use in the Kitchen Project. The names of the pair are Lucas and Oscar (these names are pseudonyms).

Part 1: Making a Plan for the Flower Project

We entered the classroom on the first day of the Flower Project, were we observed how Lucas and Oscar constructed a project plan. Both sat at a table and read the syllabus. They briefly reflected on the content of the syllabus and started drawing up a plan. One of them drew the planning decisions on paper and the other read from the syllabus as a reference (see Fig. 6.1 for an impression of this setting). It took them about 30 min to sketch out this initial plan. After this they moved to a computer

Fig. 6.1 Pair, similar to Lucas and Oscar, working on their plan for the Flower Project

where the plan was brought into a spreadsheet program. Lucas and Oscar sat jointly behind the computer with one of them typing the initial decisions into the program and the other reading from the initial plan and the syllabus. This took them another 25 min to complete.

Below is an excerpt of the interview we held with Lucas and Oscar at the end of the second project (when they had already worked with the shared workspace). In this excerpt they talk about the procedure of regular planning and their use of artifacts.

Log 6.1. Interview

Researcher	How did you like working with this tool?
Oscar	I think it works fine. It's useful. Instead of writing everything down or having to make your own squares in Excel.
Researcher	How do you normally do it, making a plan… you mentioned Excel?
Lucas	On paper.
Researcher	On paper?
Lucas	Yes.
Researcher	So, first on paper, and then in Excel. You also do that with the two of you?
Lucas	Nah. Actually only one at a time can sit behind a computer. But sometimes we just sit behind it with the two of us.
Researcher	That's like a rule that you have, that only one at a time can sit behind a computer?
Lucas	Yeah.
Researcher	But you have to carry out the project with the two of you.
Oscar	So we first make a planning on paper.

This gives us a general idea about the procedure and the use of artifacts. The teacher confirmed this idea. The students are accustomed to pass through two stages—as the teacher had instructed them at the start of the pilot program: First, the pair studies the assignments in the syllabus and sketches out an initial plan with pen and paper; second, the decisions are brought into a computer program—usually in a spreadsheet and sometimes in a word processor. In addition, there is a rule where only one student at a time can sit behind a computer, meaning that the students have to decide beforehand who will manipulate the mouse and keyboard.

We can make some inferences about the planning practice: (P1) the pair passes through two stages, where a paper-and-pen representation of the plan from the first stage serves as input for an on-screen representation in the second stage; (P2) in both stages, the pair works on the basis of a task division, whereby one of them manipulates the representational artifact and both of them comment on this manipulation.

Ideally, according to the teacher, the final plan should separate and capture distinct requirements, and it should describe these requirements in terms of tasks, sub-tasks and duration, and in order of implementation—distributed over the 2 weeks of the project. Inspection of Lucas and Oscar's plan tells us that it does not meet these specifications. During the paper-and-pencil stage, instead of identifying task requirements, sub-tasks, and external constraints, Lucas and Oscar basically added the assignments as they were presented in the syllabus in undifferentiated form into a tabular representation (i.e., in rows and columns). The first column describes the assignments, following the exact order and domain-wise grouping of the syllabus. The second column contains an estimation of the time that would be needed to complete the particular assignment. The third column indicates when a particular assignment is completed. The plan does not contain interdependencies between the different parts. Implementation order of the assignments is implicit, and it does not evidence any simulation of consequences of planning decisions. The final on-screen representation made during the second stage is an (almost) exact copy of the initial paper plan (see Appendix 2 for the final plan, made in a spreadsheet). The teacher confirmed that this type of representational form is common in the classroom. In his words they "simply looked 'what does it say here' (in the project syllabus) and 'how can we get that into the program'." The teacher tells us that this observation fits with a general lack of critical thinking in the classroom. On inspecting the final, plan the teacher remarked that he could tell that the students do not know when they will be able to do what. "They talk about the business letter (third assignment under communication, Appendix 2) while they can only do that at the end of the project. Because they will only have the necessary information at the end of the project."

This gives us some additional information about procedures and the use of artifacts. We can infer about the planning practice that (P3) in both stages of the planning process, the pair constructs a plan with a similar representational form that (P4) consists of a tabular representation, whereby assignments are implemented following their description and organization in the syllabus; this representation does not contain interdependencies between tasks, and implementation order is implicit.

It also tells us something about the socio-planning norms: (P5) the pair does not engage in a real problem representation. Instead of simulating, evaluating, and revising planning decisions, they stick with the specification and following order of the assignments as they are presented in the syllabus. To them, this is an acceptable solution to the planning problem.

Part 2: Bringing the Shared Workspace into Use

On the first day of the new project, Lucas and Oscar were introduced to the shared workspace: a networked tool designed to support joint representational activity in face-to-face settings (Fig. 6.2). The shared workspace enables representational acts via a notation scheme that supports specific contributions. A student can select a card from the notation scheme and add it to the drawing space. That student can then add a text label to the title space of that card. By double-clicking on the card, a comment window appears, where the student can further elaborate his contribution. Students can act simultaneously in the drawing space. Both students can read and move the cards through the drawing space. Once a card is placed in the space, it can be associated to other cards by linking or grouping. For the Kitchen Project, the notation scheme contained three card types, "task," "outcome," and "time" and the possibility to link cards. The drawing space contained a predefined structure: A division into ten columns, whereby each column was labeled with a date, representing 1 day of the proj-

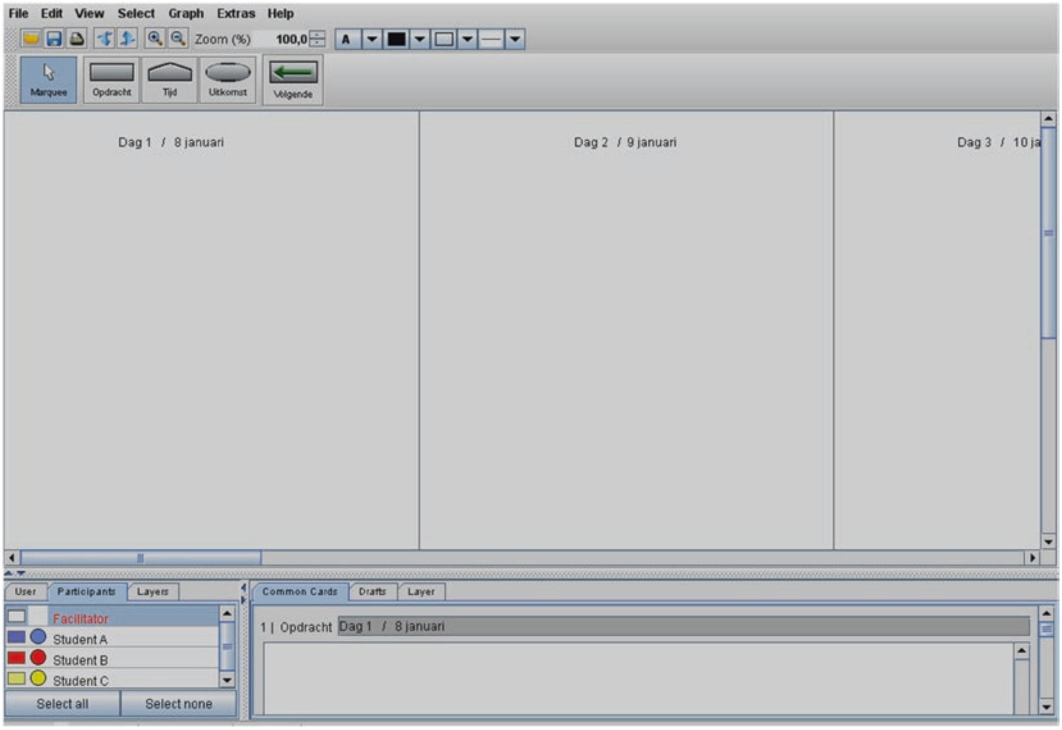

Fig. 6.2 Shared workspace with notation scheme and first three of the predefined columns

ect. These features were meant to provide representational guidance (Suthers & Hundhausen, 2003), by promoting a specification of (sub)-tasks, duration of the tasks, and dependencies between tasks (via the notation scheme) and a specification of implementation order (via the predefined structure in the drawing space). We refer to these features as soft constraints; they suggest or invite a certain use.

The teacher briefly explained the general principle of the workspace to Lucas and Oscar. He explained that they could use the workspace to construct their project plan, that they could both manipulate the representation of the plan from their personal laptop, and that their contributions would be visible on both their screens. Lucas and Oscar sat directly opposite to each other, so they could construct a representation in the drawing board and communicate verbally at the same time. Prior to the session, they read the assignments in the project syllabus (see Appendix 1). They did not have any hands-on experience with the shared workspace. At the start of the activity, both explored basic acts. They figured out how to submit a card, how to label it, and how to move cards through the drawing space. Then they explored the more advanced basic acts, that is, submitting text to the comment window of the card and applying a link between two cards. Our detailed report starts where Lucas and Oscar had mastered the basic acts.

In the analysis below, we trace out how the planning norms and practices that were identified in the first part of the case (P1–P5) informed appropriation of the artifact. The analysis shows how some norms and practices are adapted or departed from and how new procedures (NP) are introduced. The analysis is presented in two steps: In the first step, we present for each episode the actions and utterances from the protocol as sequences oriented toward the construction of a project plan (the full protocol can be found in Appendix 3). In the second step, we describe appropriation as a series of enactments, whereby norms and practices and the artifact become gradually associated.

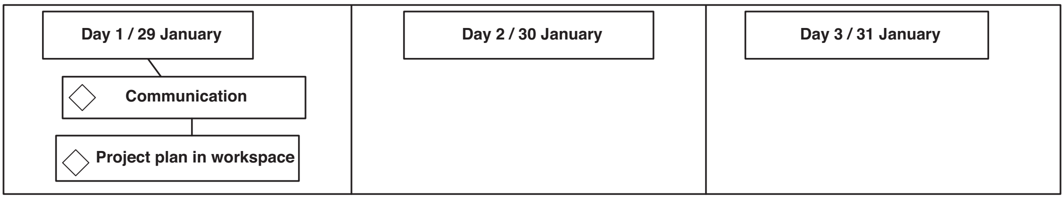

Fig. 6.3 The workspace at Episode 1

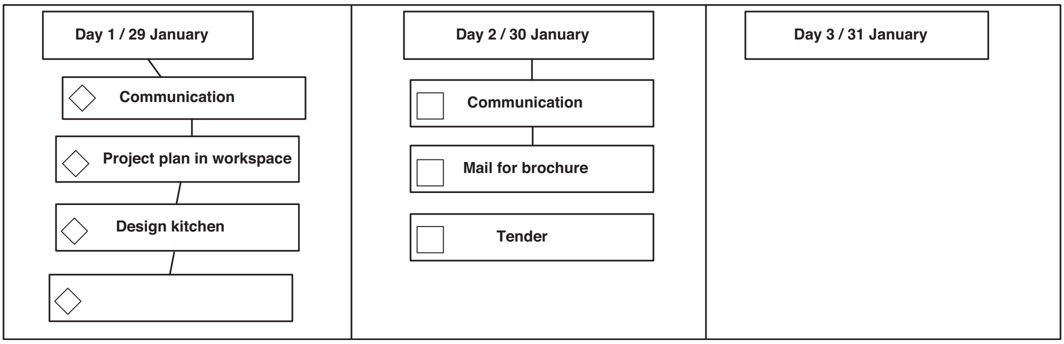

Fig. 6.4 The workspace at Episode 3

"Oh, You Do It Like That…" (Episode 1)

The first episode (see Appendix) starts where Oscar had placed a "task" card in the drawing space and labeled it "communication" [97–98]. He placed his card in the first column, on the first day of the project. Thereunder he placed a card that indicated the first assignment in the communication domain—to develop a project plan—and labeled it "project plan in workspace" [99–100] (Fig. 6.3).

By placing a card with the label "communication" at the top of the first column, and by adding a planning decision under it, Oscar initiates the construction of the representation. Lucas observes Oscar's actions on-screen and asks [101: Put everything underneath communication?]. Oscar confirms Lucas's inference to list everything under the "communication" card and proposes a task division following his example to list the assignments under the domain they are a part of [102: Yes, under communication, if I do that one, then you can do the next]. Lucas accepts this proposal [106: "Oh, you do it like that… OK"].

Oscar's enactment of the technical artifact appears to be informed by a procedure from regular practice: to organize the assignments according to the domain that they are part of, and to list them following their description and organization in the syllabus (P4). Oscar used a "task" card from the notation scheme to represent the domain and a "task" card to list an assignment under this domain. He furthermore hinted toward a task division, whereby both contribute to the drawing space simultaneously. This proposal, to enact the opportunity of simultaneous access by working on a different part of the plan at the same time, suggests a new procedure (NP1) and is a deviation from regular practice (P2). These enactments are referred to only indirectly, and they remain implicit in the dialogue.

(Episode 2)

In the episode that follows the pair keeps with the suggested task division. Both work simultaneously on a part of the representation (NP1). Oscar continues his list of communication assignments in the first column, Lucas starts to list in the second column (Fig. 6.4). They use only the "task" card from the notation scheme. Oscar inscribes some specifications with the assignments (sub-tasks) in the comment window of his cards. These specifications are not directly visible (the card had to be double-clicked to see the contents of the comment window). There is no discussion about planning decisions. The students keep with the order of the assignments as presented in the syllabus (P5). The semantics of the "soft" constraints that are produced by the drawing space (i.e., the predefined time categories) and the notation (i.e., the three card types, "task," "time," and "outcome") do not come into play. The predefined columns structure the representation, but implementation order is implicit.

"What's That a Part of?" (Episode 3)

The following episode is initiated with a question by Lucas [141: What's kitchen design a part of?]. Oscar's answer [142: That's part of technology] triggers Lucas to respond [143–144: Then we should perhaps leave communication out. But do only the things that we need to do on that day].

Lucas's question appears to address an issue of problem representation, but is in fact a rhetorical question, concerned with the representational form of the plan. Oscar had placed the "design kitchen" assignment under the heading "communication," while it is in fact part of the technology domain (Fig. 6.4). Lucas noticed this as a deviation from the procedure they had both agreed to follow in the first episode (P4). He appears dissatisfied with this inconsistency. He draws attention to the contradiction and suggests a solution to overcome it. The new procedure, suggested by Lucas' proposal to "leave communication out," would be to indicate the assignments on a specific day, without reference to the knowledge domain that they are a part of (NP2).

"But, We Are Now, Eh...Per Part..." (Episode 4)

Oscar does not respond to Lucas' proposal. Two minutes later he says [156: Where do we put technology?]. Lucas himself had already deleted the "communication" card he had placed in the second column (Fig. 6.4). Oscar attempts another solution. He adds a card labeled "Technics" and places it above the kitchen design assignment [158]. Then he deletes the "Technics" card and types "technical drawing" in the card with the "design kitchen" assignment, indicating the domain in the card instead of above it. A few seconds later, he seems confused [165: But, we are now, eh… per part…]. He moves the "design kitchen" card to the third and empty column in the drawing space. Lucas moves the "design kitchen" card back to the first column and adds a card labeled "technology" above it (Fig. 6.5). He concludes [170: So we'll also get communication].

By placing a technology assignment in the first column, Oscar created competing constraints on the representation: the first column now signified "dedicated to communication assignments" and "tasks planned on Monday." Oscar tried to resolve the inconsistency. Combining two domain labels in one column did not satisfy him. He decides to move the technology assignment away from the first column in order to regain consistency. Hereby he prioritizes the existing representational convention over a deliberate planning decision. He ignores Lucas's proposal. Lucas, who had noted the inconsistency already in the previous episode, responds by implementing a solution that combines the two principles: planning assignments per day and adding the corresponding domain with each (set of) assignment(s) (similar to Oscar what had done earlier and had then rejected). Lucas integrates the existing procedure with the new one (P4 + NP2).

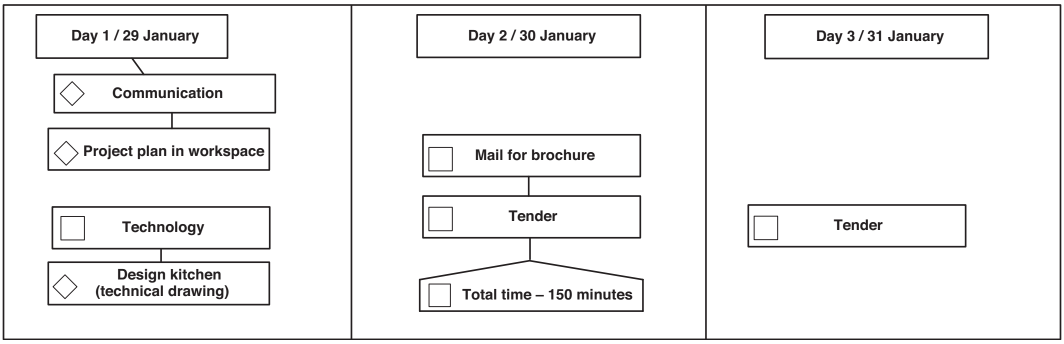

Fig. 6.5 The workspace at Episode 4

"We'll Just Do Planning for a Day" (Episode 5)

In Episode 5 Oscar restates his intention with technology assignment [242]. Lucas, in response, asks him what domain that assignment belongs to [243–244]. He proposes again to abandon the domain labels all together [246]. Oscar responds with [247: No, we'll just do planning for a day, not for a course, we'll just...shall we do that?]. This seems compatible with what Lucas had just proposed, so Lucas repeats his proposal [248]. Instead of complying, Oscar formulates an alternative that combines the proposal to plan for a day with the established convention to indicate the domain [249–250: I think we'll just have to plan what we do on that day. And then we put above there what it is, eyh?]. Lucas agrees.

In this episode Lucas and Oscar reiterate their negotiation from the previous episodes. Lucas attempts to depart from the existing procedure (P4), by suggesting to omit the domain labels. Oscar considers the fact that his planning decision requires a departure from procedure—where he seemed reluctant to do so before—and proposes the same solution Lucas proposed earlier (NP2). In his next utterance, he elaborates NP2 by integrating it with P4, precisely as Lucas had implemented in the previous episode (P4 + NP2). After this, Lucas and Oscar do not address procedure. In the remainder of the activity, they are focused on problem representation and plan construction, the actual content of the plan. Figure 6.6 shows a fragment of the final project plan.

Micro-development of Activity

The students explore several distinct, hierarchically interrelated dimensions in the activity: The production of basic acts (prior to the first episode), the construction of a representational form, making planning decisions, and coordination of both the use of the artifact and the joint task. Their orientation shifts several times within a relatively short time frame. These shifts imply an upward or downward movement in the hierarchy of micro-development.

In the first episode, Oscar's orientation shifts several times. First he is oriented toward construction of a representational form; then his orientation shifts to making a planning decision, and then it shifts to coordinating the use of the artifact with Lucas. In the second episode, both students are oriented on making planning decisions. When in the third episode, Lucas notes a contradiction, his orientation shifts from making planning decisions to construction of the representational form. In hierarchical terms, his orientation shifts downward. In the episode after Oscar's orientation shows a similar downward shift. The downward shifts appear to occur where the students experienced resistance from the artifact. When the inconsistency is resolved (or appears to be resolved), orientation shifts upward, and

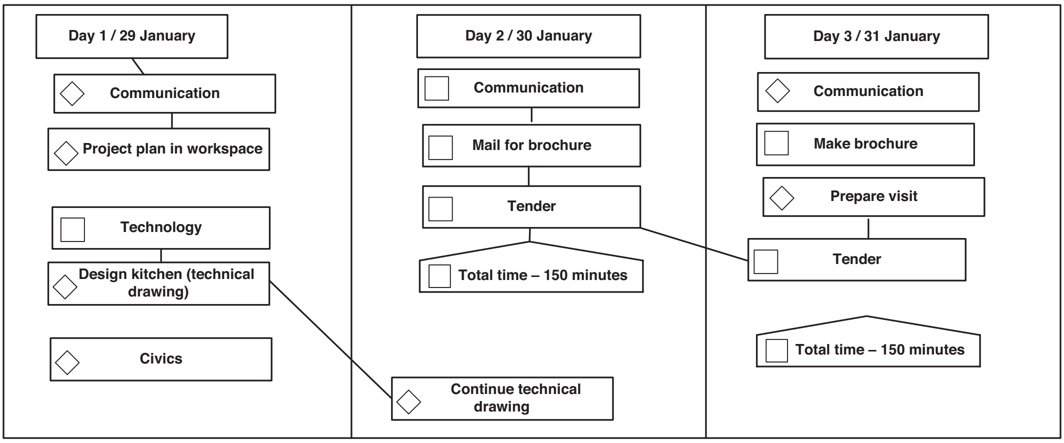

Fig. 6.6 Fragment of the final plan

both are again focused on making planning decisions. The upward shift occurs, in other words, where resistance was accommodated.

Resistance triggered reflection and led to adaptation of an existing procedure. Other procedures departed from without resistance or reflection. Out of the five norms and practices that we identified as central to regular planning, three were departed from the division in two stages, whereby the paper-pen stage serves as input for the on-screen stage (P1) and consequently the similar form of the plan in these stages (P3). Also the task division was departed from, whereby one student manipulates the artifact, and both comment on this (P2). These procedures were departed from without reflection. In the case of P1 (and P3), this is perhaps not so surprising, since the students found themselves already working on-screen. Departure of P2 was a different case. Enactment of the opportunity of simultaneous manipulation resulted in a new procedure (NP1), whereby the two students worked on a different part of the representation at the same time. They could have enacted the opportunity to take turns, whereby one would manipulate the representation at a time—perhaps more similar to existing procedure. We return to this point in the discussion below. We have seen how P4 was adapted and integrated with a second new procedure, resulting in (P4 + NP2). The one element of regular planning that did not change was the norm (P5) to stick with the specification and order of assignments in the syllabus and to not engage in a real problem representation.

Discussion

In this study we analyzed how a technical artifact was brought into use within an existing classroom practice. We addressed the appropriation of a digital shared workspace by a student pair who worked jointly on the construction of a project plan. The process of appropriation was described against a background of their regular planning practice. By zooming in on one pair, we provided a detailed description of the way in which enactment of the artifact was contingent on an interplay of situational resources. At the same time, this points to a limitation of our study: single-case analysis offers a small basis for generalization.

The conceptual framework we adopted combines elements of affordance theory (Gibson, 1979), instrumental genesis/activity theory (Rabardel, 1995), and representational practice (Enyedy, 2005; Hall, 1996). We took the general premise of affordance as a point of departure: The artifact makes action opportunities available that are relative to the needs and abilities of the ones who work with it.

But the notion of affordance alone does not explain appropriation (Overdijk et al., 2012). We adopted a micro-developmental perspective—based on instrumental genesis—to illustrate how classroom norms and practices inform the enactment of opportunities and how appropriation develops—at least during the early stages that we studied. Our study shows that enactments may change during appropriation, that it is contingent on norms and practical procedures and negotiated socially. We refer to our approach as micro-developmental because we examined appropriation over a relatively short period of time. We followed Rabardel and Bourmaud (2003) in conceptualizing the process by which an artifact is brought into use as the development of a hierarchical activity system. In this view, the artifact becomes gradually associated with cognitive schemes for utilization to form a functional system. In our framework we focused on the association of the artifact with situational resources (norms and practical procedures), rather than taking up the notion of utilization scheme. We focused on norms and practical procedures because the nature and content of cognitive schemes are not available to us as researchers. We combined, in other words, the framework of instrumental genesis with a situated approach to representational practice (Enyedy, 2005; Hall, 1996; Roth, 1996).

Resistance and Accommodation

Planning norms and practices (Cobb et al., 2001) were important situational resources in regular planning. Norms and practices more or less set the "attitude" with which the students approached the planning task. Planning practices specified practical procedures to collaborate, utilize artifacts, and construct a representational form. Planning norms set the standard for what made an acceptable solution to the planning problem and for what made an acceptable level of collaboration. With its introduction, the technical artifact became an important resource as well. Some of the norms and practices from regular planning became associated with the artifact; others were departed from. This association was not straightforward.

Important enactments took place at an early stage and seemingly without reflection. When one of the students produced (part of) the regular representational format in the drawing space, both accepted this as a way to go forward. This concurs with Bowers, Cobb, and McClain (1999), who found that where learners work together relatively autonomous, routines and conventions tend to remain implicit, and recognizable practices are taken as self-evident. Still (almost as an unnoticed by-effect), the pair departs from the task division, whereby one of them manipulates the representational artifact, and both of them comment on this manipulation—a procedure of regular practice. The enactment of the opportunity of simultaneous access results in a new procedure that is not a recognizable practice at all: the two students were working on a different part of the shared representation at the same time. It seems as if this enactment took place unreflectively—like an affordance, and apparently it did not cause substantial resistance. It has to be noted that the collaboration of the pair in our study was perhaps not as tight as it could have been. Here we have to take into account the specific setting of our study. The two students manipulated the shared representation from their own laptop, while being seated directly opposite each other. Most of the time, their attention is focused on-screen. This is quite a challenging setting that requires a high degree of coordination. Given the fact that the pair is not accustomed to engage in a real problem representation and that "loose" collaboration is an acceptable standard to them, their task division may have simply seemed evidently efficient to both of them.

Throughout the larger part of the appropriation process, a tension was present that had to be resolved. Our analysis shows how the association of a practical procedure from regular practice with the artifact led to an inconsistency in the activity. It leads to incompatible constraints on the representation: a contradiction of "soft" constraints produced by the artifact and constraints produced by the representational convention. This contradiction surfaced as resistance and triggered downward shifts in the hierarchy of micro-development, until the contradiction was resolved. The downward shift focused attention away from performing the task and toward enactment of the artifact. Miettinen (2001) points out that when people engage in practical action with artifacts, tension in the activity is experienced as resistance from these artefacts. In this sense resistance fits with the notion of disturbance that results from internal contradictions within systems of activity (Engeström, 1999). This resistance is what triggers development of activity. Also in the model of situated action put forward by Suchman (1987), resistance or disturbance in artifact-mediated activity causes users to analyze their interaction with the artifact and to formulate rules or procedures. Following these similarities between the role of resistance in Leont'ev's model and Suchman's model, we can characterize the downward shift in the hierarchy of micro-development as a breakdown: a disruption in the functioning of things that forces one to adopt a more reflective stance toward the activity (Koschmann, Kuutti, & Hickman, 1998). Accommodation of the resistance lead to an upward shift—a progressive step in the micro-development of the planning activity.

The pair accommodated resistance by integrating the existing procedure with a new procedure. They achieved this through a complex set of negotiations that combined direct manipulation of the artifact and verbal referencing to the procedure. It is not uncommon that the introduction of a representational convention leads to tension between opportunities and constraints (Enyedy, 2003, 2005). The negotiation that followed is also congruent with other studies. Danish and Enyedy, similar to our study, found that the importance given to a constraint in representational practice, and its prioritization, is negotiated within ongoing activity (2006).

Conclusion

The introduction of the technical artifact in the classroom posed a challenge to the pair. They were challenged to bring it into use, while they could not fully rely on their regular planning procedures. They did not discuss a strategy for utilization beforehand, nor did they project the consequences of choices that were made—mostly early and implicitly—during the process of appropriation. Enactment of opportunities and construction of the project plan occurred simultaneously and incrementally. Where the students did not experience resistance from the artifact, they did not reflect on their enactment or on the procedures that informed it. Reflection was triggered where resistance did occur. In our case study, resistance signaled tension in the activity, triggered reflection on the interaction with the artifact, and—because of the specific setting—had a coordinative function: It focused the students' attention on the same problem. The absence of resistance was equally important. It allowed the pair to transpose or depart from regular procedure without reflection.

Learners, like the pair in our study, are expected to shape their own learning activities in ways that fit with their personal abilities, knowledge, and needs. They have to plan their own project and decide how to move from A to B, when to do what, and where to do it. To cater these pedagogies, designers are challenged to develop instructional strategies that prevent learners from being unnecessarily restricted. The current breed of technical artifacts, and the scenarios that accompany them, shows increased flexibility. Still, there is an inherent tension: too much rigidity may downplay creative agency, but too much flexibility may not result in a productive learning trajectory. Our study suggests that "soft" constraints are an important resource in this problem. When carefully tailored, they may help learners to uncover a space of alternative action is taken-for-granted activity.

Appendices

Appendix 1: "The Kitchen Project" Syllabus (Fragment)

The project syllabus contains three chapters, each corresponding with a specific domain. Chapter 1 contains communication assignments. These are about language (i.e., native Dutch, German, and French) and the practical use of language. Chapter 2 contains technology assignments. Math, physics, and chemistry are relevant knowledge domains here. Chapter 3 contains civics assignments: about government, society, and rules and regulations. Below, one finds the technology and communication assignments (translated from Dutch) as they are presented in the project syllabus. The assignments are accompanied with several examples (e.g., of technical drawings and invoices) and other background information that is necessary to complete them. This information is not presented here.

Technology assignments

Situation

The Ten Donker family has been using their kitchen for 3 years now. They would like to have a new one.

New equipment: microwave, dishwasher, hood, and sink with tap

Other (existing) equipment is taken up in the new design.

How to go from A to B?

Attention points (math, physics, chemistry)

Making and reading of a technical drawing

Recognizing and applying technical symbols

Calculation of costs (tender/VAT on discount percentage)

Working with formulae (U = I*R and P + U*I) and derivatives

Functioning of meter cabinet

Analogy water pressure and water usage

Electric power and cost calculation

Further deepening: replacement resistance/resistance metal wire

With this assignment you will have to translate the wishes of the client to technical solutions:

"Sunday breakfast comes with fresh orange juice"

The Ten Donker family has an electric orange presser. Where have you planned the socket?

"Why should a refrigerator use more energy than necessary, it's expensive and bad for the environment"

What should the family pay attention to, according to you?

"We like clean walls with no cables and our cooker in the middle"

Where do you place the gas-, water-, and light conductors?

Communication assignments

Description

The Ten Donker family wants to have a new kitchen installed in their home. They have taken over an old kitchen with the acquisition of their house 3 years ago. They plan to outsource the work to a licensed firm. They have been told by friends that German (French) firms are particularly good in kitchen installations.

Write an email to a German (French) kitchen firm in which you kindly request a brochure.

Write an email on behalf of Kuchenland, Nordhorn (Pays des cuisines, Lille) in which you make an appointment.

With the Ten Donker family to do measurements

Kuchenland (Pays des cuisines) also invites them to visit their showroom in Nordhorn (Lille).

Kuchenland (Pays des cuisines) sends the family a tender.

Relevant competencies
For this assignment you will have to:
Write a brief letter in German or French.
Make a proper invoice in Dutch.
Write a reflection on the collaboration and functioning of the partners (in Dutch).

Appendix 2: Plan for the "Flower Project" by Lucas and Oscar

	Time	Done (check)
Communication		
1. Plan	30 min	
2. Look up export law and regulation	30 min	
3. Business letter in Dutch	20 min	
4. 10 questions about civilians	15 min	
5. Report of civilians	30 min	
6. Flying flowers:		
Summarize activities	40 min	
Make brochure	50 min	
7. Do 5 questions with German text	30 min	
8. Make reflection	20 min	
Technology		
1. Intake with customer about wishes for truck	30 min	
2. make autocad drawing	3,5 h	
3. Discuss drawing with client	30 min	
Civics		
Paper:		
1. Think of topic and questions	30 min	
2. Gather information	50 min	
3. Write paper	2 h	

Appendix 3: Excerpts from the Protocol (L = Lucas, O = Oscar)

Episode 1

Line	Time		Action
97	16.06	O	Adds "task" card under Day 1.
98	16.12	O	Labels "task" card "Communication."
99	16.14	O	Adds "task" card under Day 1.
100	16.20	O	Labels "task" card "Project plan in workspace."
101	16.24	L	Put everything underneath communication?
102	16.27	O	Yes, under communication, if I do this one, then you can do the next.
103	16.32	L	Project plan, what's that a part of, communication, right?
104	16.38	O	We already have a project plan, right?
105	16.55	O	Adds links between cards (Fig. 6.3).
106	17.01	L	Oh, you do it like that… OK.

Episode 2

129	25.01	L	Adds "task" card under Day 2.
130	25.03	L	Labels "task" card "Communication."
131	25.05	L	Adds "task" card under Day 2.
132	25.09	L	Labels "task" card "Mail for brochure."
133	25.13	O	Adds "task" card under Day 1.
134	25.17	O	Labels "task" card "design kitchen."
135	25.21	L	Adds "task" card under Day 2.
136	25.25	L	Labels "task" card "Tender."
137	25.27	L	Adds links between cards (Fig. 6.4).
138	25.28	O	Edits comment window of "task" card.

Episode 3

141	25.34	L	What's kitchen design a part of?
142	25.36	O	That's part of technology.
143	25.38	L	Then we should perhaps leave communication out.
144	25:41	L	But do only the things that we need to do on that day.

Episode 4

154	28.24	L	Adds "time" card.
155	28.26	L	Labels "time card "total time = 150 min."
156	28.27	O	Where do we put technology?
157	28.29	L	I'm not sure.
158	28.34	O	Adds "task" card.
159	28.37	O	Labels "task" card "technics."
160	28.40	O	Let's do here, I've put "technics" instead of technology.
161	28.41	L	Adds link between cards.
162	28.43	O	Deletes "technics" card.
163	28.45	O	Edits "design kitchen" card.
164	28.48	O	Adds label "(technical drawing)"
165	28:52	O	But, we are now, eh… per part.
166	28.54	O	Moves "design kitchen" card to third column.
167	28.57	L	Moves design kitchen" card back to first column.
168	28.59	L	Adds "task" card.
169	29.61	L	Labels "task" card "technology" (Fig. 6.5).
170	29.62	T	So we'll also get communication.

Episode 5

242	38.55	O	I would like to continue with technical drawing.
243	39.08	L	What's that a part of?
244	39.14	L	Is that part of communication, or not?
245	39.15	O	Yeah, well, it's not necessarily communication, but I think it belongs there...
246	39.20	L	Shouldn't we just remove communication?
247	39.25	O	No, we'll just do planning for a day, not for a course, we'll just… shall we do that?
248	39.28	L	Shall we then remove communication and stuff?
249	39.34	O	I think we'll just have to plan what we do on that day.
250	39:37	O	And then we put above there what it is, Eyh?
251	39.38	L	Ok.
252	39.40	L	Like I've put "technology" above it.
253	39.43	O	yeah, like that.

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Investigation 7. Instrumental Genesis in Technology-Mediated Learning: From Double Stimulation to Expansive Knowledge Practices

Giuseppe Ritella and Kai Hakkarainen

Abstract

The purpose of the present paper is to examine the sociocultural foundations of technology-mediated collaborative learning. Toward that end, we discuss the role of artifacts in knowledge-creating inquiry, relying on the theoretical ideas of Carl Bereiter, Merlin Donald, Pierre Rabardel, Keith Sawyer, and L. S. Vygotsky. We argue that epistemic mediation triggers expanded inquiry and plays a crucial role in knowledge creation; such mediation involves using CSCL technologies to create epistemic artifacts for crystallizing cognitive processes, remediating subsequent activity, and building an evolving body of knowledge. Productive integration of CSCL technologies as instruments of learning and instruction is a developmental process: it requires iterative efforts across extended periods of time. Going through such a process of instrumental genesis requires transforming a cognitive-cultural operating system of activity, thus "reformatting" the brain and the mind. Because of the required profound personal and social transformations, one sees that innovative knowledge-building practices emerge, socially, through extended expansive learning cycles.

Keywords

Epistemic mediation · Chronotope · Knowledge practices · CSCL · Knowledge building · Expansive learning · Instrumental genesis · Double stimulation

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G. Ritella (✉)
Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland

K. Hakkarainen
Department of Education, University of Helsinki, Helsinki, Finland
e-mail: kai.hakkarainen@helsinki.fi

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Introduction

The purpose of the present article is to analyze challenges and constraints involved in implementing technology-mediated collaborative learning and associated inquiry-based and knowledge-building pedagogies. Our central question is: Why is it often difficult for teachers and students to appropriate the technology-mediated practices of learning and instruction that we promote and to willingly adopt sophisticated learning environments created by CSCL researchers? This problem is not an accidental phenomenon or a characteristic of local conditions but an essential aspect of technology-mediated human activity. For example, Collins and Halverson (2009) argued that there are some incompatibilities between traditional educational practices and potentials for innovative learning technologies; they then proposed that the future of learning is from outside school. From our perspective, those incompatibilities may be overcome if the social practices associated with schooling are transformed in association with the use of a technological medium. Indeed, since a technology "does not exist in a 'pure objective form' outside the context of social practices" (Tuomi, 2002, p.12), to analyze the implementation of new media in education will require that we put expansive knowledge practices in the center of the investigation. Hakkarainen (2009) has crystallized our perspective with the slogan, "technology enhances learning only through transformed social practices." In order to work as an instrument of learning and teaching, educational technologies have to be integrated, "fused," with the social practices enacted by participants. This was a reason for introducing the concepts of "knowledge practices" and "chronotopes." *Knowledge practices* are defined as routine personal and social activities related to working with knowledge. They represent deliberate efforts to expand one's intellectual resources by creating and building epistemic artifacts (Hakkarainen, 2009; Knorr-Cetina, 2001). The patterns of space-time management emergent during the enactment of knowledge practices have been called *chronotopes* (Ligorio & Ritella, 2010).

We will address this issue by building on the contributions of Vygotsky, Donald, Bereiter, Rabardel, and Sawyer. Vygotsky's and Donald's theoretical frameworks assist in explaining how cultural-historical development profoundly transformed the human cognitive architecture in a way comparable to major leaps in biological evolution, bringing radical externalization and collectivization of cognition. In his effort to explain semiotic mediation and psychological development, Vygotsky (1978) analyzed the process that permits people transforming their own psychological processes through the use of external tools (especially signs and symbols). The author noticed that cultural historically developed tools, initially irrelevant, are picked up from the environment and included in mediated activities when people face challenging situations. In particular, he pointed out that this process permits the reframing of challenging situations in a way that makes agency possible, through the use of external resources he called psychological tools. In Vygotsky's view, psychological tools are not aimed at transforming the environment in the same way as conventional tools, but they expand the depth and scope of psychological processes, triggering psychological development. The basic principle underlying this process was called double stimulation, since the challenging situation was conceived as a first stimulus and the artifacts picked up as a second stimulus. Donald's (1991, 2000, 2001) investigations indicated that human beings are "maximal cognitive over-achievers" whose complex creative and intellectual achievements are piggy backed by the cultural invention of external cognitive technologies and the associated cultural "reformatting" of the mind and the brain. A crucial role in the emergence of our civilization was the emergence of external memory fields (EXMFs) that allowed using our powerful visual system for elaborating, sharing, and building on externally represented ideas and creating exponentially growing external symbolic storage systems (ESSS). As explained below, to function in interaction with such cognitive-cultural networks constitutes the semiotic-material basis of human cognition and requires the gradual development of the "cognitive-cultural operating system" required capitalizing on external cognition, which can be obtained through in-depth socialization.

In the present period, practices of learning and instruction prevailing at schools and educational institutions are being profoundly transformed through intensive use of ICTs in general and CSCL technologies in particular. In understanding this process, the pioneering contributions of Bereiter's (2002; Scardamalia & Bereiter, 2006) knowledge-building theory provide fruitful material. These researchers have provided a theory of knowledge-creating inquiry, developed the Knowledge Forum (KF) environment to transform practice, and carried out design experiments in close interaction with practitioners. Bereiter construes knowledge building as a process of advancing externalized conceptual artifacts, but the focus of his theoretical reasoning has been mainly on the development of ideas, as immaterial objects of Popper's (1972) world of cultural knowledge (World 3). It appears that Bereuter's approach may be usefully extended by addressing the importance of building knowledge at the EXMF provided by CSCL environments, through the construction of knowledge artifacts, which constitute locally created cognitive-cultural networks and exert epistemic mediation. Learning to engage in knowledge building requires the deliberate transformation of learning activities, capitalizing on the epistemic mediation provided by the cultural worlds embodied in external artifacts.

Rabardel (Béguin & Rabardel, 2000; Vérillon & Rabardel, 1995), in turn, assists us in understanding the developmental processes that individuals need to gradually transform artifacts into instruments of their activity. Appropriating novel tools for remediating activity requires adapting and transforming both the external tools (instrumentation) and the cognitive-cultural schema (instrumentalization). We think that Rabardel's ideas of instrumental genesis are complementary to Vygotsky's notion of double stimulation. Such stimulation permits one to explain instrumental genesis and mediation in terms of inclusion and use of artifacts in the processes of problem-solving, thinking, and inquiry. The concepts of instrumentation and instrumentalization permit us to improve our understanding of the "mutual shaping" between people and tools (Overdijk & van Diggelen, 2008, p. 3) that occur when second stimuli are iteratively used as instruments. Such a developmental process – sometimes called "appropriation" (ibid) – is close to the transformation of the cognitive-cultural operating system of activity that Donald (2000) emphasized. Finally, we see technology-mediated knowledge practices essentially as cultural, social practices, which can be fruitfully analyzed using the theory of collaborative emergence, addressed by Sawyer (2005). He has argued that the phenomena studied by social scientists emerge from "complex systems of individuals in interaction" (2009, p. 1). We consider technology-mediated learning practices a phenomenon of this type, involving both real-time and long-standing trajectories of development, which are reached first at the inter-psychological (social) level and then at the intra-psychological (individual) level (Vygotsky, 1978).

In short, in this chapter, we argue that all of these investigators address complementary aspects of the transformations that are needed for productive participation in technology-mediated collaborative learning; such learning is tightly integrated and embedded in social and collective practices cultivated within a community. In the following sections, we first discuss the role of epistemic mediation in human learning and activity. Second, we address the relations between instrumental genesis and double stimulation. Third, we look at the space-time relations (chronotopes) involved in knowledge-creating learning and at the collaborative emergence of innovative knowledge practices. In the end, we discuss how all of these elements permit one to obtain a critical understanding of technology-mediated learning and to contribute to bridging the gap between theory and practice in CSCL.

Epistemic Mediation and Technology-Mediated Collaborative Learning

We examined technology-mediated collaborative learning as a process of transforming the present knowledge practices in schools toward those that engage students, teachers, and their communities in building knowledge embodied in epistemic artifacts. This process capitalizes on the epistemic mediation provided by those artifacts, which play the role of stepping stones for reaching deeper understanding. In order to examine the psychological underpinnings of such a process, a short excursion regarding human cognitive evolution is in order. According to Donald's (1991, 2001, see also Olson, 1994; Sterelny, 2004) analysis, the emergence of literacy transformed the human cognitive architecture as profoundly as earlier leaps in biological evolution, allowing radical externalization and collectivization of cognition. A central aspect of the fundamental cognitive transformation in question was harnessing the extremely powerful human visual system to support thinking and reasoning. Ideas and concepts materialized with human vocal apparatus were ephemeral and impossible to explore analytically. Production of knowledge by writing on sand, paper, or a digital surface opened up an external memory field (EXMF) in which complex ideas and associated epistemic systems can be extensively refined in a way not attainable for the unaided human mind. In fact, thinking and learning very profitably capitalize on literate practices involved in externalizing, crystallizing, and objectifying ideas and thoughts occurring in inquiry processes to epistemic textual or graphic artifacts, as shown in the following anecdote:

> When the Nobel-winning American physicist Richard Feynman gave a manuscript full of text and diagrams to Charles Weiner who was investigating the history of his thought, the latter asked if this was "a record of the day-to-day working." "I actually did the work on the paper" Feynman responded. Slightly confused Weiner specified: "Well, the work was done in your head, but the record of it is still here." "No, it's not a record, not really. It's working. You have to work on paper, and this is the paper. Okay?" (Gleick, 1992, p. 409, quoted by Donald, 2001, p. 301)

Human beings do not have cognitive capacities to engage in the development of complex ideas within their individual minds; in order to pursue "longer trains of thought" (Darwin, quoted by Gruber, 1981), they have to "work on paper." Experts' complex reasoning and memory capabilities become internalized only through sustained pursuit of externally embodied cognitions (Galperin, 1957). Writing and visualization allow human beings to establish a theoretic culture based on gradually accumulating the external symbolic storage systems (ESSSs).

Humans are biologically cultural and social creatures (Donald, 2001; Rogoff, 2003; Tomasello, 2009) whose intelligence is adapted to coevolve with cognitive-cultural macrostructures that are subject to cultural-historical change. Our intelligence is not only inside the mind but in its multifaceted networking connections and downloaded to various peripherals, i.e., artifacts that can be understood as cognitive prostheses that expand and augment human creativity and intelligence when integrated with the cognitive architectures of the participants' minds (Clark, 2003; Skagestad, 1993). Following Donald's (2001) line of thought, a wide range of in-depth learning accomplishments may be interpreted as the developmental process of acquiring the cognitive-cultural operating system that productive working at EXMF, utilizing ESSS, requires.[1] The operating system is an internalized aspect of a sociocultural or socio-technological activity system (Engeström, 1987), i.e., an integrated array of tools, instruments, objects, division of labor, and specific social structures with particular rules and principles. Thus deep intellectual socialization to massively distributed cognitive-cultural networks, facilitated by years of systematic education, augments the participants' cognitive capacities to the extent that enables them to solve significantly more complex problems than would otherwise be possible. Such capacities are best not thought of as individual characteristics but rather as the appropriation, within individuals, of the capabilities of the culture in which they live. Across such an expansive transformation, culture literally reformats and reprograms the human cognitive architecture (Clark, 2003; Donald, 1991, 2001; Hakkarainen, 2003). As a consequence of extensive cultural reshaping,

[1] In particular, we refer to learning that involves the development or transformation – or both – of participants' practices; roughly it corresponds to levels II and III of learning in Bateson's (1972) taxonomy and to expansive learning (Engeström, 1987).

cultural knowledge and competencies become internalized as a part of human cognitive architecture and affect the available cognitive resources at many levels. When artifacts become fully integrated within an activity, they are represented in our brains in a way comparable to our physical limbs; cultural programming takes place through creating novel functional systems (Luria, 1974) or "virtual machines" (Dennett, 1991) for pursuing culturally programmed rather than biologically given problem-solving.

From this perspective, ICT may be seen as a continuation of the collectivizing cognitive evolution at a new level of integration of internal, external, and distributed cognitive processes (Donald, 2000). Indeed, as McLuhan (McLuhan & Lapham, 1964; see also Goody, 1977; Olson, 1994) theorized, ICT generates new media having different material features from other media. They transform semiotic processes in terms of perceptual features of semiotic arrays, workability of semiotic arrays, and sharing of semiotic arrays. For example, word processor software permits one to modify texts without rewriting them on new sheets of paper (workability) or to visualize them in different sizes, different colors, different brightnesses, and so on (perceptual features) and often to share documents with anyone in real time (sharing). A spreadsheet, in contrast, easily visualizes symbols and words in tables and graphs that trigger different cognitive processes than a discursive text (Goody, 1977). Those features of ICTs allow for delegating cognitive processes to technological systems, creating technologies for fusing intellectual efforts in collaboration, and complementing personal epistemic resources with global networks that are immediately accessible. ICTs impel the creation of qualitatively different ESSSs, by permitting integration of hybrid and heterogeneous forms of media in a way unthinkable in the past. Rather than examining digital artifacts as merely isolated tools and signs, we should examine how digitizing will revolutionize human cognition and activity (Rückriem, Ang-Stein, & Erdmann, 2011). Technological instruments are at the same time medium and sign (Cole, 1996), and the characteristics of medium (material relations) are as important as the characteristics of the signs and symbols (semiotic relations).

It appears that the Internet represents a revolutionarily expanding digitized aspect of ESSS relevant in the present-day knowledge-intensive society. In-depth intellectual socialization to digital literate practices throughout educational careers may provide the basic elements of the cognitive-cultural operating system that contemporary society requires. In order to profit from the "extension" of cognitive system that the Internet provides, people need to adapt their internal cognition to the features of the EXMF they use (both medium and sign system). In this regard, it is essential that the young generation appears to consist of "digital natives" (Prensky, 2001, 2010) who are able to completely merge ICTs with their intellectual system. Because a revolutionary expansion of the digital ESSS has taken place in an extremely short period of time, investigators do not know the longitudinal psychological consequences of ICT-intensive activity. Some investigators worry that constant embodiment of human activity in ICT in general and the Internet in particular may have some undesirable neurological effects (Carr, 2010).[2] They are concerned that constant interruptions associated with the Internet, shallow surfing from one website to another, and a tendency to work with relatively short fragments of text produce "grasshopper minds" (Carr, 2010; Papert, 1994) unable to undertake coherent and disciplined thought, minds for whom knowledge is a matter of "cut and paste."

A limitation of Carr's (2010) position is that he focuses mostly on using the Internet for acquiring and consuming rather than creating knowledge. From a psychological perspective, using ICT for pursuing collaborative inquiry and shared building of knowledge appears critical if students are to master large bodies of knowledge and learning to synthesize and extend rather than merely to consume knowledge (Bereiter, 2002; Hakkarainen, 2004). Writing and visualization, then, have to be considered crucial vehicles of epistemic mediation, and promoting corresponding knowledge practices plays

[2] See also http://www.guardian.co.uk/commentisfree/2011/aug/14/marshall-mcluhan-analytic-thought.

an essential role in CSCL. Pioneering research on epistemic mediation by Bereiter and Scardamalia (1987) focused on teaching experts' transformative ways of working with knowledge to promote students' learning. These studies revealed that students' capacity to produce knowledge can be significantly facilitated when they are presented with material embodied in critical questions and hints (pieces of paper) at their EXMFs during the writing process. Later on, such cognitive scaffolding played a crucial role in the design of knowledge-building technologies focused on assisting students' engagement in complex and challenging inquiries in which material practices of writing played critical roles. Practices of knowledge-building classrooms differ from ordinary oral discourse taking place in conventional classrooms because participants' intangible insights are entered into a learning environment's database and are transformed into digital form. The insights are thereby materially embodied as ideas that exist outside of the participants' minds. Such entities are conceptual artifacts (Bereiter, 2002), having both idea-like and thing-like characteristics. From this perspective, conceptual artifacts in Bereiter's theory roughly correspond to the semiotic arrays that constitute EXMF.

Epistemic mediation plays an important role in the "knowledge-creation" approach to learning that Hakkarainen and his colleagues have been developing (Paavola, Lipponen, & Hakkarainen, 2004). To summarize, by epistemic mediation, we refer to a deliberate process of deepening inquiry by creating external knowledge artifacts (written notes or visual representations) at EXMFs that crystallize, promote evolving understanding, and provide stepping stones for directing and guiding further personal or collective inquiry efforts. We say that the use and operation of these artifacts involve a process of epistemic mediation between the user (or user community) and the evolving objects of their activity. We are talking about an object-centered approach to CSCL, because the nature of the epistemic objects worked on significantly determines the nature of inquiry; they are centers around which corresponding practices are organized. When designing technology-mediated learning environments for supporting knowledge-building inquiry, CSCL investigators deliberately create new types of EXMFs. Such environments provide the material agency (Pickering, 1995) that enables even elementary school students to participate in deliberate knowledge advancement, with adequate guidance and facilitated by teachers. The current textual practices prevailing at school, however, often guide students to use writing mostly for reporting what their textbooks say about issues being studied rather than writing for epistemic mediation, i.e., as a tool of extending thinking and deliberately generating new ideas and working theories. Adopting and cultivating a cognitive-cultural operating system that enables effective use of writing as a tool of thinking is difficult; it is an extended struggle to acquire embodied, and to a large extent, tacit capabilities rather than direct assimilation of well-specified skills (Russell, 1997).

Double Stimulation and Instrumental Genesis: The Microgenesis of a Cultural-Cognitive Operating System

As indicated above, the extended-mind approach constitutes a theoretical framework that helps accounting for the role of technological tools in cognitive processes related to knowledge building. In the following, we discuss how the framework can be fruitfully enriched using the concepts of double stimulation (Vygotsky, 1978) and instrumental genesis (Lonchamp, this issue; Rabardel & Bourmaud, 2003). We conceptualize *double stimulation* as a basic principle regarding the incorporation of artifacts in problem-solving, thinking, and learning. The theory of instrumental genesis concerns the process of appropriation or operating system reformatting, necessary for the transformation of artifacts into instruments. *Instrumental genesis* involves short-term developmental processes of appropriation of technological tools across situations, analogous to the long-term formatting and reprogramming of the mind that reflect the historical development of technology-mediated cultural practices. We think that micro-genetic and middle-/long-term processes both account for the use of technological tools in learning: while the theories explained in the preceding paragraph permit one to explain the macro-level, in this section, we focus on the microlevel of analysis and use the concepts of double stimulation and instrumental genesis to account for the role of instruments in knowledge building.

Double stimulation is a complex concept that can be examined at multiple levels. Here, we stay close to the original Vygotskian interpretation associated with the process of psychological development. (For application of the method to examining the transformation of activity systems, see Engeström, 2007). Basically, the setting of Vygotsky's (1997) double stimulation experiments was as follows: A participant is given a task or problem to solve (first stimulus). Additionally, a neutral stimulus is placed at the perceptual field of his or her activity. While engaging in creative problem-solving efforts, the participant is likely to adapt and transform the neutral stimulus (second stimulus) into an instrument, opening a pathway toward the zone of proximal development (Vygotsky, 1962). The classical example Vygotsky uses to describe the principle is the experiment of the meaningless situation, in which a subject is observed while waiting a long time for the experiment to begin. The author notes that people in this situation transform the "meaningless situation" by the use of external tools present in the environment. For example, people may make a decision that when the minute hand of the clock will be in a certain position, he/she will undertake an action. So, the clock is used as a tool to frame the challenging situation in a way that makes agency possible. In the same way, students facing a problem can frame the problem – and learn – by using any kind of tool present in the educational environment, e.g., finding appropriate information in a book or in the Internet; representing ideas with pen and paper or in a virtual space; transforming artifacts to fit the needs of the moment; and so on.

Apart from the apparent simplicity of the principle, double stimulation is not a mechanical process; the prevailing instruments and procedures have to be creatively adapted for solving the problems encountered. Indeed, once the second stimuli are picked up, people willingly adapt them to their aim and use them to transform their psychological model of a problematic situation. His or her ways of interpreting, modifying, adapting, and using the second stimulus reveal a great deal of information concerning how the participant interprets the task and what kinds of principles are utilized in the process of solving the problem. It is essential that the artifacts be materially embodied so as to transform the semiotic array of EXMF and become a sign on the basis on which a subsequent leap of inquiry can be accomplished; without external embodiment the double stimulation would not work and assist in bringing about novelty.

Learners participating in CSCL experiments are in a similar situation to that of the children investigated by Vygotsky: while starting to pursue their inquiry, they encounter challenging learning tasks that cannot be solved without using meditational means. They have to appropriate, through participating in educational practices, various instruments and methods and eventually use them as a second stimulus. Nevertheless, as Rasmussen and Lund (20082008, p. 390) suggest, in order to use double stimulation in CSCL, one needs "to align this principle with situations where we have a series of complex tools as second stimulus," instead of a neutral relatively stable tool as was the case in Vygotsky's experiment. Moreover, CSCL environments often offer a multiplicity of tools so that investigating "which tools are actually picked up and appropriated by learners and how they put them to use for object-oriented endeavors" (Lund & Rasmussen, 2008) is a foundational issue. In fact, educational environments often consist of systems of tools that can be arranged in different ways and used at different times in the learning process. Investigating students' and teachers' strategies of tool selection and tool use appears to be a promising area of research that may be explored according to the theoretical perspective presented in this paper.

The creative process of double stimulation involves, then, turning the artifacts (which constitute the ESSS) to instruments (Béguin & Rabardel, 2000, see Virkkunen, 2006) of participants' inquiry.

Rabardel argued that the process of appropriating and integrating external artifacts as instruments of human activity is a developmental process (for a description of Rabardel's approach, see Lonchamp, this issue) described in terms of two dimensions: instrumentation and instrumentalization. "Instrumentalization" refers to the "technical/material part" of instrumental genesis, i.e., the emergence and evolution of the artifact to support activity in a local cultural context. Available cultural tools have to be adapted to local needs and purposes of the activity; a potential for flexible adaptation and customization is, of course, a central characteristic of ICT. In CSCL context, this has involved both tailoring hardware and software to support inquiry projects in question and structuring associated activities. "Instrumentation," in turn, is related to the "human part" of instrumental genesis and involves gradual formation and evolution of scripts (Schank & Abelson, 1977) and schemas (Piaget, 1985) for using the instrument in question in practice. One of the strengths of this conceptualization is that Rabardel examines both the transformation of the external artifact and the transformation of the user in instrumental genesis. Indeed, productive utilization of epistemic mediation in learning and inquiry presupposes sustained efforts to use associated technologies in practice and cultivation of required personal skills and practices. In our view, the basics of double stimulation investigated by Vygotsky correspond roughly to the first level of instrumental genesis in Rabardel's theory. Indeed, at the first level of instrumentalization "an instrument is momentarily instrumental-ized for a particular action" (Lonchamp, this issue), so that a relatively neutral stimulus is transformed into a relevant tool. Beyond this "situational" aspect, instrumentalization involves linking the instrument permanently to a category of situations and transforming it to perform the new functions in a certain type of situation. Through the process of instrumental genesis, technological artifacts that initially were at the centers of conscious attention (their exploration being the object of activity) gradually become tools that are used automatically and, partially, an invisible background; the participants become aware of these tools only when encountering disturbances and breakdowns of activity (object-tool dialectics, Engeström, 1987).

In light of these considerations, it appears useful to expand the Vygotskian notion of double stimulation to consider extended processes of knowledge creation. Such processes involve expansive stimulation (Barowy & Jouper, 2004; Virkkunen & Schaupp, 2011, see also Stetsenko, 2005) in respect of going through a complex process of internalization and externalization and creating a whole series of materially embodied epistemic artifacts in parallel with reshaping internally represented knowledge. Collaborative pursuit of epistemic artifacts piggybacks the advancement of young students' inquiry within knowledge-building classrooms by capitalizing on double stimulation. The epistemic artifacts created appear to have "pointers" (hints, implicit directions) regarding what is missing from the picture; thereby intuitively suggesting which ways to look and how to focus further inquiries (Knorr-Cetina, 2001). In the course of activity, epistemic artifacts may become instruments for subsequent inquiry efforts, making them a part of the invisible background of activities intuitively guiding and constraining further inquiries (Engeström, 1987). By using the created epistemic artifacts as stepping stones for reaching deeper knowing and understanding, an inquirer and his or her community may gradually break their epistemic boundaries. From this perspective, knowledge creation may be seen as a process of building a bridge across a river so that earlier rocks (epistemic artifacts) are used as a basis for laying new ones (novel epistemic artifacts) until one has created a dynamic pathway from older (initially known) to newer knowledge and understanding (initially unknown). Learners may appropriate knowledge-building practices to the extent that pursuit of epistemic mediation relevant for knowledge creation becomes their second nature, i.e., an integral aspect of their activity system. Sustained participation in such process is not cognitively neutral; going through a long series of double stimulation processes that involve creating epistemic artifacts massively reformats and restructures the participants' minds (comparable to representational redescription, Karmiloff-Smith, 1992) across long-standing efforts. Sustained expansive stimulation is likely to elicit maximal cognitive adaptations (Ericsson & Lehmann, 1996) that play an important role in formation of the long-term working memory (Ericsson & Kintsch, 1995); such adaptation transforms the cognitive architecture of a participant through providing a virtual space for experts' complex cognition.

We consider Rabardel's theory extremely relevant for CSCL research because we have had a tendency to underestimate challenges and constraints involved in instrumental genesis. Rabardel's approach to instrumental genesis highlights the importance of developmental processes involved in appropriating technology-mediated practices of learning and instruction. In this regard it appears to come close to ideas and visions of the pragmatic web (see Hakkarainen, Engeström, Paavola, Pohjola, & Honkela, 2009 for references) that underscore the crucial role of social practices in using technology for gradual learning and socialization for using ICT. With respect to technology-use-practices, the present discourse of information and communication technologies is biased in respect of focusing, as the term implies, either on the information-transmission genre or social-communication genre. Otherwise attractive visions regarding the emergence of collectively intelligent Metaweb (Nova Spivack[3]) are "flat" because it is assumed to arise from increased information connectivity, on the one hand, and social connectivity, on the other hand. The pragmatic web guides one to examine social practices related to the historical-developmental use of technology, as the topography or third dimension of the Metaweb, a dimension that reveals an extremely rough terrain of the surface. Going through instrumental genesis in learning to use a new technology and appropriating associated scripts initially requires so large an investment of both personal and collective efforts that it can be compared to climbing to the top of a steep mountain. Required cognitive adaptations do not take place without an extended effort of adapting, tailoring, and reformatting technology-mediated competences. After going through such an extraordinary effort, the participants may be reluctant to start climbing another mountain without very good reasons for doing so; it is always easier just to slide down the familiar hill in terms of relying on already mastered ICT. Personal appropriation of even relatively simple technology, such as email, is initially challenging because it requires appropriating new social practices in gradually adapting and changing one's cognitive-cultural operating system of activity.

Instrumental genesis may be studied at personal, community, or collective levels. Transformations, at the personal level, of competencies of using ICTs are, of course, crucial. Skills and competencies of using ICTs in general and CSCL environments in particular, which emerge through genesis of a transformed cognitive-cultural operating system and enable participation in creative personal and educational activity, are called technological fluency (Barron, 2004, 2006). Technological fluency emerges on the condition that participants have appropriated ICT tools as "intellectual prostheses" (Clark, 2003) to support their personal learning, peer collaboration, social networking, and creative working with knowledge. Technological fluency implies that ICTs are used as flexible tools of personal and collective activity. Only after teachers and students have developed novel practices of using ICTs as instruments for pursuing their epistemic objectives and cultivated corresponding knowledge practices, are significant advantages of educational technology likely to emerge. Barron (2006) stated that the development of technological fluency requires agentic efforts in building self-sustained networks of learning by integrating school knowledge with extended authentic knowledge sources and disciplinary systems; actively seeking connections with tools, practices, and knowledge of expert cultures; and various actors capable of supporting and mediating learning efforts. It appears also that only technologically fluent teachers are able to stretch technology to support their pedagogical goals and purposes.

Remediating practices of classrooms or whole schools by ICT appears many degrees more challenging than transformation of personal practices. The specific challenge of CSCL is to have a whole, heterogeneous, and often unwilling learning community appropriate shared CSCL technologies and

[3] See http://novaspivack.typepad.com/nova_spivacks_weblog/2004/04%20/new_version_of_.html.

corresponding knowledge practices. It is difficult to get a whole community to climb to a mountain rather than to do it individually, only by themselves. The exact route cannot be planned beforehand; participants need to learn, improvisationally, to negotiate partially unforeseen challenges and obstacles. As explained in the section addressing collaborative emergence, the transformation is difficult because there are no ways of moving straightforwardly from present to new practices; an iterative and expansive process of transforming practices, gradually, step by step in the desired direction is needed (Engeström, 1987). Human beings cannot directly change their cognitive-cultural operating systems; transformations take place gradually through interacting practical exploration and reflection supporting directed evolution of technology-mediated practices. Consequently, technology-mediated practices of learning and instruction consolidate very slowly, and advancements tend to take place in courses and practices of exceptionally enthusiastic and committed teachers with a high level of technological fluency (Barron, 2004). Because such teachers are not common and many are reluctant to use ICTs, technology-mediated practices of even the best schools are likely to remain very heterogeneous across long periods of time.

Although it is not realistic to expect profound overall transformations of educational practices to take place in the short run, some groups of students and teachers are likely to appropriate new ICT tools, go through personal developmental learning processes, and cultivate “information ecologies” (Nardi & O’Day, 2000), i.e., local practices and innovations of using technology. To summarize, technological artifacts become instruments of human activity only through sustained and iterative efforts of using them in practice, a process through which the cognitive-cultural operating system of activity gradually transforms and adapts according to evolving practices of using technologies. This evolution is reflected in deep-level changes in mental processes, such new capabilities being, in effect, cognitive prostheses adapted to changed modes of learning and creating knowledge. Such technologies are themselves being developed and tailored to requirements of activity.

The Space-Time of Technology-Mediated Learning Practices

The view of technology-mediated learning proposed in this paper prioritizes external processes and the role of the context in cognition. In particular, we consider double stimulation and instrumental genesis as the basic principles that explain how artifacts constitute external memory fields and exert epistemic mediation. Rather than being a simple part of an observable physical space, we consider EXMF part of a dynamic semiotic field that intersects the boundaries of mental, virtual, and social spaces of activity (Nonaka & Konno, 1998). In order to describe such a dynamic space, we use the concept of heterotopia. *Heterotopia* was described by Foucault (1967) as “juxtaposing in a single real place several spaces, several sites that are in themselves incompatible.” The examples chosen to illustrate this concept are theaters, cinemas, libraries, or ships. This concept led Foucault to predict the birth of a “heterotopological science.” If it is applied to our context – education – we may consider the schools and universities as highly complex heterotopias in which heterogeneous physical, relational, organizational, cultural, and virtual spaces overlap and alternate. As in a cinema, where the audience and screen spaces overlap, or in a library, where the physical space overlaps with both the timeless space of the written pages and the “historicized” space of the culture laid down within those pages, so in a university, we can see a complex overlap of heterogeneous spaces. These spaces exist, both in the classroom and in other working spaces – laboratories, textbooks, computer labs, or informal meeting places such as the corridors or the playground.

Learning environments, then, are heterotopias in which multiple EXMF are generated, relying on different types of media. We consider a medium as a space-type within a heterotopia, which mediates the semiotic processes at stake in learning activities and permits the generation of EXMF. As argued above, new media drastically transform the heterotopia that previously consisted of more stable symbolic spaces (initially clay, then papyrus, paper, and so on), bringing ESSSs that are qualitatively different from old ones, especially in terms of workability and shareability of epistemic artifacts. In this sense, digitalization brings a revolution that involves essentially the "medium" (Rückriem et al., 2011). Learning environments involving ICT are often multimedia, so that students and teachers are embedded in a diversified heterotopia filled with semiotic resources of different types.

Therefore, educational activities can be said to be laminated (Prior, 1998) thanks to the heterogeneity, multimodality, and multimedia triggered by the coexistence and by the alternated and/or the combined use of many tools and artifacts. Those artifacts generate multiple semiotic resources useful for the activity and used in a coordinated way by researchers. Besides the spatial frame (semiotic field distributed in tools), also the time frame (in terms of typical ways to organize temporally actions) of the activity is impacted by the features of media. In order to deal with the space-time relations as they are changed by the presence of new media – which introduce, in human relations, changes of proportion, rhythm, or schema (McLuhan & Lapham, 1964) – we use the concept of *chronotope* (Bakhtin, 1981) that permits us to propose a perspective on knowledge creation that is able to capture how the spaces of interaction offered by the instruments impact the temporal organization of the activity and how the management of the work time impacts the selection and the use of different tools. In other words, there is a strong relationship – investigable through the use of the concept of chronotope – between the way in which people organize their time and the way in which they organize (dynamically) the space (full of tools and artifacts) in which activity is embedded. We argue that by carefully investigating those spatial and temporal configurations of technology-mediated practices and how they change over the instrumental genesis process, one may achieve a deeper understanding regarding how new technologies can productively be implemented in educational and knowledge-intensive activity. Although there is research about either space or time in knowledge-creation settings, the way in which these dimensions are interrelated with each other has not been on the agenda of scholars.

The concept of chronotope was originally devised by Bakhtin (1981) for understanding how literate genres of novels define specific ways of interconnecting spatial and temporal relations. Adapting the concept to our investigations, we define chronotope in ICT-mediated activities as the emergent configuration of temporal and spatial relations in knowledge-creation practices as they are impacted by ICT. In fact, the entire flow of activity, in terms of temporally organized sequences of actions undertaken by subjects, is impacted by the use of different types of technology. As shown by Norman (1994), the use of an instrument requires the accomplishment of temporally layered procedures and practices that differ significantly from the practices carried out while using a different instrument for the same purpose. The spatial transformation related to the use of ICT, instead, involves (1) sharing inquiries regardless of location and making remote information sources immediately accessible and (2) interacting with qualitatively different external resources that provide subjects with spaces of interaction organized in multiple ways. Suffice it to think of the difference between the ways in which books are organized in a library from the way in which they are organized in Google Books. Technology-mediated practices of working with knowledge, then, both transform the flow of activity and bring qualitative changes when dynamic ICT-based tools are integrated as instruments of activity. Following Bakhtin, we consider these spatial and temporal processes to be fused: chronotope invokes a whole, so that "reciprocal impact" of space and time is an approximation in the understanding of the process.

An examination of the chronotope of technology-mediated learning is important because ICTs break many traditional spatial and temporal boundaries of human activity. From our perspective, research on CSCL has serious lacks if it merely focuses on either providing an account of here-and-now practical activity and associated social interaction or analyzing the content of textual artifacts (and ideas involved) generated. In order to obtain comprehensive understanding of the chronotope in technology-mediated learning, such learning has to be studied as multimodal and "laminated" (spatiotemporally layered) activity (Prior, 1998) in which social practices related to epistemic mediation play a crucial role. Following a similar thread from the perspective of classroom pedagogy, Brown and Renshaw (2006, p. 249) have shown how pupils' participation in classroom activities is linked to the way in which they discursively shape "the space-time context of the classroom" and to the way they "ground" their thoughts. In our perspective, we designate chronotope as the emergent pattern of spatial and temporal structure and arrangement of activity within a computer-supported community. Being at the intersection between space and time, it has been characterized elsewhere by a musical metaphor for the analysis of the tempo of the flow of activity. So, three chronotopes have been identified, related to different rhythms emergent in collaborative interaction (Ligorio & Ritella, 2010): (1) adagio, characterized by a slow flow of the activity; (2) andante, characterized by an acceleration in the flow of the activity; and (3) allegretto, in which the configuration of participation allow a fluid and dynamic course of actions. Some specific features such as the "the depth and the size of the space of interaction" and "how participants move around the computer and within the digital space" play an important role in the emergence of chronotope (Ligorio & Ritella, 2010).

Moreover, as we argued previously, the creation of epistemic artifacts impacts the entire practice of knowledge creation and the underlying cognitive processes by altering the space-time structure of knowledge creation. Knowledge-creating inquiry is mediated by deliberate construction of epistemic artifacts that crystallize the participants' intellectual processes; the evolving network guides subsequent participants' inquiry efforts. The temporal structure of activity is transformed at a very fundamental level in this process. In fact, technology-mediated collaborative learning impacts the context of learning, providing participants with amplified semiotic resources based on integrated and partially merged physical, virtual, social, and mental spaces of activity. Pursuit of such artifacts also entails cultivation of corresponding social practices that channel the participants' activities in a way that elicits advancement of inquiry; hence ICT-mediated knowledge practices may define certain chronotopes that allow deliberate collaborative pursuit of knowledge advancement. As mentioned above, expansive stimulation is an integrated aspect of such advancement in that epistemic artifacts provoke a long series of double-stimulation experiences that guide the further direction of inquiry (Hakkarainen et al., 2009). The following principal features appear to characterize the chronotope of knowledge practices for technology-mediated learning:

- The chronotope is marked by changes in the tempo of the ongoing activity and occasional spatiotemporal intensification of collaborative activity, and it permits us to explain variation in the pace as well in the emerging organization of the collaborative process (Ligorio & Ritella, 2010);
- The chronotope of knowledge-creating learning is mediated by collaborative technology, such as Knowledge Forum, that amplifies and expands the possibility of inquiry of a physically present learning community, generating "blended learning communities" (Ligorio & Sansone, 2009). While other types of virtual learning may have their own chronotopes, they are not the focus of the present investigation.
- The architecture of sophisticated technology-mediated learning is that of a literate culture; consequently epistemic mediation plays a crucial role in the corresponding chronotope. Epistemic mediation is the principal mechanism of temporal integration between past, present, and future. Thanks to text durability and workability enhanced by ICTs, past inquiries crystallized in epistemic artifacts transform current distributed problem space and provide anticipatory guidance for directing future inquiry.
- Simultaneously, the chronotope of technology-mediated learning is heterogeneous and multimodal in nature. It follows that epistemic mediation should not be examined only as an actual production of texts because it involves actions hybridizing and intermixing modalities and medias. Typically, discursive activities also involve successive periods of reading and writing, searching information

and exchanging emails, thinking and talking, drafting and reviewing, intensive writing and taking a break, and solo and collaborative working. Writing taking place in CSCL is laminated/layered in respect of taking place in the context of heterogeneous network activities from field trips to classroom experiment, library visits, Internet searches, and so on.

- The chronotope of technology-mediated learning is also laminated with respect to being locally improvised in conjunction with being mediated by sociohistorically developed genre, technology-based instruments, and educational practices (Prior, 1998). So, while the chronotope may be examined in terms of situational and improvised here-and-now activities, it is essential also to address not only micro- but also meso- and macro-level fluctuations and transformations of activity. As explained below, a chronotope of mature inquiry is a developmental achievement that emerges collaboratively through sustained collective efforts.

Collaborative Emergence of Innovative Knowledge Practices

Despite two decades of intensive efforts, methods and practices of technology-mediated collaborative learning have not yet fully penetrated educational systems in Finland, Europe, or elsewhere. This is partially because there were neither the required technological infrastructure nor human capital (teacher competence) when the practices of technology-mediated learning were first promoted in the 1990s. Although the situation has radically changed in respect of building information networks and training, new generations of teachers who are familiar with ITC, technology-intensive practices of learning and instruction, have not become predominant, beyond exceptional communities and schools. It appears to us that beyond institutional and structural reasons, ICTs in general and CSCL technologies in particular have not penetrated the educational system because CSCL researchers – including the present investigators – have underestimated the in-depth challenges associated with instrumental genesis at the personal and collective levels. In particular, we have argued for the necessity to understand the transformations that the ICTs bring in the space-time of learning activities and for the requirement of transforming the cognitive-cultural operating system to capitalize on the resources that the new contexts of learning offer. Further, the problem of developing cultural practices of learning that trigger meaningful pedagogical uses of technology has not yet been successfully addressed.

In many cases, participants in our CSCL experiments have been expected to appropriate educational technologies provided and to find meaningful practices for using them, without questioning preexistent practices of schooling or reflecting on the role that every technology plays in transforming the context of education. When there are no sufficient opportunities to socialize to the use of technology, it remains as a weakly integrated external tool that does not mediate participants' overall activity. Many CSCL studies focus on one-shot experiments in which a group of students both has to learn a novel pedagogy (knowledge-building inquiry) and remediate their activities with a collaborative technology. The temporal scope of the experiment is, in many cases, such that the participants cannot truly go through the expansive learning required for instrumental genesis, transformation of the participants' cognitive-cultural operating systems, and cultivation of novel technology-mediated collaborative practices of working creatively with knowledge. When ICTs are starting to be used, traditional school learning is likely to prevail with associated personal roles and responsibilities, individual learning tasks and assessments, and patterns of asking fact-seeking questions and reproductive use of information sources. The technology is initially likely to represent a mere additional layer of activity, and its usage easily involves excessive copying of knowledge. Rooting innovative inquiry practices within a learning community requires sustained iterative and expansive efforts of cultivating shared practices that channel, spatiotemporally, the participants' effort in a way that elicits advancement of inquiry. Although it may be difficult to go through personal and social transformations that the initial rise of innovative technology-mediated knowledge practices requires, new cohorts or generations of students may be directly socialized to advanced inquiry practices that channel their activities in a way that elicits in-depth inquiry, epistemic mediation, collaborative sharing of knowledge, and so on (Hakkarainen, 2003). We argue that all successful cultures of CSCL are simultaneously also expansive learning communities (Engeström, 1987) focused on problematizing current practices, envisioning changes, and gradually, step-by-step, consolidating novel inquiry practices (Hakkarainen, 2004; Hakkarainen, Bollström-Huttunen, & Hoffman, 2008).

The development of practices concerning innovative knowledge-creating inquiry is, then, a collaboratively emergent process (Sawyer, 2005), seldom analyzed by investigators who either pursue one-shot experiments or describe locally created, mature, inquiry cultures. Collaborative emergence is a methodological perspective for studying the dynamic and fluid, recursive, and iterative aspects of inquiry and evolving knowledge practices (Sawyer, 2005). Detailed multilevel developmental or longitudinal data on transformative personal and collective activities are needed to account for such dynamic emergent processes. In fact, directed evolution of practices is elicited by selectively consolidating ephemeral (temporally varying patterns of using collaborative technologies and participating in relation to evolving themes and contexts) as well as stable (emerging local practices of using ICTs, stabilizing group cultures, enacted discursive practices, collective memory inquiry efforts) emergent possibilities for technology-mediated learning. Through sustained collaborative improvisation, ideas, artifacts, methods, and practices that do not belong to any one of the individual participants emerge situationally and interactionally from self-organized collaborative processes (Fleck, 1979). Tensions, ruptures, breakdowns, and discontinuities of activity may be seen as important signs of the collaborative emergence of novelty (Engeström, 1987). Emerging novel elements or aspects of activity break the smooth flow of activity down and push the participants personally or collectively to explore novel possibilities, transform prevailing instruments and practices, and utilize resulting changes in the situation in order to find opportunities to move inquiry forward (Wertsch, 1998). The collaborative emergence of new chronotopes and new knowledge practices may be studied at micro-, meso-, and macro-levels. The microlevel involves analyzing real-time improvisational activity; the meso-level addresses collaborative emergence in pursuing an inquiry project as a whole; and the macro-level involves expansive learning across generations or evolving networks of projects (Blunden, 2010). Through projects, ephemeral possibilities that need to be recognized, utilized, extended, and stabilized so as to advance inquiry emerge collaboratively.

Technological and social innovations are interdependent (Batane, Engeström, Hakkarainen, Newnham, & Virkkunen, submitted; Perez, 2002; Venkatraman, 1994). Arrival of novel technological innovations encourages hyperintensive investment in building infrastructure of technology-mediated activity. Despite some educators' illusory hopes of solving persistent educational problems, new ICTs are initially used to promote traditional practices of teaching and learning. Only after appropriating and using technologies through intensive iterative efforts for multiple purposes, do radical transformative possibilities start emerging, ones that change the logic and scope of prevailing activities. Going through successive waves or generations of technology-intensive practices of learning and teaching, which involve criticizing and rising above preceding approaches, appears to play a crucial role in ICT-related educational transformations. Although it is not realistic to expect profound overall transformations of educational practices to take place quickly, those communities of students and teachers which are engaged in expansive learning efforts are likely to appropriate new ICT tools, go through personal and collective transformation processes, and cultivate "information ecologies" (Nardi & O'Day, 2000), i.e., local practices and innovations of using technology. In order to elicit expansive learning, it is essential to engage participants in practical activities, which gradually integrate the use of CSCL into shared knowledge practices (Béguin & Rabardel, 2000). On one hand, this impacts on the perception and the arrangement of the physical and symbolical space of knowledge practices. On the other hand, it requires practice to adapt to a new space and the new time perspective associated with it. Initially fragile and error-prone activities become more stable after corresponding operations and actions become consolidated and the participants' capacity to troubleshoot ruptures and breakdown improves. Although the participants are likely to be initially dependent on guidance provided by visible ICT-mediated objects, structures, and processes, such are gradually replaced by anticipatory response to the likely progress of the situation.

Discussion

The sociocultural foundations of technology-mediated collaborative learning were addressed in the present paper. In particular, we showed some interconnections between theoretical ideas and traditions that may serve complementary roles in research on technology-enhanced learning. We examined the role of epistemic mediation in knowledge-creating inquiry and the importance of the process of instrumental genesis for integrating CSCL technologies with shared inquiry practices. We argued that the cognitive extension and the cumulative expansive stimulation provided by epistemic mediation play a crucial role in complex cognition; consequently, it is of strategic importance to put corresponding knowledge practices in the center of technology-mediated learning. We also emphasized that because ICTs are transforming the learning context, changes of the spatial and temporal frames of learning practices need to be addressed in order to knowledgeably manage the implementation of new educational environments. Dealing with these issues constitutes the integrated agenda of research we are undertaking.

From the sociocultural perspective, it is essential that students engage in using collaborative technologies, creating shareable external digital artifacts for supporting collective knowledge building and personal learning, because this permits them to exploit both the advantages of participating in a dynamic literate culture and the advantages that new media may provide to such cultures (especially thanks to the shareability and workability of semiotic resources that they allow). Scardamalia and Bereiter's (2006) research and development of technologies and practices of knowledge building, aimed at the collectivization of learning and inquiry, have played a pioneering role in this regard. Knowledge building is not, however, only a matter of creating, elaborating, and sharing ideas; CSCL environments appear to be children of hybridization, providing material technology for sustained working with shared digital (but objectified and materially embodied) artifacts (Hakkarainen, 2009).

There appears to be discontinuity between CSCL studies that report failures of developing productive practices of using collaborative technologies and those reporting activities of mature CSCL cultures. What appears often to be left between these extreme poles is the instrumental genesis – i.e., temporally extended developmental process through which collaborative technologies become instruments of the participants' activities (Rabardel & Bourmaud, 2003). Technology appropriation is difficult because instead of learning discrete and well-specified skills, it requires adapting and changing the cognitive-cultural operating system both at personal and collective levels. Cultivation of knowledge-building practices implies, among other things, extending cognitive resources by deliberately capitalizing on epistemic mediation, i.e., using CSCL environments as instruments for externalizing ideas to digital artifacts, forming evolving networks intentionally used as a stepping stone of advancing inquiry. The participants have to go through a messy struggle of learning to use writing as an instrument for solving problems, thinking, and extending knowledge (Prior, 1998; Russell, 1997). Changing core epistemic aspects of human activity that epistemic mediation and fruitful participation in knowledge building appear to require is not possible without extended participation in cultivating corresponding knowledge practices. Going through the transformation is easier if a participant has an opportunity to gradually socialize and grow up into established and consolidated technology-mediated social practices cultivated by advanced knowledge-building communities. We have these kinds of deeper transformations in mind, when we argue that technology enhances learning only through transformed social practices. Participants have to be able to personally, as well as collectively, align their epistemic activities with technology-mediated pursuit of collaborative inquiry.

Many studies of CSCL are biased because they either focus on shallow here-and-now interaction or they analyze mere ideas (contents of epistemic artifacts) created by participants.

Although it is relatively easy either to categorize knowledge produced in CSCL environments' databases or videotape activities with computers, it is much more difficult to analyze instrumental genesis and collaborative emergence developmentally across multiple timescales (Lemke, 2001). We are too often carrying out one-shot experiments or relying on retrospective generalizations on past technology-mediated activities (Reis & Gable, 2000). Consequently, only a few investigations have revealed the heterogeneity, hybrid spaces, and multimodality of enacted CSCL practices or provided rich and multifaceted descriptions of the longitudinal emergence of innovative inquiry practices. Instead, we have descriptions of poor CSCL implementations in which novel epistemic practices did not have time to emerge, as well as static analyses of mature inquiry cultures that take almost no account of the developmental processes. In order to make progress, it appears essential to initiate developmentally oriented investigations of participants appropriating ICTs as tools of learning and teaching; such studies should aim at acquiring deeper understanding of associated challenges of personal and social learning (Williams, Stewart, & Slack, 2005).

Some of our own investigations involve collecting both longitudinal video data of CSCL practices in conjunction with teacher's reflective diaries and database data; such bodies of data allow one to trace the emergence of collaborative learning and design processes (Viilo, Seitamaa-Hakkarainen, & Hakkarainen, 2011). In order to provide an account of collaborative emergence of knowledge-creating practices, multilevel longitudinal data have to be collected. Such data involve real-time video data of enacted classroom practices, screen recordings of ICT-mediated inquiries, contextual sampling of students and teachers' reflective self-reports (e.g., project diaries (Bolger, Davis, & Rafaeli, 2003), analyses of contents and processes of artifacts in a CSCL environment's database, CSCL log files, and possible pre- and posttest measures. It is essential to develop instruments and methods of repeatedly and contextually sampling technology-mediated activities and associated user experiences (Muukkonen et al., 2009). On the basis of these kinds of considerations, we are planning to engage in major efforts in following instrumental genesis from primary to higher education level by collecting multilevel qualitative and quantitative data of technology-mediated learning and instruction (data of teachers, students, parents, classrooms, school, and neighborhood). Within the frame of an overall longitudinal follow-up study, we will carry out and investigate pedagogic effects of CSCL interventions. Embedding CSCL studies in such broad investigative frames appears to be essential for providing a proper account of instrumental genesis, collaborative emergence, and psychosocial effects of technology-intensive knowledge practices.

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Investigation 8. Thinking as Communicating: Human Development, the Growth of Discourses and Mathematizing

Gerry Stahl

Abstract

Sfard's book, reviewed here, describes the discursive construction of math objects as a foundation for understanding how students learn mathematics. It defines a math object as a recursive tree of its manifold visual realizations and provides a set of concepts for analyzing its construction. By reconceptualizing thinking as communicating, Sfard suggests a promising path for researching and analyzing CSCL approaches to math education.

Keywords

Acquisition metaphor · Deep understanding · Participation metaphor · Realization · Reification · Routine

Anna Sfard raised the methodological discourse in the CSCL community to a higher niveau of self-understanding a decade ago with her analysis of our two prevalent metaphors for learning: the acquisition metaphor (AM) and the participation metaphor (PM). Despite her persuasive argument in favor of PM and a claim that AM and PM are as incommensurable as day and night, she asked us to retain the use of both metaphors and to take them as complementary in the sense of the quantum particle/wave theory, concluding that

> *Our* work is bound to produce a patchwork of metaphors rather than a unified, homogeneous theory of learning (Sfard, 2008, p. 12).

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G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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A first impression of her new book (Sfard, 2008) is that she has herself now come closer than one could have then imagined to a unified, homogeneous theory of learning. It is a truly impressive accomplishment, all the more surprising in its systematic unity and comprehensive claims given her earlier discussion. Of course, Sfard does not claim to give the last word on learning, since she explicitly describes how both learning and theorizing are in principle open-ended. One could never acquire exhaustive knowledge of a domain like math education or participate in a community culture in an ultimate way, since knowledge and culture are autopoietic processes that keep building on themselves endlessly.

Sfard does not explicitly address the tension between her earlier essay and her new book. To reconcile her two discourses and to assess their implications for the field of CSCL, one has to first review her innovative and complex analysis of mathematical thinking.

Understanding Math Objects

Sfard introduces her presentation by describing five quandaries of mathematical thinking. I will focus on just one of these, which seems particularly foundational for a theory of math cognition, although all are important for math education: What does it mean to *understand* something in mathematics? Sometimes we ask, What is *deep understanding* in math (as opposed to just being able to go through the procedures)? I am particularly interested in this question because in my research group we are observing the chat of an algebra student who repeatedly says things like, “the formula makes sense to me…but I do not see why it should either” (see chat screenshot in Fig. 8.1). For us as analysts, it is

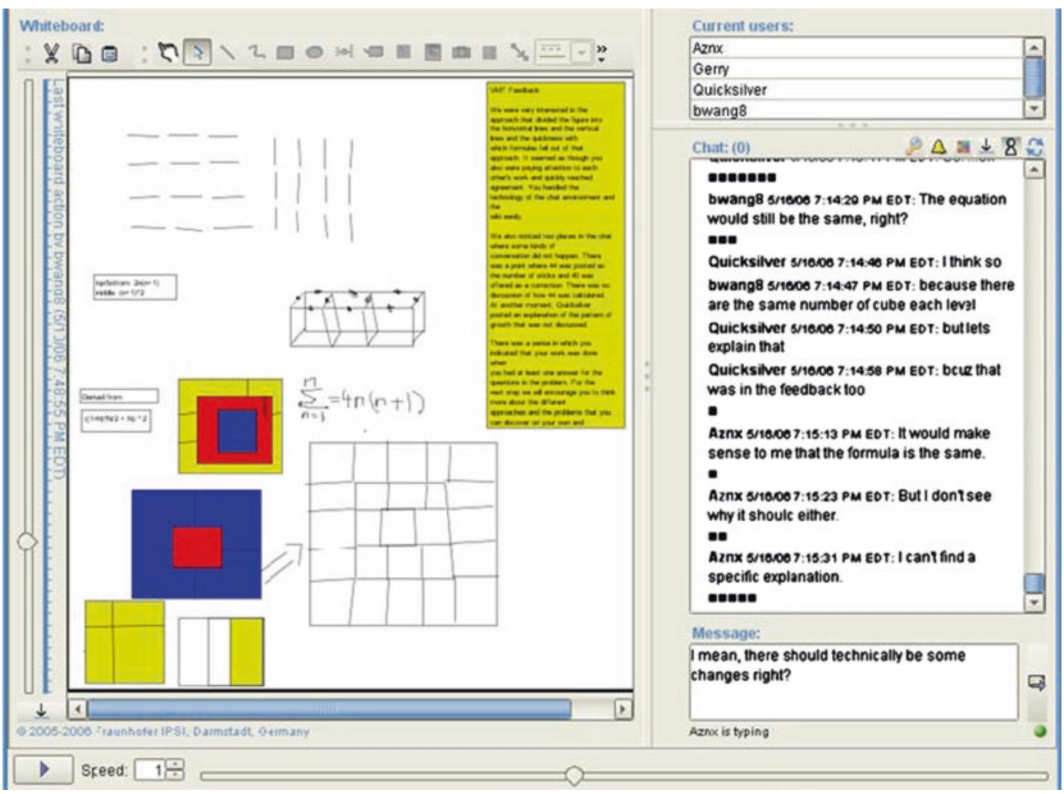

Fig. 8.1 Three students chat about the mathematics of various formations of stacked blocks. Aznx expresses uncertainty about his understanding of Bwang’s proposal about a formula and his ability to explain the formula in response to Quicksilver

hard to know how Aznx cannot see why the equation is right if it makes sense to him; the nature of his understanding seems to be problematic for him as well as for us. One assumes that either he "possesses" knowledge about the applicability of the formula or he does not.

According to Sfard's theory, a math object—like the equation that Bwang is proposing in the chat for the number of blocks in stage N of a specific kind of pyramid—is an *objectification* or reification of a discursive process, such as counting the blocks at each stage (see also Wittgenstein, 1944/1956, p.3f, §3). In fact, we observe the team of students in the chat environment visibly constructing the pyramid in their shared whiteboard. Looking through Sfard's eyes, we can watch the students counting in a variety of ways, sometimes by numbering the graphical representations of blocks, other times by referencing shared drawings of the blocks from the chat postings, or by coordinating the sequential drawing of arranged blocks with the chat discussion in ways that make visible to the other students the enumeration of the pattern.

Sfard's central chapters spell out the ways in which math objects are subsequently co-constructed from these counting communication processes, using general procedures she names *saming*, *reification*, and *encapsulation.* Note, for instance, that Bwang is explicitly engaged in a process of saming: claiming that a set of already reified math objects (previous and current equations the students are discussing) are "the same." He states, "The equation would still be the same, right? Because there are the same number of cube[s on] each level." He has reified the counting of the blocks into the form of a symbolic algebraic expression, which looks like an object with investigable attributes, rather than a discursive counting process. If he were a more expert speaker of math discourse, Bwang might even encapsulate the whole set of same equations as a new object, perhaps calling them *pyramid equations.* And so it goes.

In our case study, Aznx, Bwang, and Quicksilver engage in four hours of online collaborative math discourse. They consider patterns of several configurations of blocks that grow step by step according to a rule (see also Moss & Beatty, 2006). They develop recursive and quadratic expressions for the count of blocks and number of unduplicated sides in the patterns. They decide what to explore and how to go about it, and they check and question each other's math proposals, collaboratively building shared knowledge. Their group knowledge[1] is fragile, and the team repeatedly struggles to articulate what they have found out and how they arrived at it and was encouraged to explain their work by the facilitator, who placed the textbox of feedback in their whiteboard. During their prolonged interaction, the group creates a substantial set of shared drawings and chat postings, intricately woven together in a complex web of meaning.

Sfard describes the discursive construction of math objects, which—as Husserl (1936/1989) said—is *sedimented* in the semiotic objects themselves. To paraphrase and reify Sfard's favorite Wittgenstein quote,[2] the use (the construction process) is embodied in the sign as its meaning. She lays out the generative process by which a tree of *realizations* is built up through history and then reified by a new symbolic realization that names the tree. The algebraic equation that Bwang proposes is one such symbolic expression. The students have built it to encapsulate and embody various counting processes and graphical constructions that they have produced together. The equation also incorporates earlier math objects that the group has either co-constructed or brought into their discourse from previous

[1]The use of the term group cognition for referring to the discursive methods that small groups collaboratively use to accomplish cognitive tasks like solving problems often raises misunderstandings because readers apply AM when they see the noun cognition. They wonder where the acquired cognitive objects are possessed and stored, since there is no individual physical persisting agent involved. If one applies PM instead, in line with Sfard's theory, then it makes much more sense that discursive objects are being built up within a publicly available group discourse.

[2]"For a large class of cases—though not for all—in which we employ the word 'meaning' it can be defined thus: the meaning of a word is its use in the language." (1953, p. 20, §43).

experience (e.g., Gauss' formula for the sum of *N* consecutive integers, previously learned in their math classrooms).

A centerpiece of Sfard's theory is the definition of a math object as the recursive tree of its manifold visual realizations. I will not attempt to summarize her argument because I want to encourage you to read it first hand. It is presented with all the grace, simplicity, insight, and rigor of an elegant mathematical proof. It is itself built up from quasi-axiomatic principles, through intermediate theorems, illustrated with persuasive minimalist examples.

It is this definition of math object that, I believe, provides the germ of an answer to the conundrum of deep math understanding, that is, to understand a math object is to understand the realizations of that object. One must be able to unpack or de-construct the processes that are reified as the object. To be able to write an equation—e.g., during a test in school, where the particular equation is indicated—is not enough. One must to some extent be able to re-create or derive the equation from a concrete situation and to display alternative visual realizations, such as graphs, formulas, special cases, and tables of the equation. There is not a single definition of the equation's meaning but a network of interrelated realizations. To deeply understand the object, one must be conversant with multiple such realizations, be competent at working with them, be cognizant of their interrelationships, and be able to recognize when they are applicable.

Routines of Math Discourse

Sfard then moves from ontology to pedagogy—from theory of math objects to theory of discourses about such objects, including how children come to participate in these discourses and individualize the social language into their personal math thinking. Based on her intensive work with data of young children learning math, she describes with sensitivity and insight how children come to understand words like *number*, *same*, and *larger* and other foundational concepts of mathematical cognition. It is not primarily through a rationalist process of individual, logical, mental steps. It is a discursive social process: not acquisition of knowledge but participation in co-construction of realizations. Sfard describes this as participation in social *routines*—much like Wittgensteinian language games. She describes in some detail three types of routines: *deeds*, *explorations*, and *rituals. Routines* are meta-level rules that describe recurrent patterns of math discourse. Like Sfard's discussion itself, they describe math discourses rather than math objects. *Deeds* are methods for making changes to objects, such as drawing and enumerating squares on the whiteboard. *Explorations* are routines that contribute to a theory, like Bwang's proposal.

Rituals, by contrast, are socially oriented. The more we try to understand Aznx's chat postings, the more we see how engaged he is in social activity rituals. He provides group leadership in keeping the group interaction and discourse moving, reflecting, explaining, responding to the facilitator, positioning his teammates, and assigning tasks to others. His mathematical utterances are always subtly phrased to maintain desirable social relations within the group and with the facilitator—saving face, supporting before criticizing, leaving ignorances ambiguous, checking in with others on their opinions and understandings, positioning his teammates in the group interaction, and assigning tasks to others. Each utterance is simultaneously mathematical and social, so that one could not code it (except for very specific purposes) as simply *content*, *social*, or *off-topic* once one begins to understand the over-determined mix of work it is doing in the discourse. Similarly, Bwang's explicitly mathematical proposals (explorations) are always intricately situated in the social interactions. Quicksilver often reflects on the group process, articulating the group routines to guide the process. Sfard's analysis helps us see the various emergent roles the students' participations play in their discourse—without requiring us to reduce the complexity of the social and semantic interrelationships.

Just as Vygotsky (1930/1978, 1934/1986) noticed that children start to use new adult words before they fully understand the meaning of the words (in fact, they learn the meaning by using the word), Sfard argues that children advance from passive use of math concepts to routine-driven, phrase-driven and finally object-driven use. They often begin to individualize group knowledge and terminology through *imitation.* Again, the part of the book on routines requires and deserves careful study and cannot be adequately presented in a brief review. I would encourage trying to apply Sfard's analysis to actual data of children learning math.

In our case, we see Aznx *imitating* his partners' routines and thereby gradually individualizing them as his own abilities. He often makes a knowledgeable-sounding proposal and then questions his own understanding. He does not *possess* the knowledge, but he is learning to *participate* in the discourse. In a collaborative setting, his partners can correct or accept his trials, steering and reinforcing his mimetic learning. During our 4 h recording, we can watch the group move through different stages of interaction with the symbols and realizations of math objects. The students we observe are not fully competent speakers of the language of math; as they struggle to make visible to each other (and eventually through that to themselves) their growing understanding, we as analysts can see both individual understanding and group cognition flowering. We can make sense of the discourse routines and interactional methods with the help of Sfard's concepts.

Participation in the discourse forms of math routines—such as exploration, ritual, and imitation—can expose students to first-hand experiences of mathematical meaning-making and problem-solving. As they individualize these social experiences into their personal discourse repertoire, they thereby construct the kind of deep understanding that is often missing from acquisitionist/transmission math pedagogies (see Lockhart, 2008, for a critique of the consequences of AM schooling).

Situating Math Discourse

Sfard's theory resolves many quandaries that have bothered people about participationist and group cognitive theories. How can ideas exist in discourses and social groupings rather than in individual minds? It provides detailed analyses of how people participate in the discourses of communities—at least within the domain of math discourses, both local and historical. It provides an account of some basic ways in which individual learning arises from collaborative activities. It indicates how meaning (as situated linguistic use) can be encapsulated in symbols. It explains how children learn, and that creativity is possible, while suggesting ways to foster and to study learning. It describes some of the mediations by which public discourses—as the foundational form of knowledge and group cognition—evolve and are individuated into private thinking.

Sfard has done us the great service of bringing the "linguistic turn" of twentieth-century philosophy (notably Wittgenstein) into twenty-first-century learning science, elaborating its perspective on the challenging example of math ed. She shows how to see math concepts and student learning as discourse phenomena rather than mental objects.

The kind of theoretical undertaking reported in this book must restrict its scope in order to tell its story. However, if we want to incorporate its important accomplishments into CSCL research, then we must also recognize its limitations and evaluate its contributions vis a vis competing theories. In addition to noting its incomplete treatment of socio-cognitive theory, knowledge building, activity theory, ethnomethodology, or distributed cognition, for instance, we should relate it more explicitly to the characteristics of CSCL.

First CSCL. By definition of its name, CSCL differs from broader fields of learning in two ways: its focus on *collaborative learning* (e.g., small group peer learning) and its concern with *computer support* (e.g., asynchronous online discussion, synchronous text chat, wikis, blogs, scripted environments, simulations, mobile computing, video games). Sfard does not present examples of small group interaction; her brief excerpts are from dyadic face-to-face discussions or adult-child interviews. Her empirical analyses zero in on individual math skills and development rather than on the group mechanisms by which contributions from different personal perspectives are woven together in shared discourse. We now need to extend her general approach to computer-mediated interaction within small groups of students working together on the construction and deconstruction of math objects.

Fine-grained analysis of collaboration requires high-fidelity recordings, which—as Sfard notes—must be available for detailed and repeated study. She makes the tantalizing hypothesis that Piaget's famous distinction between successive developmental stages in children's thinking during his conservation experiments may be a misunderstanding caused by his inability to review children's interactions in adequate detail. Tape recordings and video now provide the technological infrastructure that made, for instance, conversation analysis possible and today allow multi-modal observation of microgenetic mechanisms of interaction and learning. Computer logs offer the further possibility of automatically recording unlimited amounts of high-quality data for the analysis of group cognition.

For instance, in our study of the case shown in Fig. 8.1, we used a replay application that lets us step through exactly what was shared by everyone in the chat room. Our replayer shows the window as the participants saw it and adds across the bottom controls to slow, halt, and browse the sequential unfolding of the interaction. This not only allows us to review interesting segments in arbitrarily fine detail in our group data sessions but also allows us to make our raw data available to other researchers to evaluate our analyses. Everyone has access to the complete data that was shared in the students' original experience. There are no selective interpretations and transformations introduced by camera angles, lighting, mike locations, transcription, or log format.

Of course, the analysis of group interaction necessarily involves interpretation to understand the meaning-making processes that take place. The analyst must have not only general human understanding but also competence in the specific discourse that is taking place. To understand Aznx's utterances, an analyst must be familiar with both the "form of life" of students and the math objects they are discussing. As Wittgenstein (1953, p. 223, §IIxi) suggests, even if a lion could speak, people would not understand it. Sfard's talk about analyzing discourse from the perspective of an analyst from Mars is potentially misleading; one needs *thick descriptions* (Geertz, 1973; Ryle, 1949) that are meaning-laden, not "objective" ones (in what discourse would these be expressed?).

Sfard's discussion of the researcher's perspective (p. 278f) is right that analysis requires understanding the data from perspectives other than those of the engaged participants—for instance, to analyze interactional dynamics and individual trajectories. However, it is important to differentiate this removed, analytic perspective (that still understands the meaning making) from a behaviorist or cognitivist assumption of objectivity (that recognizes only physical observables or hypothetical mental representations). The analyst must first of all understand the discourses in order to "explore" it from an outsider's meta-discourse, and neither a lion nor an analyst from Mars is competent to do so.

Sfard defines the unit of analysis as the discourse (p. 276). The use of CSCL media for math discourses problematizes this, because the discourse is now explicitly complex and mediated. Although Sfard has engaged in classroom analyses elsewhere, in this book her examples are confined to brief dyadic interchanges or even utterances by one student. In fact, some examples are made-up sentences like linguists offer rather than carefully transcribed empirical occurrences. Moreover, the empirical examples are generally translated from Hebrew, causing a variety of interpretive problems and lessening the ability of most readers to judge independently the meaning of what took place. Computer logs allow us to record and review complex interactions involving multiple people over extended interactions. The unit of analysis can be scaled up to include groups larger than dyads (Fuks, Pimentel, & de Lucena, 2006), the technological infrastructure (Jones, Dirckinck-Holmfeld, & Lindström, 2006), the classroom culture (Krange & Ludvigsen, 2008), and time stretches longer than a single session

(Sarmiento & Stahl, 2008). One can observe complex group cognitive processes, such as problem-solving activities—from group formation and problem framing, to negotiation of approach and sketching of graphical realizations, to objectification and exploration of visual signifiers, to reflection and individualization. The encompassing discourse can bring in resources from the physical environment, history, culture, social institutions, power relationships, motivational influences, and collective rememberings—in short, what activity theory calls the activity structure or actor-network theory identifies as the web of agency.

While Sfard uses the language of sweeping discourses—like the discourse of mathematics from the ancient Greeks to contemporary professional mathematicians—her specific analyses tend to minimize the larger social dimension in favor of the immediate moment. This is particularly striking when she uses terms like *alienation* and *reification* to describe details of concept formation. These terms are borrowed from social theory—as constructed in the discourses of Hegel, Marx and their followers, and the social thought of Lukacs, Adorno, Vygotsky, Leontiev, Engeström, Lave, Giddens, and Bourdieu. Sfard describes the reification of discursive counting processes into sentences about math objects named by nouns as eliminating the human subject and presenting the resultant products as if they were pre-existing and threatening. She does this in terms that all but recite Marx's (1867/1976, pp. 163–177) description of the fetishism of commodities. However, whereas Marx grounded this process historically in the epochal development of the relations of social practice, the forces of material production, and the processes of institutional reproduction, Sfard often treats mathematics as a hermetic discourse, analyzable independently of the other discourses and practices that define our world, although in her concluding chapter she emphasizes the need to go beyond this in future work.

Mathematics develops—both globally and for a child—not only through the interanimation of mini-discourses from different personal perspectives but also from the interpenetration of macro-discourses. Math is inseparable from the world-historical rise of literacy, rationalism, capitalism, monotheism, globalization, logic, individualism, science, and technology. CSCL theory must account for phenomena across the broad spectrum from interactional details contained in subtle word choices to the clashes of epochal discourses. While Sfard has indicated a powerful way of talking about much of this spectrum, she has not yet adequately located her theory within the larger undertaking. One way to approach this would be to set her theory in dialog with competing participationist theories in CSCL and the learning sciences.

Continuing the Discourse

Issues of situating math discourse in social practice return us to the quandary of the metaphors of acquisition and participation. Sfard's book works out an impressive edifice of participation theory. Math can be conceptualized as a discourse in which people participate in the social construction of math objects; because of such participation, they can understand and individualize elements of the discourse. In doing so, she follows a path of dialogical and discursive theory starting at least with Bakhtin, Vygotsky, and Wittgenstein and propounded by numerous contemporaries. Within the domain of math discourse, Sfard has pushed the analysis significantly further.

Her argument 10 years ago was that there is something to the metaphor of *objects* of math but that the ontological status of such objects was unclear and was perhaps best described by AM. In addition, she felt that multiple conflicting metaphors breed healthy dialog. But now she has shown that math objects are products of math discourse (so they now exist and make sense within PM). As for healthy dialog, there is plenty of opportunity for controversies among multiple discourses within PM itself. Thus, we can conclude that Sfard is justified in moving to a fully PM metaphor because this stream of thought is capable of resolving former quandaries and it contains within itself an adequate set of potentially complementary, possibly incommensurable discourses to ensure a lively and productive ongoing debate. Sfard has provided us with one of the most impressive unified, homogeneous theories of learning; it remains for us to situate that theory within the specific field of CSCL and within the broader scope of competing theoretical perspectives. This includes extending and applying her analysis to group cognition and to computer-mediated interaction. It also involves integration with a deeper theoretical understanding of social and cultural dimensions.

At the other end of the spectrum, one must also resolve the relationship of "thinking as communicating" with the psychological approach to individual cognition as the manipulation of private mental representations. Is it possible to formulate a cognitivist view without engaging in problematic acquisitionist metaphors of a "ghost in the machine" (Ryle, 1949)? Assuming that one already understands the mechanisms of math discourse as Sfard has laid them out, how should hypothetical-deductive experimental approaches then be used to refine models of individual conceptualization and to determine statistical distributions of learning across populations? Questions like these raised by the challenge of Sfard's book are likely to provoke continuing discourse and meta-discourse in CSCL—and in *ijCSCL*—for some time to come, resolving intransigent quandaries and building more comprehensive (deeper) scientific understandings.

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Investigation 9. Tracing the Change in Discourse in a Collaborative Dynamic-Geometry Environment: From Visual to More Mathematical

Diler Öner

Abstract

This case study investigated the development of group cognition by tracing the change in mathematical discourse of a team of three middle-school students as they worked on a construction problem within a virtual collaborative dynamic geometry environment. Sfard's commognitive framework was employed to examine how the student team's word choice, use of visual mediators, and adoption of geometric construction routines changed character during an hour-long collaborative problem-solving session. The findings indicated that the team gradually moved from a visual discourse toward a more formal discourse—one that is primarily characterized by a routine of constructing geometric dependencies. This significant shift in mathematical discourse was accomplished in a CSCL setting where tools to support peer collaboration and pedagogy are developed through cycles of design-based research. The analysis of how this discourse development took place at the group level has implications for the theory and practice of computer-supported collaborative mathematical learning. Discussion of which features of the specific setting proved effective and which were problematic suggests revisions in the design of the setting.

Keywords

Mathematical discourse development · Mathematical routines · Group cognition · Collaborative dynamic geometry · Dependencies

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D. Öner (✉)
Boğaziçi University, Istanbul, Turkey
e-mail: diler.oner@boun.edu.tr

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Introduction

Documenting processes by which learning takes place in collaborative settings has been one of the most important research agendas for CSCL researchers. This endeavor is even more challenging in the context of learning geometry, which has been considered a classic example of individual intellectual development (Stahl, 2016). Shifting the focus from individual cognition to group cognition, this study examines the development of a group of students' geometrical thinking in the Virtual Math Teams (VMT) environment (Stahl, 2009). VMT is an open-source, virtual, collaborative learning setting that affords synchronous text-based interaction (chat) with an embedded multi-user dynamic geometry application, GeoGebra (www.GeoGebra.org). VMT is regarded as the first sustained effort supporting a collaborative form of dynamic geometry (Stahl, 2013a).

Learning within a dynamic geometry environment (DGE) is indicated by the ability to construct figures, which marks the transition toward formal mathematics. There is a crucial distinction between *drawing* and *construction* within a DGE. Drawing refers to the juxtaposition of geometrical objects that *look* like some intended figure (Hoyles & Jones, 1998). Construction, however, depends on creating theory-based relationships, in other words *dependencies* (Stahl, 2013a), among the elements of a figure. Once relationships are constructed accordingly, the dynamic figure maintains these theoretical relationships even under dragging.

The transition from visual to formal mathematics is, however, neither straightforward nor easy for students working with dynamic geometry (Jones, 2000; Marrades & Gutierrez, 2000). Students often think that it is possible to construct a geometric figure based on visual cues (Laborde, 2004), although constructing dynamic geometry figures requires defining dependencies. Corresponding to this contrast, one can distinguish between two different *mathematical* discourses (Sfard, 2008) in which students may engage when working within DGEs. Within one of these, students may talk about geometrical figures as if they are merely visually perceptible entities without making any connections between them and the theoretical relationships they signify. When presented with a geometry construction problem, students might adopt a solution *routine* (Sfard, 2008) that is based on visual placement and verification, which produces a *drawing* (Hoyles & Jones, 1998). Taking a more sophisticated mathematical discourse, however, they would frame the problem as *construction*, that is, one that involves establishing dependencies.

Sfard (2008) argues that such a discursive jump to more sophisticated discourses takes place "while participating in the discourse with more experienced interlocutors" (p. 191). However, this study will show that participation within a well-designed collaborative learning setting, such as VMT, can also help students move forward from visual toward more formal ways of dealing with construction problems. That is, interacting with expert interlocutors (e.g., teachers) may not be the only path toward advancing one's mathematical discourse. This process may also take place within a virtual collaborative setting where feedback from dynamic geometry software, collaboration with peers, and guidance from task instructions collectively fulfill a role similar to that of the discourse of experts.

Constructing Dependencies with Dynamic Geometry

In geometry, entering the theoretical domain is challenging given that students need to deal with the double role that diagrams play. On the one hand, diagrams refer to *theoretical* properties of geometrical objects and their relations. On the other hand, they are *spatio-graphical* figures that are immediately accessible through *visual* perception (Laborde, 2004). These two worlds come in close contact in DGEs. When one uses theory to *construct* a geometrical object, theoretical relationships are preserved even when the elements of the construction are visually altered through dragging. That is, spatio-graphical aspects of the construction keep reflecting invariant theoretical properties dynamically. For instance, when one properly constructs two line segments to be perpendicular bisectors of each other, not only will the segments look and measure as though they bisect each other at 90°, but they will remain so even if the points of the construction are dragged into other positions. Within a DGE, in order to construct a perpendicular bisector, one needs to create *dependencies* by defining the theoretical relationships that determine perpendicularity. The counterpart of the classical Euclidean compass-and-straightedge construction within a DGE makes uses of circle and line software tools, which can, for instance, create a rhombus whose diagonals bisect at right angles. In that way, dynamic geometry constructions provide a computer-based context in which the connections between spatio-graphical and theoretical worlds are maintained.

Although dynamic geometry affords unique possibilities for learning geometry, there have been concerns regarding the nature of mathematical truth that students may be deriving when working in DGEs (Chazan, 1993a; Hadas, Hershkowitz, & Schwarz, 2000; Hoyles & Jones, 1998). Some researchers and teachers worry that when students can easily generate empirical evidence, the need and motivation for formal explanations may vanish. More fundamentally, students may not make the transition toward the theoretical aspects of geometry (Marrades & Gutierrez, 2000) and build the connection between spatio-graphical and theoretical worlds that is an essential aspect of meaning in geometry (Laborde, 2004). Learners may become stuck in the transition area between a visually produced solution and the underlying theoretical relationships (Hölzl, 1995).

On the other hand, it can be argued that focusing on constructing dependencies may help students move toward noticing relevant mathematical relationships (Jones, 2000). Dynamic geometry constructions are associated with formal geometry because created dependencies can correspond to elements of a mathematical proof (Stahl, 2013a). One starts with creating dependencies as if listing the givens in a mathematical proof task. These built-in relationships in turn constrain the elements of a figure in certain ways that lead to further relationships, which reflect the ideas underlying a corresponding explanatory proof.

Some researchers stress the differences between Euclidean geometry and dynamic geometry. For instance, Hölzl (1996) argues that dynamic geometry software imposes a hierarchy of dependencies that alters the relational character of geometric objects. He states that a distinction arises between free points (that can be dragged) and restricted points (such as intersections), which may not be geometrical or necessary in a paper-and-pencil environment. This is not surprising given that Euclidean geometry and dynamic geometry rely on "qualitatively different technologies" (Shaffer & Kaput, 1999). Despite the lack of complete congruence between the two, many researchers believe that explicitly stating the steps of a dynamic geometry construction can break down the separation between deduction and construction (Chazan & Yerushalmy, 1998; Hoyles & Jones, 1998; Stahl, 2013a), that is, well-designed DGEs may be able to help students to transition toward formal mathematics.

Constructions are also taken as a form of *mathematization* (Gattegno, 1988; Treffers, 1987; Wheeler, 1982) by Jones (2000), who defined the term for elementary-school geometry using dynamic geometry software. When mathematizing,

> students can be said to be involved in modeling the geometrical situation using the tools available in the software. This involves setting up a construction and seeing if it is appropriate, and quite probably having to adjust the construction to fit the specification of the problem. (p. 62)

Thus, when students move forward from a visual solution toward one that is based on constructing dependencies in a DGE, this is taken as an indication of the development of students' geometric thinking.

Theoretical Framework

In this study, Sfard's (2008) commognitive framework is used to examine students' mathematical discourse. Defining learning as the development of discourses, Sfard frames (mathematical) thinking as an individualized form of communication. Thus, she suggests a developmental unity between the processes of thinking and communicating, which leads to naming her approach "commognitive." Commognitive researchers are interested in mathematical discourses, as this is where one can trace the processes of learning. Sfard distinguishes mathematical discourses in terms of their tools (*words* and *visual means*) and the form and outcomes of their processes—*routines* and *narratives* (Table 9.1). Each of these constructs is explained below, but the focus will be on the notion of routines, which is the most relevant construct for the analysis in this study.

Different mathematical discourses employ certain mathematical *words*, which might signify different things in different discourses, and *visual objects*, such as figures or symbolic artifacts. In addition to using these discourse tools, participants functioning in different discourses produce what Sfard calls *narratives*, that is, sequences of utterances about mathematical objects and relations among them. Narratives are subject to endorsement or rejection under certain substantiation procedures by the community. Endorsed narratives usually take the form of definitions, axioms, theorems, and proofs. In order to produce mathematical narratives, participants engage in mathematical tasks in certain ways. They follow what are called *metarules*, which are different than object-level rules. Rules that express patterns about mathematical objects, say about triangles, are defined as object-level rules (e.g., the sum of interior angles of a triangle is 180°). Metarules, on the other hand, are about actions of participants, and they relate to the production and substantiation of object-level rules. The set of metarules that describe a patterned discursive action are named *routines*, since they are repeated in specific types of situations.

Routines take two forms: the how and the when of a routine. The how of a routine, which may be called *course of action* or *procedure*, refers to a set of metarules describing the course of the patterned discursive action. The when of a routine, on the other hand, is a collection of metarules used by participants to determine the appropriateness of the performance. The researcher might observe the how of a routine more easily when a specific task is assigned. Examining the when of a routine, however, requires extended periods of observation, when participants are asked to solve problems that are more complex. In this study, given that students were provided with a well-defined task, the how of a routine was analyzed.

Sfard (2008) states that metarules and routines are the researcher's construct based on observations of participants' discursive actions. Therefore, they are about the observed past. They are useful constructs for the researcher because "constructed metarules allow us to map thetrajectoryofone's discursive development" (p. 209).

Table 9.1 The four distinguishing aspects of mathematical discourses

Tools of math discourses		Form and outcomes of math discourses	
Words	Visual means	Routines	Narratives
Use of certain keywords that signify different things in different discourses	Visible objects that are operated upon within communication	Set of metarules that describe a patterned discursive action and that relate to the production and substantiation of object-level rules	Sequences of utterances about mathematical objects and relations among them

Method

This is a case study of a team of three eighth-grade students (about 14 years old) who worked on a geometry construction problem collaboratively within the Virtual Math Teams (VMT) environment. These three students were participants in the VMT Project, the larger design-based research (DBR) project that incorporates cycles of data collection and analysis to refine technology, curriculum, and theory for collaborative learning. As part of the VMT project, the participants worked on the tasks of a geometry curriculum for the VMT environment written by Stahl (2013b) for about a semester. Although the participants had very little formal background in geometry, this particular team was able to solve a challenging task (Oner, 2013) in session 5. That brought this team to the attention of the project research team leading to this study to understand the team's mathematical development (see Stahl, 2016 for an analysis of all eight of their sessions).

The study focuses on one of the team's problem-solving sessions, namely, session 3. This session was chosen for analysis as it represented an "extreme case" (Patton, 1990) given that it displayed characteristics from which one could learn the most for the purposes of the larger DBR project. Detailed analyses of such cases could suggest ways of refining the VMT technology, pedagogy, and curriculum to provide better support for future online groups.

The Context and Participants

The team was named the "Cereal Team," because the members selected their online handles to be Cheerios, Cornflakes, and Fruitloops. None of the team members had previously studied geometry; they were taking first-year algebra at the time of data collection. They are all females. Before the session analyzed in this study, they had met within the VMT online environment for 2 h-long sessions, trying basic GeoGebra tools, such as the software tools for creating points, lines, and line segments, or working on the task of equilateral-triangle construction (in sessions 1 and 2).

In session 3, students worked on Topic 3 of the VMT dynamic geometry curriculum (Stahl, 2013b) that involved two tasks:

> *Task* 1: Construct two lines that are perpendicular bisectors of each other. A list of steps is provided so that students can construct the diagonals (AB and CD) of a rhombus (ACBD). A completed construction is provided as an illustration for students (Fig. 9.1a).
> *Task* 2: Construct a perpendicular line to a given line through a given point. The expected solution for this task is provided in Fig. 9.1b. Here, one first needs to define the given point H as a midpoint between two points using the circle tool (i.e., drawing the circle at center H with radius AH). Since H is the center of this circle, AH and HB are congruent, which are the radii of this smaller circle. Now one can use points A and B (the intersections of line FG and the small circle) as centers and line segment AB as the radius to construct the two larger circles. As line segments DB, BC, CA, and AD are all radii for these circles (r), they are congruent. Connecting these line segments would create four congruent triangles (by the SSS congruency theorem involving triangles CHB, CHA, DHA, and DHB). This implies that angle CHB is a right angle and line CD is perpendicular to the line FG at H.

Participants work on geometry problems in the VMT software environment within chat rooms created for each session. Figure 9.1c shows the VMT room created for session 3. The screenshot was taken at the very beginning of the session. Note that a completed perpendicular bisector construction is provided for students. In VMT rooms, there is a chat panel on the right hand side and a whiteboard area for multi-user GeoGebra. One can post a chat anytime during the session. However, in order to manipulate objects in the GeoGebra area, one has to click on the "Take Control" button (at the bottom). Thus, only one person at a time can interact with the dynamic geometry section of the room. The GeoGebra view is, however, shared by everyone in the team so they can all observe changes to the figures as they are made.

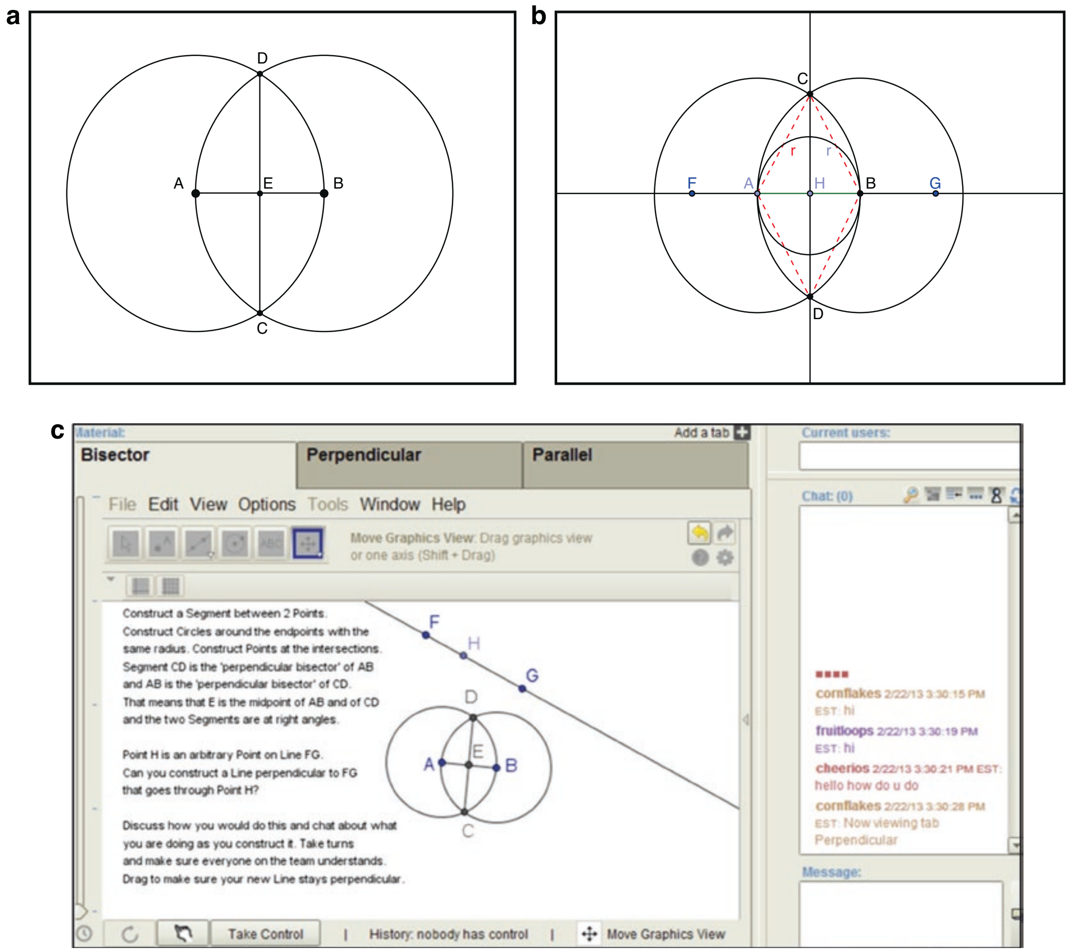

Fig. 9.1 (**a**) Construction of two line segments that are perpendicular bisectors of each other (Task 1). (**b**) Construction of the perpendicular to the line FG through a given point H (solution for Task 2). (**c**) The VMT window at the start of work on session 3. Note the task instructions and example figures. The chat section is in the panel on the right

Data Collection and Analysis

The team's meeting in the VMT environment was part of an after-school club organized by their math teacher in an American public school. The Cereal Team worked on Topic 3 for about an hour. The problem-solving session was recorded as a VMT log file to be replayed later allowing subsequent observation of the team's problem-solving process in micro-detail. All chat postings and GeoGebra actions produced by the team members are automatically logged and digitally recorded.

In order to investigate the changes in participants' discourse, both the chat postings and the actions of the participants recorded in their VMT session were examined through Sfard's (2008) discursive lens. As summarized in Table 9.2, the particular focus was on the changes in (a) the team's use of the word "perpendicular," (b) the visual mediators they acted upon (i.e., the perpendicular bisector construction), and (c) their mathematical routines, since the changes in these features were the most salient aspects of their changing discourse.

Given the nature of the assigned geometry tasks, this study investigated two routines:

Table 9.2 Sfard's (2008) three discourse aspects used in the present analysis

Words	Visual means	Routines
The use of the word "perpendicular"	The perpendicular bisector construction	The production of the perpendicular The verification of perpendicularity

Table 9.3 Characteristics of *visual* vs. *formal* mathematical discourses in session 3

Visual discourse	Formal discourse
Production of the perpendicular is based on visual placement of a perpendicular-looking line (spatio-graphical)	The production of the perpendicular is based on constructing dependencies
Verification of perpendicularity involves visual check (spatio-graphical)	Verification of perpendicularity derives from theoretical relationships
The use of the word perpendicular reflects a visual image of which two lines look perpendicular	The use of the word perpendicular signifies a theoretical relationship between geometrical objects

- *The production of the perpendicular*: This routine involved the use of a set of procedures referring to the repetitive actions in producing a perpendicular line, such as construction (by creating dependencies) or visual placement (drawing).
- *The verification of perpendicularity*: This routine is a set of procedures describing the repetitive actions in substantiating whether a solution (a line produced) is in fact perpendicular to a given line. These procedures could include visual judgment, numerical measurements, or use of theoretical geometry knowledge to justify proposed solutions.

Two discourses are considered different when they are *incommensurable*, that is, when they have different rules for the same type of task (Sinclair & Moss, 2012). One can therefore distinguish between two mathematical discourses when they entail two different ways of solving the tasks in Topic 3 as summarized in Table 9.3. In one discourse, students' production of the perpendicular and verification of perpendicularity are exclusively based on spatio-graphical cues without any concern for theoretical relationships. More specifically, the solution and verification routine is based on visual placement of a perpendicular-looking line (spatio-graphical solution), which produces a drawing (Hoyles & Jones, 1998). Along the same lines, the use of the word "perpendicular" reflects a visual image in which two lines perceptually look perpendicular. Thus, this discourse is categorized as *visual*. In another discourse, which is called *formal*, the production of the perpendicular line involves constructing dependencies— that is, defining relationships using the software tools. The verification routine within this discourse is theoretical deriving from geometrical relationships. The word "perpendicular" within this discourse signifies a theoretical relationship between geometrical objects.

As the first step in the analysis, the chat postings and GeoGebra actions of the Cereal Team were divided into episodes, mainly based on the detected changes in participants' routines of solving the task (i.e., routines of production and verification). In each episode, what is said and done was examined focusing on the three aspects of their mathematical discourse when relevant: their use of the word "perpendicular," the visual means acted upon, and routines of the production of the perpendicular or verification of perpendicularity in each episode. In what follows, an analysis of the most notable moments of these episodes will be presented by providing excerpts from the chat postings and VMT room screenshots.[1]

Analysis

Based on the team's routines of production and verification, the interaction is divided into the following episodes: (1) constructing the perpendicular bisector, (2) drawing a perpendicular-looking line, (3) drawing the perpendicular using the perpendicular bisector construction (PBC) as straightedge, (4) use of circles with no dependencies defined, (5) constructing dependencies, and (6) discussing why the construction worked.

Episode 1: Constructing the Perpendicular Bisector (3:32:15–3:40:20)

As the first task, the team was asked to construct two line segments that are perpendicular bisectors of each other. They were provided the steps to construct a line segment first and then to construct two circles around its endpoints, with the line segment as their radii (see Fig. 9.1a for the expected answer). By constructing the two intersections of the two circles and connecting them, the participants would obtain two line segments perpendicular to each other at their midpoints.

At the start of the first episode, Fruitloops and Cheerios were active with the construction of the two line segments as perpendicular bisectors of each other. The team decided that Fruitloops should take control and tackle the task (Log 9.1, Lines 14–16). However, Fruitloops asked how she could make a line segment after creating two points (I and J). At that moment, the segment tool was not visible; it needed to be pulled down in the toolbar. Cornflakes provided some direction by saying that the segment tool is next to the circle tool (Log 9.1, Line 19). This information was sufficient for Fruitloops, as she was then able to construct a line segment (IJ).

Log 9.1

Line	Post time	User	Message
11	3:31:02.6	fruitloops	who wants to take control
12	3:31:16.1	fruitloops	do you was to delete the instruction
13	3:31:21.5	fruitloops	want*
14	3:32:11.4	fruitloops	want me to start?
15	3:32:13.4	cheerios	take control
16	3:32:16.0	cornflakes	Yes
17	3:33:03.9	fruitloops	how do i make the line segment?
18	3:33:08.0	cheerios	do u need help
19	3:33:26.1	cornflakes	its by the circle thingy
20	3:33:38.1	fruitloops	got it thanks
21	3:34:06.5	cornflakes	no problem
22	3:35:54.1	fruitloops	i did it
23	3:36:02.0	cheerios	good job my peer
24	3:36:14.4	cornflakes	Nice
25	3:36:15.6	fruitloops	someone else want to continue?
26	3:36:23.6	fruitloops	thankyou thankyou
27	3:36:32.5	cheerios	release control
28	3:37:40.4	fruitloops	so now you need to construck points at the intersection
29	3:38:12.1	fruitloops	no you dont make a line you make a line segment
30	3:38:35.1	fruitloops	good!!
31	3:39:20.4	fruitloops	so continue
32	3:39:29.9	cheerios	i just made the intersecting line and point in the middle
33	3:39:40.0	cheerios	it made a perpindicular line

Another problem Fruitloops had difficulty with was constructing circles at the endpoints of the line segment with the same radius, which establishes the dependency crucial for the construction. She created two circles centered at points I and J with radius IK and JL, respectively, which were not congruent but *looked* the same (Fig. 9.2a). To define the radii of the circles centered at points I and J, she used arbitrary points (K and L), not the line segment IJ, that is, her circles *looked* to have the same radius,

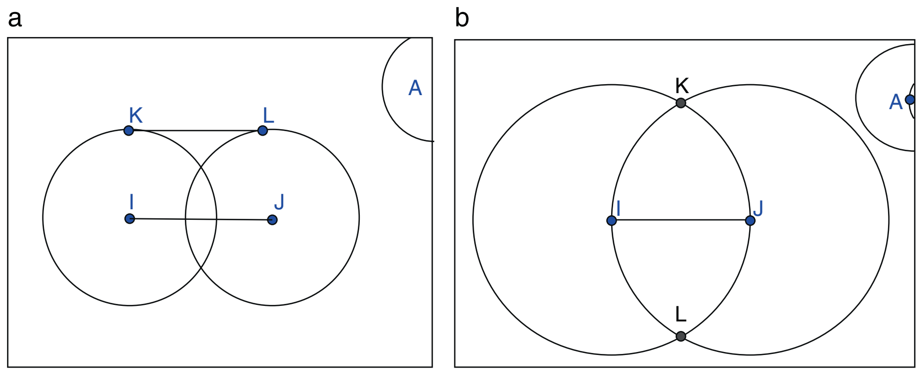

Fig. 9.2 (**a**) Two circles with different radii (IK and JL) centered at I and J. (**b**) Two circles with the same radius IJ centered at I and J

but they were not *constructed* based on an equal-radius relationship. Later, however, after playing with the circle tool for a while, Fruitloops did the construction again and managed to construct two circles around the endpoints (points I and J) with the same radii (IJ) (Fig. 9.2b).

Next, Cheerios took control and continued the work by constructing the intersection points of the two circles (new points K and L) and the line that passed through them. Yet, as the following move, Cheerios removed the line she just constructed. Next, she reconstructed it, and then again deleted it and the intersection points. Finally, she reconstructed the intersections. At this point, Fruitloops drew attention to the instructions, saying they needed to construct a line segment, not a line (Log 9.1, Line 29). This time, Cheerios constructed the line segment KL through the intersections and created point M, the intersection of the two segments (KL and IJ). Cheerios explained her actions by saying "i just made the intersecting line and point in the middle," calling M "the point in the middle." She continued, "it made a perpindicular line" (Log 9.1, Lines 32–33).

In this episode, the routine for solving the first task simply involved following the instructions. Yet, Fruitloops had two difficulties. While one had to do with finding the needed menu item in the software, the other was related to constructing the key dependency, that is, same-radius circles at the endpoints of the line segment. Cheerios also had to pay attention to the wording in the instructions (i.e., the difference between "line" and "line segment"). She used the word "perpendicular" once (Log 9.1, Line 33). At this point, it seems reasonable to argue that the word "perpendicular" was just a revoicing of the task instructions.

Episode 2: Drawing a Perpendicular-Looking Line (3:40:27–3:55:30)

Moving to the second part of the given task, the team now had to work on a more challenging problem, which was constructing a perpendicular to a line through a given point. In this episode, the team's problem-solving discourse took a visual character, which was evidenced by (a) producing a perpendicular-looking line (a drawing), (b) verifying perpendicularity by visual perception, and (c) using the word "perpendicular" to refer to a visual image. One other important aspect of this episode was Cornflakes' bringing the illustrative perpendicular-bisector construction to the team's attention.

On their screen, a line FG and the point H was provided to them (Fig. 9.1c). Initially, however, how to use these givens was not clear to any of the team members. For Cornflakes and Cheerios, the production of the perpendicular first required creating another reference line that was somehow related to the line FG, as they both tried to construct lines that either *looked* parallel to or intersected the line FG. Fruitloops elegantly suggested using the line that was already there (Log 9.2, Line 37). Furthermore, she next uttered the word "perpendicular." She said "perpindicular no intersecting" (Log 9.2, Line 39). This use was different than that of Cheerios in the first episode. Fruitloops used the word to evaluate Cheerios' line, which intersected the line FG. At this stage, this use of "perpendicular" may have just implied a visual image rather than a construct with mathematical properties.

Log 9.2

Line	Post time	User	Message
34	3:40:27.5	fruitloops	okay cornflakes go next
35	3:41:11.5	cornflakes	what are you supposed to do?
36	3:41:42.6	fruitloops	just follow the instructions
37	3:43:48.5	fruitloops	were we supposed to just use the line that was already there?
38	3:44:10.2	cornflakes	i think so
39	3:44:44.2	fruitloops	perpindicular no intersecting
40	3:44:46.1	fruitloops	not*

After this initial stage, Cornflakes took control. She constructed a point N and a line through N and H that looked perpendicular to line FG at H (Fig. 9.3a). Then she removed this line but later reconstructed it in the same manner and deleted it once more. She was just picking a location for point N such that a line NH would visually appear to look perpendicular to line FG.

Next, however, she did something rather unexpected: she started moving the perpendicular-bisector constructions (PBCs) around. She dragged both the one that was given with the topic and the one they had just constructed in Episode 1 changing their shape and location. Not seeing any of the use of the PBC immediately, she repeated her production of a line that seemed (visually) perpendicular to line FG through H, after creating points N and O. While the line looked as if it passed through O, N, and H, it was only passing through O and H (Fig. 9.3b).

After Cornflakes' attempt to provide a solution, Fruitloops took control. She first deleted the line Cornflakes constructed (line OH), the one that appeared to be perpendicular to FG at H (Fig. 9.3b). She played with constructing some other points and line segments, which did not seem relevant. It is reasonable to argue that she was not happy with Cornflakes' seemingly perpendicular line. She then released control and asked in the chat: "can you remake it?" (Log 9.3, Line 43). In response, Cheerios took control and added points O and Q and a line through them that passed through H (Fig. 9.4a). This line again was a visual solution that looked perpendicular to FG through H. Cheerios then added another point (R) on the line placing it in the upper plane. Fruitloops, however, questioned defining extra points (O and Q) (Log 9.3, Line 44) while Cornflakes was fine with them (Log 9.3, Line 45). In response, Cheerios removed point R and then her line OQ. She reconstructed point R and constructed another line through R, which this time did not even look perpendicular to line FG at H (Fig. 9.4b). She then asked if the line was okay (Log 9.3, Line 46). Fruitloops once again evaluated the line Cheerios constructed saying "its not perpinicuklar" (Log 9.3, Line 48). Then Cornflakes deleted this line and constructed a more perpendicular-looking one first through H and S (a new point) and then, deleting line HS, through H and N (Fig. 9.4c). Even though Fruitloops seemed satisfied this time saying, "I think that'sgood," (Log 9.3, Line 49), Cornflakes erased the perpendicular-looking line (line HN) once more

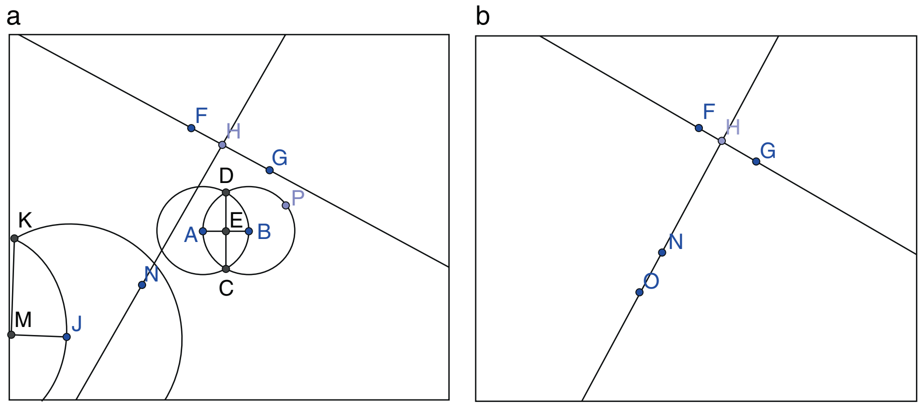

Fig. 9.3 (**a**) Construction of line NH that looks perpendicular to line FG. (**b**) Construction of another line (line OH) that looks perpendicular to line FG

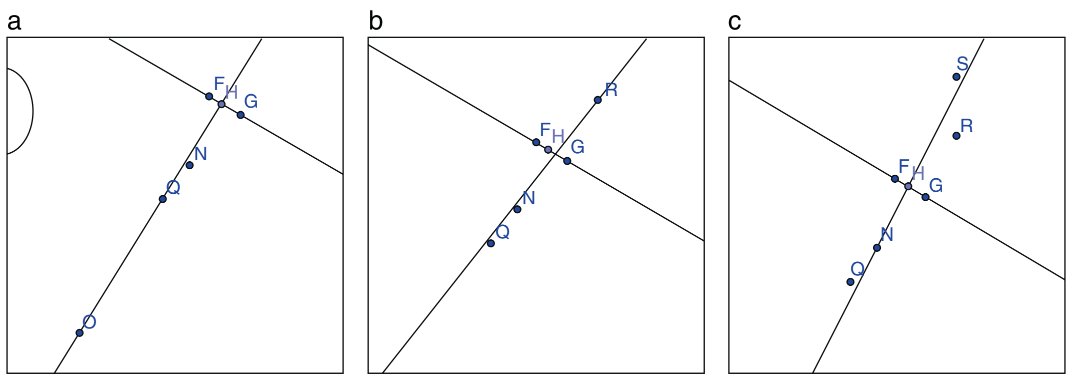

Fig. 9.4 (**a**) Construction of the perpendicular-looking line OQ. (**b**) Construction of a perpendicular-looking line passing point R. (**c**) Construction of the perpendicular-looking line HN

The solution offered by Cornflakes included placing a perpendicular-looking line visually (a spatio-graphical solution), which did not depend on creating dependencies. Cheerios also worked toward producing a line that would look perpendicular to the line FG at point H. However, there was also some level of discomfort with this solution, which was evidenced by deletion actions immediately followed by creating such lines. Fruitloops did not explicitly undertake the same production routine. She used the word "perpendicular," judging Cheerios' line as not fitting her notion of perpendicular. However, she eventually agreed on the line produced by Cornflakes in response (Log 9.3, Line 49). Therefore, at this stage, one can say that all team members' production of the perpendicular routine involved creating a line that was a *drawing*. An important aspect of this episode was Cornflakes' little play with the available PBC. Even though PBC had not been used as a mediator of the production of the perpendicular routine just yet, Cornflakes made its presence known and highlighted it as a potential tool.

Log 9.3

Line	Post time	User	Message
41	3:48:09.7	fruitloops	sorry i did it by accident
42	3:48:23.5	cheerios	its fine :) my dear peer
43	3:48:38.3	fruitloops	can you remake it
44	3:48:52.7	fruitloops	why did you make point o and q
45	3:48:55.0	cornflakes	its alright
46	3:49:09.5	cheerios	is the line ok
47	3:49:16.0	cornflakes	i didn' t make point o and q
48	3:49:23.0	fruitloops	its not perpinicuklar
49	3:50:57.7	fruitloops	i think thats good

As the team did not seem completely satisfied with their (visual) solution, some of their efforts next focused on finding ways to judge perpendicularity. This stage was marked and initiated by Cheerios when she suggested rotating the line FG (she referred to it as FHG) "so it is easier to make it horizontal" (Log 9.4, Line 50). With this statement, she meant dragging the given line FG into a horizontal-looking position so that one can test when a line was perpendicular to it more easily. Presumably, the prototypical visual image of perpendicularity involves a horizontal base line and a vertical perpendicular to it. This statement added a new routine to the problem: verification of perpendicularity along with a production routine.

However, neither Cornflakes nor Fruitloops took up this suggestion. Cornflakes was busy reconstructing another perpendicular-looking line passing through H. Fruitloops also adjusted this line so that it would look more perpendicular. Cheerios first helped Fruitloops by removing some of the extra points on or around that line and adjusting the line. Next, she implemented what she suggested by making the line FG horizontal looking, so that the team could better test the perpendicularity of the line it was to construct (Fig. 9.5a). This would of course be a visual test, not a mathematical one. Seeing the line FG in a horizontal position, Cornflakes asked Cheerios to construct the perpendicular line (Log 9.4, Line 53). Cheerios then constructed another two points (R and O) and a line through them that looked perpendicular to FG, but this did not go through point H. Cheerios deleted her first construction and then cleared the area deleting some extra points. Then she constructed line NH, which looked nearly perpendicular to FG through H (Fig. 9.5b). Cornflakes seemed satisfied with the new line, saying, "that's good" (Log 9.4, Line 54). Fruitloops said, "I think its perpendicular cause they are all 90° angles" (Log 9.4, Line 55).

Log 9.4

Line	Post time	User	Message
50	3:50:59.8	cheerios	turn line fhg so its easier make it horizontal
51	3:52:54.4	fruitloops	Hey
52	3:54:06.9	fruitloops	which point did you move to get the line like that
53	3:54:07.5	cornflakes	now construct the line
54	3:55:10.7	cornflakes	thats good
55	3:55:30.5	fruitloops	i think its perpendicular cause they are all 90° angles

To summarize, Cheerios produced yet another drawing (Line NH, Fig. 9.5b) at this point, and Cornflakes and Fruitloops agreed on that solution (Log 9.4, Lines 54–55). Furthermore, Fruitloops' approval involved the use of the word "perpendicular." She said: "i think its perpendicular cause they are all 90° angles" (Log 9.4, Line 55). With this sentence, it became clearer that she used the word as representing a visual image of perpendicularity as she referred to the measure of the angles without measuring. Thus, all group members were still realizing the perpendicular line as a figure that could be produced perceptually. Moreover, Cheerios felt the need to verify their solution. She suggested

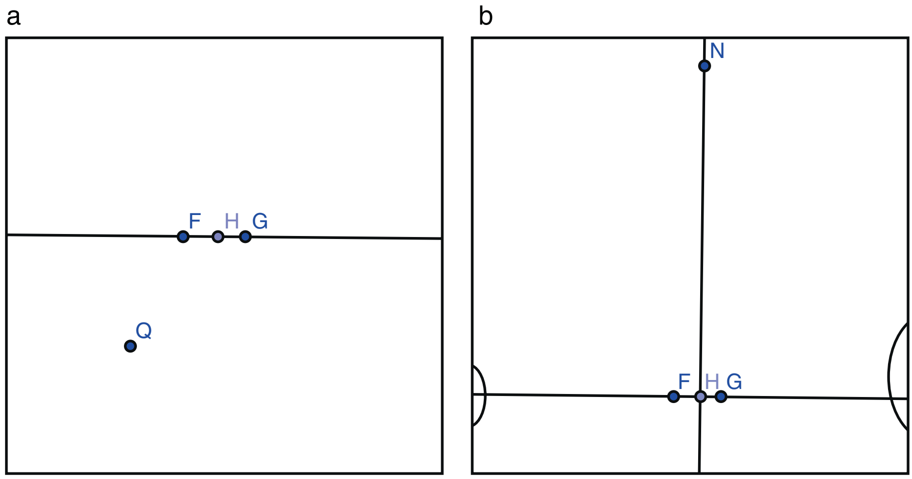

Fig. 9.5 (**a**) Dragging line FG into a horizontal position. (**b**) Construction of line NH that looks perpendicular to line FG

Table 9.4 Summary of Episode 2 in terms of discourse characteristics

Production of the perpendicular routine	Verification of perpendicularity routine	Use of the word *perpendicular*	Use of visual mediators
Creating another reference line in relation to line FG (Cornflakes and Cheerios)		Signifying a visual image of perpendicular to disagree with a spatio-graphical solution (Fruitloops)	
Spatio-graphical solution/ drawing a perpendicular-looking line (Cornflakes)			PBC random dragging (Cornflakes)
Spatio-graphical solution/ drawing a perpendicular-looking line (Cheerios & Cornflakes)		Signifying a visual image of perpendicular to disagree and then agree with a spatio-graphical solution (Fruitloops)	
Spatio-graphical solution (Cornflakes, Fruitloops, Cheerios)	Spatio-graphical verification/ vertical-horizontal alignment of the lines (Cheerios)	Signifying a visual image of perpendicular to agree with a spatio-graphical solution (Fruitloops)	

producing the perpendicular line in a horizontal-vertical arrangement of two lines (the prototypical visual image for perpendicularity), which allowed a visual verification. Therefore, at this stage, a new routine for verifying perpendicularity emerged, although it was also spatio-graphical.

Table 9.4 provides a summary of the analysis presented for Episode 2.

Episode 3: Drawing the Perpendicular Using the PBC as Straightedge (3:55:55–3:58:26)

Something interesting happened next. Cornflakes started moving the PBC around as if she wanted to use it as a protractor—to verify the right angles. She was not able to get the orientation correct. Getting the idea, Fruitloops took control and dragged the PBC (the one they constructed) placing the middle point M on top of H and aligning with the line FG (Fig. 9.6a). Cornflakes was satisfied, as she responded with a “yes” (Log 9.5, Line 56). These moves signaled a new and different verification routine of perpendicularity, one that is based on measurement rather than based on a visual judgment.

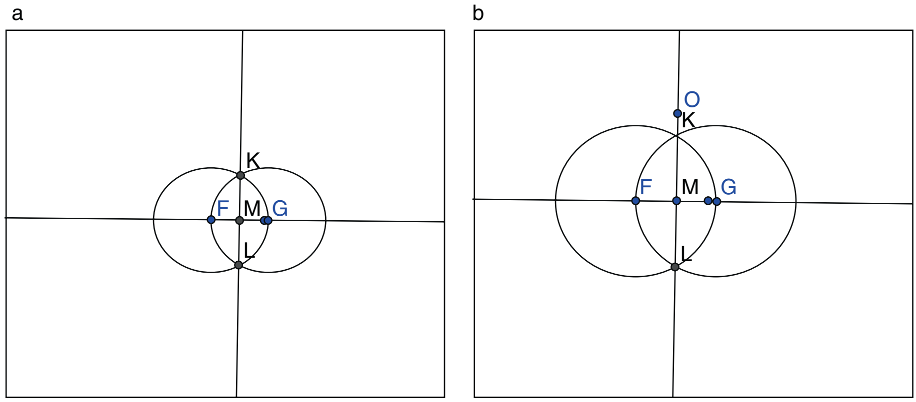

Fig. 9.6 (**a**) Placing PBC on top of H and aligning with line FG. (**b**) Constructing line OH using PBC as a guide

Meanwhile, Fruitloops realized another procedure for producing the perpendicular. Even though she was able to superimpose the two figures well, she deleted the perpendicular-looking line (Line NH). This move suggested that rather than using the PBC as a tool for measuring the angles, she could use it as a straightedge to draw the perpendicular. This still represented a visual production of the perpendicular (a spatio-graphical solution); meanwhile it perhaps marked the point of new possibilities for approaching the problem. Cornflakes was following Fruitloops one step behind saying “so after construting the line we put the circle on top” (Log 9.5, Line 57). She was still seeing the PBC as a tool for checking perpendicularity rather than as a tool for drawing. Fruitloops, on the other hand, constructed another line (line OH) that looked like it concurred with the line segment KL (the segment perpendicular to segment IJ in the PBC construction, Fig. 9.6b). Cornflakes then realized what Fruitloops was trying to do as she typed “so put the line thru the line on the circle” (Log 9.5, Line 58). Fruitloops, however, was not sure how to proceed. She deleted her line (line OH) and even constructed an intersecting line (not a perpendicular). She next deleted that too and finally said “I don’t know what I am doing help” (Log 9.5, Line 59).

In this episode, two new routines emerged. First, initiated by Cornflakes, the routine of verification shifted from one that is based on perception to one that is based on measurement by making use of a new visual mediator, the PBC. She wanted to use the PBC, which is known to be perpendicular, to check perpendicularity. She got help from Fruitloops to do that. Secondly, the production of the perpendicular also changed character involving the same visual mediator. While helping Cornflakes, Fruitloops wanted to imitate a paper-pencil routine of drawing the perpendicular using the PBC as a straightedge, yet she left the work unfinished. Cornflakes adopted this new routine as well.

Log 9.5

Line	Post time	User	Message
56	3:56:28.6	cornflakes	Yes
57	3:57:05.2	cornflakes	so after construting the line we put the circle on top
58	3:57:56.8	cornflakes	so put the line thru the line on the circle
59	3:58:18.5	fruitloops	i dont know what i am doing help
60	3:58:24.8	fruitloops	someone else take control

Table 9.5 provides a summary of the analysis presented for Episode 3.

Table 9.5 Summary of Episode 3 in terms of discourse characteristics

Production of the perpendicular routine	Verification of perpendicularity routine	Use of the word *perpendicular*	Use of visual mediators
Spatio-graphical solution/imitation of paper-pencil routine of drawing the perpendicular using PBC as straightedge (Fruitloops & Cornflakes)	Measurement-based verification using PBC (Cornflakes & Fruitloops)		PBC as protractor (Cornflakes) PBC as straightedge (Fruitloops)

Episode 4: Use of Circles with No Dependencies (3:58:27–3:59:52)

Taking control after Fruitloops, Cornflakes first dragged the PBC away. For a while, she seemed to play with the PBC: randomly constructing points on it, dragging them, and moving the labels of the points. Then, Cheerios jumped in, suggesting to "make the line first" (Log 9.6, Line 61). One can infer that Cheerios was still trying to produce the perpendicular line visually. In response, Fruitloops clarified her approach: "i think you need to make the circles first" (Log 9.6, Line 62). This statement signaled a new routine regarding the production of the perpendicular, that is, Fruitloops proposed using the construction of circles to produce the perpendicular just as the team had done with the PBC and the equilateral triangle in the previous topic (Topic 2).

Following her statement, Fruitloops took control and embarked on constructing. At this moment, Cornflakes said "put point m on top of h" (Log 9.6, Line 63), that is, she proposed moving the PBC back on top of point H. This statement suggested that she was not yet following Fruitloops. She wanted either to use the PBC to check perpendicularity or, more plausibly, to use it as a guide to draw the perpendicular. Fruitloops, on the other hand, started the construction by creating two circles with centers at F and G and with radii GQ and FR, respectively (Fig. 9.7). However, although GQ and FR looked the same, they were not constructed as equal. This was, in fact, the same procedure she had initially followed with the PBC construction at the very beginning of their session (Fig. 9.2a). She later constructed another and larger circle with center H and radius HS around these two circles but immediately deleted it. Thus, although she realized that there had to be a construction involving circles, she failed to create the dependency for equal-radius circles. She then released control.

At this stage, Fruitloops suggested a new routine for the production of the perpendicularity, the one that included creating circles. It is quite plausible that this newly emerged routine had been triggered by the presence of the PBC in the problem-solving environment. Although she wanted to follow a procedure that involved constructing circles, she was not able to build the necessary dependencies. Neither Cornflakes nor Cheerios was at this level yet.

Log 9.6

Line	Post time	User	Message
61	3:58:35.8	cheerios	make the line first
62	3:58:51.2	fruitloops	i think you need to make the circles first
63	3:59:19.0	cornflakes	put point m on tp of h

Table 9.6 provides a summary of the analysis presented for Episode 4.

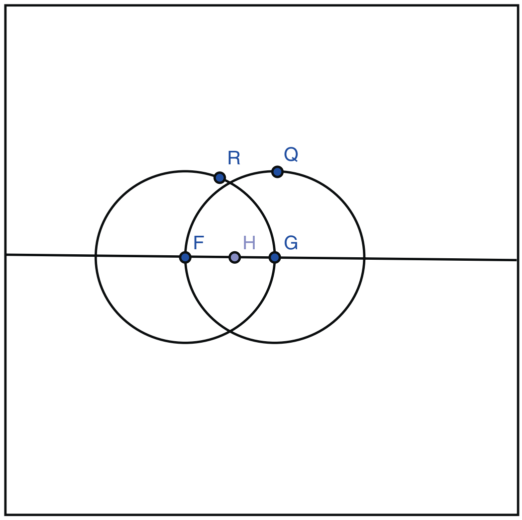

Fig. 9.7 Construction of two circles with different radii (GQ and FR) centered at F and G

Table 9.6 Summary of Episode 4 in terms of discourse characteristics

Production of the perpendicular routine	Verification of perpendicularity routine	Use of the word *perpendicular*	Use of visual mediators
Use of circles with no dependencies defined (Fruitloops)			PBC as image of construction (Fruitloops)

Episode 5: Constructing Dependencies (3:59:53–4:14:15)

Although Fruitloops was not able to complete what she had started immediately, Cheerios eventually took up her new reframing of the problem. After Fruitloops, Cheerios took control. She constructed a line through points T and S (new points) and adjusted it so that line TS would look like it passed through not only H but also the intersections of the circles that Fruitloops constructed (Fig. 9.8a). Cheerios tried several strategies to make the line TS go through the intersections of the circles and point H, such as constructing a point very close to H (point U) and a line through that. However, as Fruitloops observed, the line was not going through H (Log 9.7, Line 64). Thus, although Cheerios was now building on what Fruitloops had started, there were two problems with their attempts to construct the perpendicular. First, H was not defined as the midpoint of a line segment. Secondly, the circles around the endpoints did not have the same radius. In other words, although their production of the perpendicular routine now included the use of circles, no dependencies were constructed.

At this point, Cornflakes provided a definition for bisection, saying, “bisection is a division of something into two equal parts” (Log 9.7, Line 65), which was not given to them with this task. Cheerios then took control and moved point H to the line; however it did not attach to the line. Next, Cornflakes played with the line as well moving it around point H and saw that it was not set to pass through H. Then Fruitloops realized the problem saying, “we didn’t put a point between the circles so the line isn’t perpendicular” (Log 9.7, Line 66) and later adding “the part where the circles intersect” (Log 9.7, Line 69).

Although Fruitloops was not using a formal mathematical language to explain her reasoning, this statement provided a new perspective on the production of the perpendicular as creating certain dependencies (which she demonstrated by actually performing the construction later). In response, Cornflakes dragged line FG and saw that dragging messed up their solution (Fig. 9.8b). Cheerios

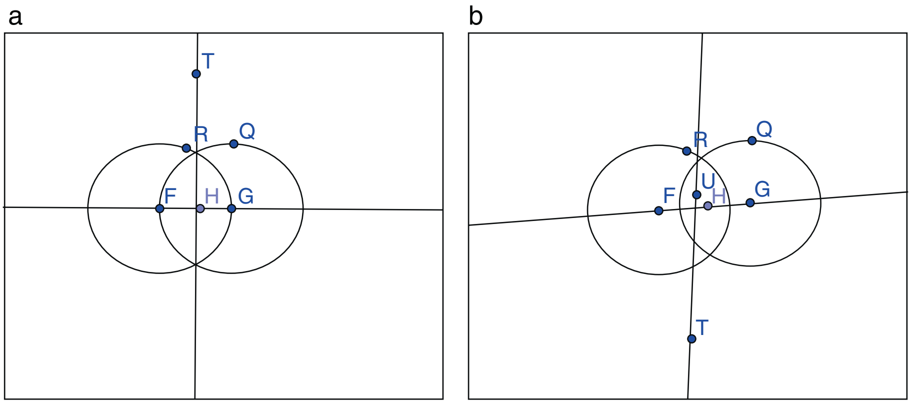

Fig. 9.8 (**a**) Construction of line TS. (**b**) Dragging line FG

agreed with Fruitloops immediately saying "oh I see now" (Log 9.7, Line 68). Cornflakes, however, kept on moving other parts of the figure (such as points H and F) to make intersections and their perpendicular-looking line (TH) concur. Observing that Cornflakes was not convinced, Fruitloops suggested that she look at the examples. Finally, Cornflakes said, "ok I see" (Log 9.7, Line 71).

Now that the team members seemed to be all on the same page, they spent some time discussing who would do the construction. Finally, Fruitloops took control and cleared up the space first by removing some points and their perpendicular-looking line. Then she created two circles at centers F and G with the same radius FG correctly (Fig. 9.9). She also constructed the intersections (points Q and R) and explained what she did: "so i made two circles that intersect and the radius is the same in both circles right?" (Log 9.7, Line 79). Cheerios agreed, "yea they are the same" (Log 9.7, Line 80). Fruitloops highlighted once more that their radii were FG: "and segment fg is the radius" (Log 9.7, Line 81). These statements confirmed that Fruitloops wanted to focus the group's attention on constructing certain relationships. Cornflakes followed with a "yes" (Log 9.7, Line 82). Cheerios said, "now we have to make another line" (Log 9.7, Line 83). However, Fruitloops did not want to continue, saying: "yeah someone else can do that" (Log 9.7, Line 84).

Log 9.7

Line	Post time	User	Message
64	4:02:26.9	fruitloops	the line isn't going through part h
65	4:02:39.5	cornflakes	bisection is a division of something into two equal parts
66	4:04:58.2	fruitloops	we didn't put a point between the circles so the line isn't perpendicular
67	4:05:03.8	fruitloops	line*
68	4:05:19.4	cheerios	oh i see now
69	4:05:20.6	fruitloops	the part where the circles intersect
70	4:05:34.8	fruitloops	look at the examples and you'll see
71	4:05:46.9	cornflakes	ok i see
72	4:05:51.8	cheerios	r u fixing it
73	4:05:54.7	fruitloops	do you want to do it?
74	4:06:02.0	cornflakes	so we have to put a poijt between the circles
75	4:06:19.4	fruitloops	yeah you can do it if you want
76	4:06:43.5	fruitloops	or should i do it?
77	4:06:49.4	cornflakes	you can
78	4:06:49.6	cheerios	yea u should
79	4:08:23.3	fruitloops	so i made two circles that intersect and the radius is the same in both circles right?
80	4:08:41.9	cheerios	yea they are the same

Line	Post time	User	Message
81	4:08:55.1	fruitloops	and segment fg is the radius
82	4:08:58.4	cornflakes	yes
83	4:09:04.1	cheerios	now we have to make another line
84	4:09:14.8	fruitloops	yeah someone else can do that

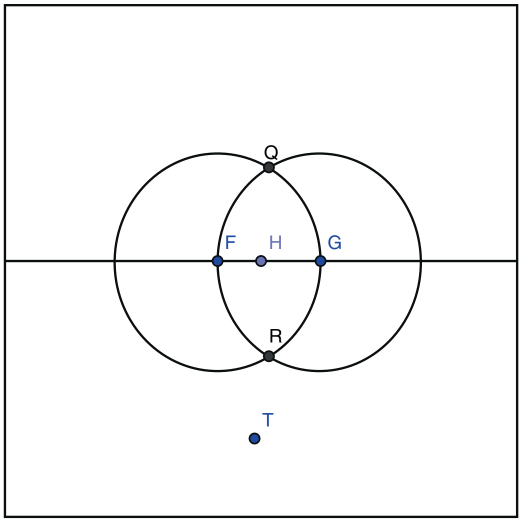

Fig. 9.9 Construction of two circles with the same radius (FG) centered at F and G

In this episode, Fruitloops identified one of the problems with the construction in Line 66 (Log 9.7): the need to create equal-radius circles. Although one can argue that she was not fully aware of the mathematical meaning of this dependency, she must have come to a realization that the way circles are constructed matters. She furthermore carried out the construction and drew attention to the defined relationships (circles with the same radius). The team members agreed upon this procedure. Thus, Fruitloops turned the routine of production of the perpendicular into a construction, one that is based on defining dependencies. Her use of the word "perpendicular" in Line 66 (Log 9.7) also reflected this change in the production routine. Here "perpendicular" was not used to represent a visual image or to evaluate a figure based on that image, as in her previous uses of the word. Rather, the word referred to a mathematical relationship that results from the way the circles were constructed.

There was still one other dependency the team needed to consider. This issue came up when Cornflakes responded to Fruitloops' invitation and constructed a line passing through Q and R (the circle intersections) and U (Fig. 9.10a). Seeing that it did not pass through H, Cornflakes deleted almost half of Fruitloops' construction hoping to solve it, even going back to making the same mistake Fruitloops made (not noticing the role of equal-radius circles at the endpoints of a line segment). However, she eventually repeated the same construction steps and went back to the point where she started. Since H was not defined as the midpoint of the radius, the line through the circles' intersection points was not going through it. At this point, Fruitloops suggested a solution with the problem of H: "you make the points go through qr and then you move h ontop of the line" (Log 9.8, Line 85). Q and R were the intersection points of the circles Cornflakes deleted. Next, Fruitloops took control and she performed what she said; she constructed the intersection points Q and R back again and the line through them and attached H to that line by simply dragging it (Fig. 9.10b). Then she announced that she finally did it (Log 9.8, Line 86).

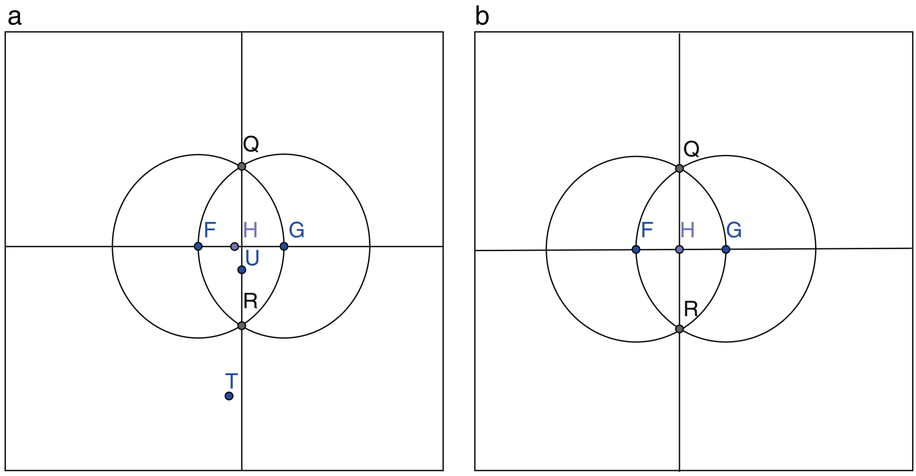

Fig. 9.10 (**a**) Construction of line QR. (**b**) Attaching point H to line QR

Table 9.7 Summary of Episode 5 in terms of discourse characteristics

Production of the perpendicular routine	Verification of perpendicularity routine	Use of the word *perpendicular*	Use of visual mediators
Constructing dependencies/use of equal-radius circles (Fruitloops) Dynamic solution/attaching the arbitrary point H to the line (Fruitloops)		Signifying a mathematical relationship (Fruitloops)	

Although the team seemed to be on the same page regarding one of the dependencies (constructing equal-radius circles), the dependency regarding the point H was overlooked. Fruitloops simply attached the arbitrary point to their perpendicular line, and this procedure seemed to work. Therefore, her routine of constructing a perpendicular through an arbitrary point did not involve taking that arbitrary point as the reference point as the task author intended. Rather, she took advantage of the dynamic geometry by simply dragging the point to the perpendicular.

Log 9.8

Line	Post time	User	Message
85	4:11:09.8	fruitloops	you make the points go through qr and then you move h on top of the line
86	4:13:08.4	fruitloops	i think i did it finallyu
87	4:13:49.1	cornflakes	the klines bisec the circle
88	4:14:15.3	cornflakes	*the lines bisect the circle

Table 9.7 provides a summary of the analysis presented for Episode 5.

Episode 6: Discussing Why the Construction Worked (4:14:29–4:16:17)

Immediately after producing a solution, Fruitloops raised the question, “but how do we know for sure that the line is perpinmdicular” (Log 9.9, Line 89). Cheerios said she was not sure (Log 9.9, Line 90).

Cornflakes first mentioned the spatio-graphical aspect of the figure by saying: “there 90° angles” (Log 9.9, Line 91). However, Fruitloops was looking for another explanation. She said, “but you cant really prove that by looking at it” (Log 9.9, Line 93). In response, Cornflakes participated within this new discourse sensing that the explanation had to do with the circles. She said, “they intersect throught the points that go through the circle” (Log 9.9, Line 94). Fruitloops built on that and said, “it has to do with the perpendicular bisector” (Log 9.9, Line 95). The two continued the discussion with Cornflakes saying “they ‘bisect’ it” (Log 9.9, Line 96). Fruitloops must have thought Cornflakes referred to the line segment by “it” and added, “and the circles” (Log 9.9, Line 97). Cheerios was relatively quiet when Fruitloops and Cornflakes were looking for a deeper understanding. She simply said, “oh I see” (Log 9.9, Line 98) as a response. However, before they moved to the next tab, she was the one who dragged their perpendicular construction extensively, confirming the integrity of the construction as suggested by the final step in the topic instructions.

In this episode, it became clear that Fruitloops was not content with a spatio-graphical verification routine. She completed the task yet also wondered why it worked. This may indicate that she was ready for a formal mathematical explanation. While Cheerios remained silent, Cornflakes participated within this conversation. Fruitloops’ use of the word “perpendicular” in line 89 (Log 9.9) sounded more mathematical as she asked, “how do we know for sure the line is perpendicular?” She further mentioned the PBC as if highlighting its significant role within this problem-solving session.

Log 9.9

Line	Post time	User	Message
89	4:14:29.8	fruitloops	but how do we know for sure that the line is perpinmdicular
90	4:14:39.6	cheerios	im not sure
91	4:14:42.1	cornflakes	there 90° angles
92	4:14:45.4	cheerios	do u cornflakes
93	4:14:59.4	fruitloops	but you cant really prove that by looking at it
94	4:15:06.8	cornflakes	they intersect throught the points that go through the circle
95	4:15:17.7	fruitloops	it has to do with the perpendicular bisector
96	4:15:19.8	cornflakes	they “bisect” it
97	4:15:31.2	fruitloops	and the circles
98	4:15:37.2	cheerios	oh i see

Table 9.8 provides a summary of the analysis presented for Episode 6.

Table 9.8 Summary of Episode 6 in terms of discourse characteristics

Production of the perpendicular routine	Verification of perpendicularity routine	Use of the word *perpendicular*	Use of visual mediators
	-Spatio-graphical (cornflakes) -Looking for a verification routine beyond spatio-graphical evidence (Fruitloops & Cornflakes)	Signifying a mathematical relationship (Fruitloops)	

Discussion

Mathematical experiences at the middle-school level are considered critical for students to develop deductive and formal thinking (Ellis, Lockwood, Williams, Dogan, & Knuth, 2012). Harel and Sowder (1998) note that it would be unreasonable to expect that students will instantly appreciate sophisticated forms of mathematics in high school, where expectations regarding mathematical rigor are higher. Therefore, it is important to provide learning opportunities for middle-school students to advance their geometric thinking. The VMT environment is designed to serve this purpose by affording virtual collaborative problem-solving with a multi-user GeoGebra component. It is important to study the ways in which teams of students using the VMT software and its curriculum are learning geometry and what problems they encounter. Toward this end, Sfard's (2008) discursive lens was employed to investigate the change in mathematical discourse of a team of three middle-school students as they worked on a geometry construction problem in the VMT environment. The analysis focused on how the team's use of the word "perpendicular," its use of the PBC as a visual mediator, and its use of routines (for production of a perpendicular and for verification of perpendicularity) shifted during an hour-long collaborative problem-solving session. The findings indicated that the Cereal Team, whose members had very limited formal geometry background, moved forward from a visual discourse toward a more sophisticated formal mathematical discourse.

To be specific, the team started constructing two line segments as perpendicular bisectors of each other following the instructions of Topic 3 (Episode 1). In this part, Cheerios' use of the word "perpendicular" was copied from the task instructions as if using a foreign language word in a sentence. The team next moved to the second task, which was built on the first one. This presented a challenge as the team needed to figure out how to construct a perpendicular to a line through a given point, which they had not done before.

Table 9.9 summarizes the team's use of the word "perpendicular," their use of visual mediators, their routines of production of a perpendicular, and their verification of perpendicularity in Episodes 2, 3, 4, 5 and 6, where the team worked on the second task in Topic 3.

In the *production of the perpendicular routine column* in the summary Table 9.9, one can see that the team started by producing spatio-graphical solutions including placing the perpendicular line visually and imitating the paper-and-pencil procedure of drawing the perpendicular by using the PBC as a straightedge guide (in Episodes 2 and 3). These routines, however, evolved into first using circles (in Episode 4) and then defining certain relationships with the circles, such as the use of equal-radius circles with the construction allowing the group to successfully complete the task (in Episode 5). The second dependency, however, was bypassed by simply attaching the arbitrary point H to the perpendicular line. Although no dependencies were created here, as Sfard (personal communication, June 2014) observed, this could be considered a legitimate move in GeoGebra. In a dynamic geometry world where everything moves, the point of reference may be redefined as well, as long as the software supports this use.[1]

A parallel progression can also be observed in the *verification of the perpendicularity routine column*. The team first felt the need to verify their solution, which was not explicitly asked in the instructions. Initially, this took a spatio-graphical form, with Cheerios wanting to arrange the lines into a vertical-horizontal position, which represents the prototypical visual image for perpendicularity (in Episode 2). Then Cornflakes, who received help from Fruitloops, wanted to use the PBC as a protractor turning the verification routine into one that is based on measurement (in Episode 3). Eventually, Fruitloops, upon completing the construction, asked how they could be sure if the line was perpen-

[1] The instructions specified that, "point H is an arbitrary point on line FG." In Euclidean geometry, that would mean that even though H can be any point on line FG, it is not something that moves. Thus, although one looks for a solution that would work for any point H, any treatment of H would be static. In dynamic geometry, however, an arbitrary point H is a free point that can be dragged along line FG. Thus, there is some legitimacy to the students' solution. Ultimately, however, the solution fails the drag test of dynamic geometry. If one properly constructs the perpendicular through point H, then one should be able to drag point H along line FG and have the perpendicular to FG move with it so that it always passes through H and remains perpendicular to FG. Cheerios, however, had only dragged their final construction by moving point G.

Table 9.9 The change in discourse in Episodes 2–6 (summary)

Episode	Production of the perpendicular routine	Verification of perpendicularity routine	Use of the word *perpendicular*	Use of visual mediators
2	Creating another reference line in relation to line FG (Cornflakes and Cheerios) Spatio-graphical solution/drawing a perpendicular-looking line (Cornflakes) Spatio-graphical solution/drawing a perpendicular-looking line (Cheerios & Cornflakes)		Signifying a visual image of perpendicular to disagree with a spatio-graphical solution (Fruitloops) Signifying a visual image of perpendicular to disagree and then agree with a spatio-graphical solution (Fruitloops)	PBC random dragging (Cornflakes)
	Spatio-graphical solution (Cornflakes, Fruitloops, Cheerios)	Spatio-graphical verification/vertical-horizontal alignment of the lines (Cheerios)	Signifying a visual image of perpendicular to agree with a spatio-graphical solution (Fruitloops)	
3	Spatio-graphical solution/imitation of paper-pencil routine of drawing the perpendicular using PBC as straightedge (Fruitloops & Cornflakes)	Measurement-based verification using PBC (Cornflakes & Fruitloops)		PBC as protractor (Cornflakes) PBC as straightedge (Fruitloops)
4	Use of circles with no dependencies defined (Fruitloops)			PBC as image of construction (Fruitloops)
5	Constructing dependencies/use of equal-radius circles (Fruitloops) Dynamic solution/attaching the arbitrary point H to the line (Fruitloops)		Signifying a mathematical relationship (Fruitloops)	
6		Spatio-graphical (Cornflakes) Looking for a verification routine beyond spatio-graphical evidence (Fruitloops & Cornflakes)	Signifying a mathematical relationship (Fruitloops)	

dicular (in Episode 6). In this episode, Cornflakes pointed at the visual appearance of the figure to convince Fruitloops. However, Fruitloops seemed to be looking for a verification routine that would go beyond the spatio-graphical. She even used the word "proof"—though not necessarily in a deductive mathematical sense. This situation is quite contrary to the findings in the literature, as students' validation of a mathematical statement often takes the form of testing it against a few examples, even at the more advanced levels (Chazan, 1993b; Coe & Ruthven, 1994). In the case of dynamic geometry, students often think that they can justify a claim by empirically checking the diagram (Laborde, 2004)—that is, by dragging.

This situation and the difficulty the team had with defining point H as the middle point suggest revisions in Topic 3. The group constructed the PBC at the beginning of their session following scripted steps. Completing the task with Fruitloops, Cheerios said, "I just made the intersecting line and point in the middle," continuing, "it made a perpindicular line" (Log 9.1, Lines 32–33). However, there was not much discussion of its mathematical aspects. The group immediately moved to the next task of constructing a perpendicular to a line through a given point. It may be necessary to lead students explicitly to discuss their constructions mathematically when scaffolding the development of higher-level discourses. If participants are genuinely wondering about the relationships and asking questions, as in the present case, additional task instructions could even provide the geometrical theory behind such constructions. Encouraging students to make explicit connections between their deduction and construction knowledge is important; otherwise, as Schoenfeld (1988) cautioned, students may be learning about dynamic constructions merely as a set of procedures to follow.

The word *perpendicular* was first used by Cheerios in the first part of the task (Episode 1). She uttered the word only once, as if to revoice the instructions. Fruitloops, on the other hand, used the word throughout the problem-solving session. Her use of the word also represented a parallel advancement along with the production and verification routines. Initially the word signified a visual image of perpendicularity and was used to evaluate produced visual solutions (in Episodes 2 and 3). Later, however, her use of the word came to refer to a certain relationship between figures (in Episodes 5 and 6).

Finally, it is reasonable to argue that the *PBC*, the already completed construction, functioned as *the key visual mediator* of the session. The PBC figure is derived from Euclid and was presented as a resource in the Topic 3 instructions. The group was also asked to construct the PBC at the beginning of their session following very specific steps. In the second task, Cornflakes brought it to the team's attention when the team seemed to be out of ideas (in Episode 2). Although at first she only played with it randomly, she later figured out a way to use it as a protractor, thus as a tool for verifying perpendicularity (in Episode 3). This use may have led Fruitloops to view it as a straightedge that could be used to draw the perpendicular (in Episode 3). More importantly, however, the PBC became a crucial resource that probably triggered Fruitloops' use of circles, which led to the framing of the problem as a construction task (in Episode 4).

These observations about the PBC are important for at least three reasons: First, when students appear to be stuck with the problem or run out of ideas, they seem to make use of every resource within their problem-solving space. Ryve, Nilsson, and Pettersson (2013) underline the crucial role that visual mediators play in effective communication. However, along with visual mediators, they have also observed that technical terms (i.e., technical mathematical words) were equally important for communication that is effective. In Episode 5, just before Fruitloops framed the task as construction, Cornflakes provided a definition for the term "bisection" (Log 9.7, Line 65). This definition was not given to the team with the task; thus Cornflakes must have found it somewhere else. A little later, when Fruitloops realized the problem with their circles, she was lacking the mathematical terms to express the situation. She said "we didn't put a point between the circles so the line isn't perpendicular" and then "the part where the circles intersect" (Log 9.7, Lines 66, 69). Hence, CSCL task designers should pay considerable attention to the type of resources to be provided to students with the problems. These resources should encompass not only visual mediators but also the technical mathematical words.

Secondly, Cornflakes initially was not able to place the PBC on top of line FG correctly, but Fruitloops completed what Cornflakes had in mind, and Cornflakes responded with a "yes." Afterward, Fruitloops realized another procedure for producing the perpendicular (i.e., use the PBC as a straightedge to draw the perpendicular). All these suggest that in a setting like VMT, "transactive dialogue" (Berkowitz & Gibbs, 1985 as cited in Barron, 2000) can take place through participants' actions using visual mediators on the shared computer screen. This seems more likely when students lack the technical terms to express themselves, as in this case. The "take control" button opens up a "joint problem space" for dynamic manipulations and affords action-based dialogue, in addition to the conversational turns supported by the chat platform. In that way, as Roschelle and Teasley (1995) observed, participants can still interact productively even when they lack the technical vocabulary to talk about the problem.

Third, and most importantly, one could observe that the PBC accompanied the moments of change in mathematical routines: first from the vertical-horizontal alignment of the lines to the use of PBC as a straight-edge guide in Episode 3 and then to the use of circles in producing the perpendicular in Episode 4. Thus, it is reasonable to assume that it played a significant role in the change in mathematical discourse in this problem-solving session.

Along with the PBC, other aspects of the VMT environment also seemed to play a role in the moments of discourse shifts. In Episode 4, Fruitloops introduced a new production routine when she suggested making the circles first (Log 9.6, Line 62) and started constructing the circles. The team constructed circles in the first part of Topic 3 (to construct PBC) and the equilateral triangle in the previous topic in the VMT curriculum (Topic 2), which also required using circles in defining dependencies. Thus, the VMT curriculum, particularly the sequence of the topics in that curriculum, might have also played an important role in supporting students' discourse development.

Initially Fruitloops' circles were not created using the necessary dependencies such as the equal-radius relationship. As no dependencies were defined, the team had problems creating the line that would go through the intersections of the circles and the point H. That is, the dynamic geometry software provided the essential feedback until Fruitloops realized that they needed to construct the circles with certain relationships (in Episode 5). Both Cheerios and Cornflakes played with their construction to see that there was something missing with their solution at that stage. This situation also confirms Roschelle and Teasley's (1995) observation that when students had differing ideas, they were able to experiment with the computer representation. In a dynamic geometry environment, the drag function enables testing the construction if dependencies are correctly defined. Eventually, this experimentation leads the participants to generate new ideas, when they see that their solution is not supported by the software.

This analysis was conducted at the group unit of analysis involving the team discourse rather than the individual cognition of the students.[2] This analysis is not necessarily meant to suggest that the individual team members, including Fruitloops, decisively moved beyond the visual discourse. Nor is the observed discursive jump by the team necessarily an indication of "individualization" (Sfard, 2008) that the team members will henceforth follow more formal mathematical procedures and

[2]In a similar analysis of all eight sessions of the Cereal Team, Stahl (2016) conceptualizes the development of the group's mathematical cognition in terms of the successive adoption of group practices, rather than routines, in order to emphasize that they are being theorized as group-level rather than individual phenomena. As illustrated in the six episodes here, the Cereal Team questions, negotiates, and adopts new practices through their discourse (including shared GeoGebra actions). This meaning-making process creates a shared understanding within the team. Once the team agrees to use a routine, it may become a group practice, which can be used in the future without further discussion.

employ more formal word uses irrespective of the context. One can observe that Cornflakes and Cheerios were mostly attending to the spatio-graphical aspects of their figure, even toward the end of the session. Even Fruitloops was not able to clearly articulate why and how circles worked.

This team of novices succeeded in participating within a collective discourse that gradually took a more mathematical character. Yet, this more formal discourse was, as Baruch Schwarz (personal communication, June 2014) suggested, *rooted* in the spatio-graphical solutions—i.e., solutions that rely on reasoning and recognition of geometric figures with their appearances without any regard to their mathematical properties (Laborde, 2004). Thus, similar to what Sinclair and Moss (2012) noted, the process of discourse change may be better described as oscillating—rather than simply shifting—between the visual and more formal discourse levels.

Sfard's commognitive framework provided an account for the development of geometrical thinking observed within this episode. Rather than talking about fixed-ordered geometrical cognitive levels, as in van Hiele levels (Van Hiele, 1986), Sfard (2008) talks about incommensurable mathematical discourses. Saying that two discourses are incommensurable does not mean that one cannot participate in both of them at the same time. It simply means that "they do not share criteria for deciding whether a given narrative should be endorsed" (Sfard, 2008, p. 257). However, moving toward higher discourse levels requires "student's acceptance and rationalization (individualization) of the discursive ways of the expert interlocutor" (p. 258). Thus, students need to interact with expert others in order to develop sophisticated mathematical discourses. The findings in this study indicate that an environment such as VMT may provide a context in which students can engage in higher-level mathematical discourses with their peers.

Thus, along with instruction by expert mathematicians, well-designed virtual collaborative learning environments can provide a form of interaction that supports significant mathematical discourse development. In that regard, the findings support Sinclair and Moss (2012), who suggested that dynamic geometry software could function as a stand-in or alternative for the discourse of experts. In the present case, multi-user dynamic geometry was a component of the VMT software, which was built to support collaborative learning with a specific geometry curriculum (Stahl, 2013b). Therefore, in addition to the dynamic geometry component, the curriculum and the collaborative interaction aspects of the VMT environment also played crucial roles in supporting students' mathematical discourse development.

There is a tendency in educational research to reduce cases of group cognition to psychological phenomena of individual cognition. Considering the Cereal Team's problem-solving session, one may be inclined to think that Fruitloops was the higher thinker in this session. Not only did she appear to be the one solving the second task, she also wondered why it worked. However, that was not where she started. Initially, her notion of perpendicular referred to a visual image. It evolved into one that represented a mathematical relationship. Similarly, at the beginning, her routine of the production of the perpendicular involved a spatio-graphical solution, the same as for everyone else in the team, which only later became one that was based on defining dependencies. These transformations took place within the context of interacting with her team members, enacting task instructions, and interacting with the VMT software. Furthermore, most of the time, her lead was negotiated with the other team members, as part of the team's coordination of social resources (Oner, 2013). These took the form of the others building on her actions (as in Episode 5) as well as engaging in *transactive dialogue* (Berkowitz & Gibbs, 1985 as cited in Barron, 2000) with Cornflakes (as in Episode 6). She received help from other team members (as in Episode 1). The PBC was brought to her attention by other team members (Cornflakes) as well. Thus, the team's success was the product of group cognition, not simply attributable to one team member (Stahl, 2006).

Would the findings be applicable for other online groups? Qualitative case studies, such as this one, are not usually designed to make grand generalizations concerning the population. They, however, allow making what Stake (1978) calls "naturalistic generalizations," that is, the findings from a case would generalize to another similar case, rather than to the population and then to particular situations. Furthermore, this case study should not be viewed as a summative assessment of the VMT environment but as part of one cycle in an iterative DBR investigation. Accordingly, it was more concerned with documenting learning and how a team of novice students accomplished significant advance in mathematical discourse within the VMT environment in order to guide modifications in technology, pedagogy, and curriculum—so that more student groups might undergo similar mathematical development in future versions of VMT.

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Investigation 10. Time Is Precious: Variable- and Event-Centered Approaches to Process Analysis in CSCL Research

Peter Reimann

Abstract

Although temporality is a key characteristic of the core concepts of CSCL—interaction, communication, learning, knowledge building, and technology use—and although CSCL researchers have privileged access to process data, the theoretical constructs and methods employed in research practice frequently neglect to make full use of information relating to time and order. This is particularly problematic when collaboration and learning processes are studied in groups that work together over weeks, and months, as is often the case. The quantitative method dominant in the social and learning sciences—variable-centered variance theory—is of limited value for studying change on longer timescales. We introduce the event-centered view of process as a more generally applicable approach, not only for quantitative analysis but also for providing closer links between qualitative and quantitative research methods. A number of methods for variable- and event-centered analysis of process data are described and compared, using examples from CSCL research. I conclude with suggestions on how experimental, descriptive, and design-oriented research orientations can become better integrated.

Keywords

Process analysis · Qualitative methods · Quantitative methods · Research methods

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P. Reimann (✉)
Research Centre for Computer-supported Learning and Cognition (CoCo), University of Sydney, Sydney, NSW, Australia
e-mail: p.reimann@usyd.edu.au

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Time (and Order) Matters

CSCL is concerned with technology-mediated learning as it takes place in groups. Independently of the context of the learning—on the level of the individual, the group, the situation, or in the interaction of these—the main object of analysis in CSCL is a process, something that unfolds over time. As Koschmann (2001) suggested, it might be a defining element of CSCL that it is about "...studying learning in settings in which learning is observably and accountably embedded in collaborative activity" and that learning within these settings is to be conceptualized as an "unfolding process of meaning making" (p. 19). More recently, Stahl argues that one can meaningfully speak about group cognition as different from the sum of individual cognitions (Stahl, 2006). This is substantially different from the psychological notion of learning as a basically unobservable process, taking place in the mind/brain, a process we can observe only indirectly by measuring learning outcomes. However, for both views of learning, the sociocultural and the individual cognitive, the nature of the process remains temporal: Learning unfolds over time.

Temporality does not only come into play in quantitative terms (e.g., durations, rates of change), but *order* matters: Because human learning is inherently cumulative, the sequence in which experiences are encountered affects how one learns and what one learns (Ritter, Nerb, Lehtinen, & O'Shea, 2007). This can certainly be generalized to learning in groups and to the communication and interaction processes that take place in groups in addition to learning.

Groups are subject to, and subject themselves to, change processes of various kinds. In a book that is dedicated to discern these types of processes, McGrath and Tschan (2004) distinguish four categories: (a) developmental processes, which are inherent to the system; (b) adaptational processes "generated by the system's response to (actual or anticipated) changes in the embedding context" (p. 6); (c) learning processes, which are based on a system's experience and reflection thereof; and (d) the system's operational processes, actions, and activities, which are hierarchically and sequentially related. Learning is seen as different from adaptation in as much as it requires intentional reflection. We can speak, with McGrath and Tschan, of different types of "forces" that are responsible for these types of processes but need to keep in mind that these forces refer to different types of causality. The developmental force would be akin to Aristotelian *formal* causality; adaptational forces are at least partially of the "push" causality type; the "operational" forces are mainly *teleological* in nature because they involve a strong element of goal orientation, of purpose.

All four sets of forces are intrinsically temporal and can operate simultaneously, as illustrated with Fig. 10.1. While a group is performing a certain task, it is also in a certain developmental stage, reacting to environmental changes, and learning from aspects of the task performance. McGrath and Tschan see all forces as acting *continuously,* but I suggest reserving this assumption for the developmental forces only. While they see process in terms of variables and are, hence, "forced" to assume continuity of causation, the event perspective on process introduced below allows us to relax this assumption.

Taking time and order into account becomes particularly relevant, but also more challenging, as the time frame considered for analysis grows. That CSCL is as much concerned with long-term collaboration as with short-term collaboration (e.g., talk) can be seen from an analysis of all empirical studies reported in the last two CSCL conferences (Chinn, Erkens, & Puntambekar, 2007; Koschmann, Suthers, & Chan, 2005). As Table 10.1 shows, the majority of studies analyze group interactions that extend beyond a couple of hours, and almost 50% of the studies concern groups that learned together for more than a month (of course, the duration assessed is not commensurate to "time on task").

The sequential organization of behavior has received extended treatment in Conversation Analysis, with one of its founders recently developing a whole book to the subject (Schegloff, 2007). Sequential organization refers "...to any kind of organization which concerns the relative positioning of utter-

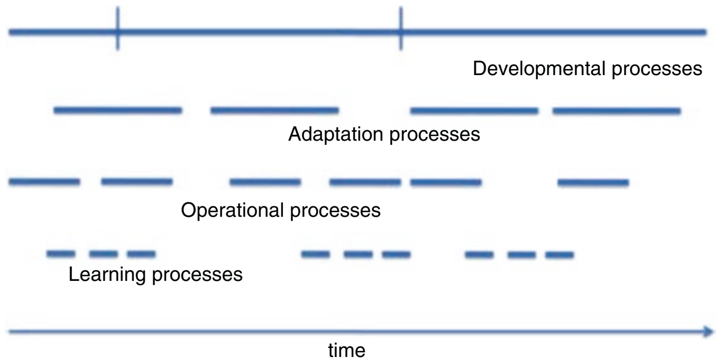

Fig. 10.1 Types of processes effective in groups on different timescales

Table 10.1 Duration of group lifetime in studies from the CSCL 2005 and 2007 conferences

"Lifetime" of groups studied	CSCL 2005	Percentage	CSCL 2007	
	No. of studies		No. of studies	Percentage
Single session (20–180 min)	25	35%	32	45%
2–6 days	5	7%	6	8%
1–4 weeks	7	10%	10	15%
Longer (1.5 months–1 year)	34	48%	23	32%

ances or actions" (p. 2). Turn taking, that is, the relative order of speakers, is a kind of sequential organization (of talk) and the most extensively studied one. However, methods developed in Conversation Analysis and ethnomethodology, with their focus on talk and embodied physical (inter-) action (Goodwin, 2000), do not carry over to interactions that are fragmented over time, stretch over longer durations, or are mediated by artifacts rather than talk. In situations where the people meet repeatedly (e.g., teamwork instead of helpline conversations), it is not only the context that matters, but each group has a history, and this history affects their activities and their learning (McGrath & Tschan, 2004). Mercer (2008) picks up on this in a recent publication for the case of communication and learning in the classroom: "Analytical methods that do not recognize or deal with the temporal development of talk, its reflexivity, and its cohesive nature over longer timescales than one episode or lesson will inevitably fail to capture the essence of the educational process" (p. 56).

In studies where interaction and learning is distributed over multiple sessions, establishing internal validity becomes difficult. For instance, as time increases, noncontrolled factors will come into play with a higher probability than is the case for short-term collaboration, and changes in group membership become more frequent, thus qualitatively changing the experimental "unit." Nonlinear changes will become more pronounced because of the self-sustaining feedback processes at work in groups over time (Arrow, McGrath, & Behrdal, 2000); that is to say, small differences can have large effects. Development in groups progresses in general in a nonlinear fashion, so that both the nature of the data and the nature of the underlying processes make it necessary to employ advanced statistical methods (Sloane & Kelly, 2008). In general, order effects will become more pronounced as groups construct their histories and make use of them, through communication, as resources for interpreting events and planning future actions.

Challenges such as these might partially account for the fact that, although CSCL researchers are privileged in the sense that they have direct access to processes as they unfold over time (via recordings), there is comparatively little research that makes use of the information contained in the order and duration of events. For instance, Kapur, Voiklis, and Kinzer (2005) made use of statistical analysis methods that take time into account, and Schümmer, Strijbos, and Berkel (2005) employ a similarity based metric to identify the similarity of change processes in log files. Muukkonen et al. (2007) use time series analysis, and Suthers, Dwyer, Medina, and Vatrapu (2007) apply graphical techniques for analysis. There is perhaps a trend, as exemplified by the Muukkonen et al. study as well as by Mochizuki et al. (2007), that CSCL researchers who employ mobile devices also use these devices to systematically gather data over time with more regular measurement intervals than is the case in studies with stationary technology such as PCs.

The goal of this paper is, in particular, to identify methods appropriate for the analysis of longtime changes (on a scale of days, weeks, months). The kind of data and the manner in which these data are analyzed and theorized need to change substantially when moving from an analysis of short-duration sequences to long-term processes. One of the reasons is that group development processes come into play, and another that multiple levels of analysis have to be considered now (Cress, 2008; Sloane, 2008). This requires extending the range of methods considered beyond those covered in reviews such as Sanderson and Fisher (1994) or Olson, Herbsleb, and Rueter (1994). In organizational science as well as in sociology, and in particular in history, the challenges of analyzing processes that capture longer stretches of time and develop on multiple levels have been intensively discussed, covering a wider range of methods than is typically done in psychology and education (see also Langley, 1999).

Building on this literature, I argue in this paper that an event-based view of process and change is an important addition to the variable-centered approach. Variables are attributes of fixed entities defined by measurement (e.g., with a scale) or by a coding and counting procedure. It is important to realize that the decision to phrase research questions in terms of variables and relations between them is a very decisive one, because many other decisions depend on this one, both metaphysical (e.g., regarding type of causality) and methodological (e.g., methods of analysis) ones. Because variables are not the only means to formulate and test (quantitative) hypotheses about time-dependent processes and data, this paper develops the case for making more use of methods in CSCL research that take *events* as the basic unit of analysis. This not only allows us to include qualitative methods but also to add additional quantitative and computational methods to the repertoire of CSCL.

The paper continues by further elaborating the difference between variable- and event-based approaches for the analysis of temporal data, at the same time illustrating some of the typical methods. I then look into the question of how one can establish causality in the event-oriented approach and touch on the relation between explanation and generalization. How to generalize over event sequences is a topic I cover because this is more challenging than in the variable approach and because a comparison of the respective generalization strategies further helps to come to terms with the differences between the two approaches. Methods for sequence mining, pattern identification, and process mining are introduced, all helpful for the business of generalizing from individual sequences. I close by identifying opportunities for combining variable- and event-based methods and pointing to possible next steps to advance process research in CSCL.

The Unit of Analysis: Variables Versus Events

In order to illustrate our discussion, let us sketch a hypothetical but prototypical scenario. The situation that we want to address is one where the researcher is interested in interaction and learning processes as they take place in online groups over time. The researchers want to test a process theory, one that says that groups need to go through a cycle of definition, conflict, and synthesis repeatedly in order to successfully engage in and learn from discussion activities. Therefore, they have developed a coding scheme that can be applied to the content of the discussion board entries and categorize them in respect to these three dimensions. The coding scheme is developed and applied following best practice (e.g., Strijbos, Martens, Prins, & Jochems, 2006). Let us further assume that the researchers are interested in design issues pertaining to the visualization of argument threads. For this purpose, they have developed a new version of the discussion board, one that includes a graphical display of the argument structure.

Our hypothetical research team has access to students in an online university course who are working together in several small groups. About half of the groups work with the old, run-of-the-mill discussion board, whereas the other half of the groups uses the new version. Data are recorded electronically in the form of the discussion board log file, so that we know who contributed what and when. Pre- and posttests are conducted to assess individual learning gains and during the pretest phase a number of other individual factors are assessed, including met cognitive capabilities. Knowledge building is assessed by analyzing the discussion board entries.

How these data are analyzed will depend largely on what the researcher considers to be the main unit of analysis. Two conceptualizations can be distinguished here. The first one, *variable-centered,* relates to analysis of variance. The second one we call *event-centered analysis* or *event analysis* for short. I use the terminology suggested by Abell (1987) and in particular by Poole, van de Ven, Dooley, and Holmes (2000), whose excellent treatment of process analysis in the social sciences informed

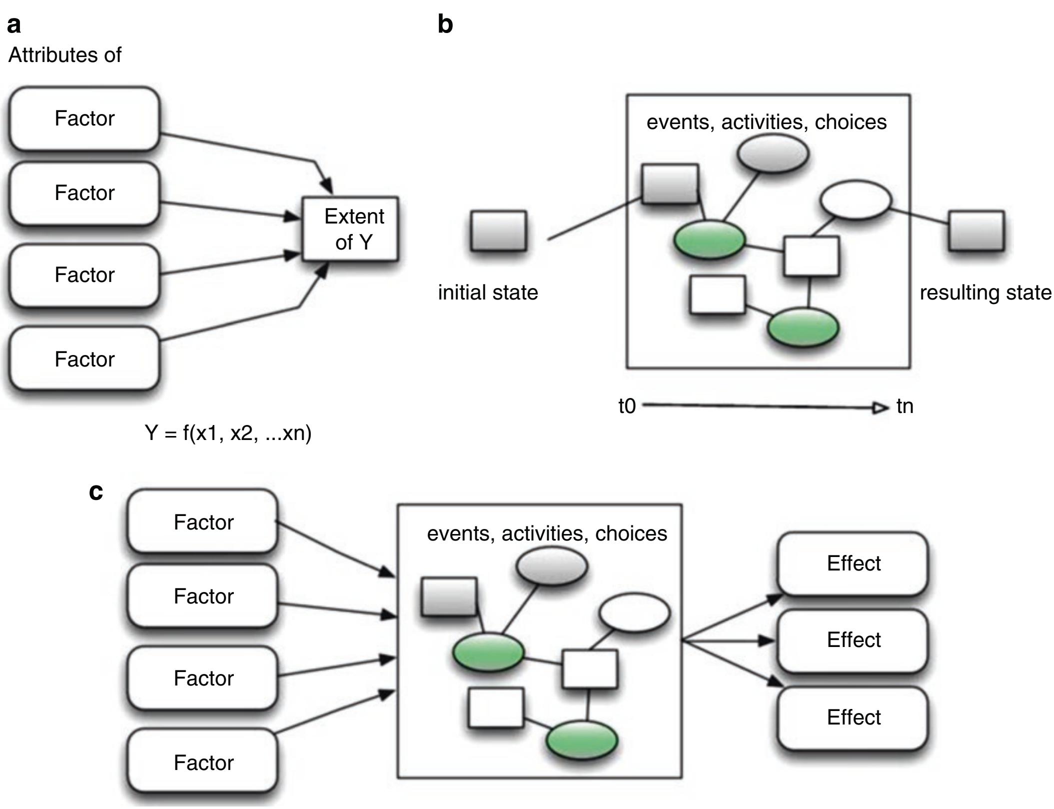

Fig. 10.2 Illustration of the variable (**a**) and event approach (**b**) and their combination (**c**)

many parts of this paper. Figure 10.2a, b depicts graphically the difference between these two views and Fig. 10.2c their combination.

Variable-Based Account

For the experimentalist, being trained in the variance method, a process takes the form of a *category of concepts* that mediate between independent and dependent variables. In CSCL, variables such as communication frequencies, learning techniques, and group decision-making techniques can play this role. Such "process concepts" are distinguished from other concepts considered to be static, such as individual learning capabilities, group makeup, or learning outcomes. A process theory for the experimentalist takes the form of a causal relationship between input and outcome variables mediated by process variables. The process concepts, like the static concepts, are operationalized as constructs and measured as variables, as fixed entities, the *attributes* of which can vary from low to high along numerical scales. A typical question that could be analyzed with this framework is the extent to which individual learning skills (exogenous independent variable) can predict learning outcomes (dependent variable), dependent on more or less successful group communication (endogenous independent variable).

For our scenario, the initial analysis would be fairly straightforward. The experimentalist would "code and count": code the data stored in the discussion board log, and count, yielding frequencies for the process categories (Definition-Conflict-Synthesis). Then these measures can be set in relation to the treatment (tool variation) as well as in relation to other variables assessed, in particular to the dependent variables: individual learning and group knowledge building. A typical analysis of variance would yield results that show if the difference in the dependent variables can be related statistically to the variation in the tool, if this relation is mediated by the process variables, and if there are (statistical) interactions with the other variables assessed (for instance, metacognitive competence).

In order to test the process theory in more detail—which says that we should see, in successful groups, cycles of issue definition followed by conflict among positions followed by synthesis/integration of positions—the researcher could treat each of these categories as a variable, using the categories' frequencies assessed at regular intervals (daily, say) as the quantitative attribute, and treat them as three time series. For each individual time series, curve fitting can be performed to test if they form a sine wave—as they should if the assumption of "repeated cycles" is correct. Having established this (and, before that, having established that the time series variables follow approximately a Gaussian distribution), the researcher could go ahead and use multivariate time series (ARIMA) models to test the dependencies between the three time series (they should follow each other and "peak" with a certain time lag, but in the order Definition-Conflict-Synthesis) and to test if and to what extent extraneous factors, in particular, the type of discussion board, affect the time series. Based on the same logic, one could also look for the effects of differences between groups (using a criterion for "successful" and "less successful" groups, for instance) and for differences between individuals (using metacognitive competence as a criterion, for instance).

There is neither need nor space for statistical details here (see, e.g., Box & Jenkins, 1976). Instead, a word on the assumptions behind the variable-centered research method may be in order. A basic assumption that underlies any research logic based on the analysis of variance is that independent variables are acting *continuously* on the dependent variables. I would argue that this basic assumption is, for CSCL scenarios, often not met. Obviously, students in our scenario will, over the duration of the semester, do many things other than the type of activities captured by the measurements. Even when they are actively engaged online, only a small set of the factors represented as independent variables might be effective at any point in time; for instance, the students using the enriched discussion board might not attend to the information offered on the visualizations. This *fragmented* nature of the underlying causal processes is not easily captured in variable-centered models.

Another thorny problem in process studies arises from the fact that all variables must be measurable at the same time point, and the temporal unit or measurement must be equal for all variables *(minimal unit of time)*. Because we will find, in any group, processes unfolding on different timescales (McGrath & Tschan, 2004), relating them in one model is a challenge indeed. As was mentioned before, the variable-centered method cannot accommodate qualitative changes in the variables. For instance, when a group loses a member or gets a new member, it is not clear if variables that build on group activities can be considered to be qualitatively the same as before.

Event-Based Account

Processes can be analyzed with statistical methods that do not require the data to be represented as variables. An example for such *stochastic* methods is Markov chain modeling. Stochastic modeling methods have a fairly long tradition in the social sciences and psychology, for example, Coleman (1964) and Suppes and Atkinson (1960), yet are not as widely taught and used in learning research as are variance analysis methods and other members of the General Linear Model family.

This is not the place to introduce stochastic modeling in any detail, but in order to provide a flavor, a simple example might be appropriate. Let us again assume that we want to test if the life cycle model that presupposes that (successful) groups will go through a cycle of Definition-Conflict-Synthesis is supported by the data. One can also see this as a dialectical model if the cycle is not imposed on groups by the pedagogical design or strongly afforded by tool design but emerges out of the interactions. We could have coded incidents directly in these terms, yielding an event sequence in each group of a form like DDDCCDCCSCCSSSS..., with D for Definition, C for Conflict, S for Synthesis. To test if this mini-theory describes the behavior in the groups adequately, one could use a Markov chain model. Markov chains belong to the class of homogenous Markov models, which are appropriate for cases where time can be considered as consisting of discrete intervals and where the only aspect we need to know about an event is when it was present in time. Being stochastic, Markov models do not predict the occurrence of a specific event but predict the probability distribution of a set of possible events at a given point in time. The Markov chain predicts the probability of occurrence of an event at time t as a function of the event occurring immediately before. No other information is taken into account.

A more complex but also more realistic case is one where we do not define events in terms of the comprehensive descriptors (Definition-Conflict-Synthesis) directly but code on a finer level of analysis. For instance, we could code the interactions in the groups with a taxonomy that is inspired by speech act or dialogue act theory (adapted to the asynchronous case). We would use, say, a coding scheme with 12 different categories, c1 to c12 (omitting any further details here). We would then look at sequences in the groups of the form like c3c1c1c5c3c12c3c6c6c6c1c2c6. To test our mini-theory of the three phases in this case, phasic analysis (e.g., Holmes, 1997) or Hidden Markov modeling (Rabiner, 1989) could be used.

These matters cannot be discussed further here (see Soller, Wiebe, & Lesgold (2002) for an example of Hidden Markov modeling in CSCL). Suffice it to say that further generalizations of Markov models have been developed. For instance, nonhomogeneous Markov processes add variables other than the events to the model. With them, we could test if two tool conditions (conventional vs. enhanced discussion board) make a difference or if individual differences add predictive power. The so-called semi-Markov process models allow information about the *duration* of events to be included (still assuming discrete events).

Like variable-based modeling, Markov models entail the assumption that history does not matter: "The entire influence of the past occurs through its determination of the immediate present, which in turn serves (via the process) as the complete determinant of the immediate future" (Abbott, 1990, p. 378). Histories are a kind of "surface reality" (Abbott) that are generated by deeper, underlying probabilistic processes that find expression in the value of variables or the conditional probabilities of event transitions. In the variable-based case, this "deep structure" is expressed in terms of linear transformations; in the event-based case, as transition probabilities. For situations where history (and/or anticipated future) does matter, we need to find different forms of modeling a process.

There are other views of process as event sequence that do not depend on this limited view of history entailed in the Markov assumption. These will be discussed further below. But before that, I will further elaborate the difference between the variable- and event-based views of process.

By using stochastic modeling, an important decision has been made: The phenomenon under study is not phrased in terms of variables and their relations. We are not primarily looking at how quantitative attributes change their value over time but deal with a (constructed) event sequence directly. The limitations of the variable-centered approach (in the social sciences) to describe change processes are mainly due to a restricted view of causation. Independent variables are seen as "acting on" dependent variables; the underlying process is supposed to operate continuously over time; the nature of the variables does not change over time—all that can change are the values of the quantitative attributes used to operationalize the variable—and no qualitatively different kinds of forces are deemed necessary to explain changes in the dependent variables. If too much variance remains unexplained, one has to look for additional independent variables and/or include specifications of relationships (statistically: interactions) between the variables. The underlying notion of causality is *efficient causality,* the "push" type causality that has been so instrumental for theories in physics.

To account for group (and in general, for social) phenomena, a process method should, in addition to *efficient cause,* be able to deal with at least two other kinds of causes (of the four Aristotle identified overall [Aristotle, 1941]), namely, *formal* cause, referring to the patterns of which things are made, and *final* cause, the end for which things are made, or a teleological "pull." In groups, formal causality is at work whenever constraints—as imposed on them in terms of workflow, scripts, or roles—are effective. For instance, many events taking place in online learning groups are a consequence of the manner in which groups have been set up (scripts, roles, workflow, deadlines). In organizations, the way team members interact with each other and with other teams is to some extent affected by the organizations' design and their business processes, all best captured as *formal cause,* and not requiring reduction to efficient causes (where the invariants and the explanatory power would be lost because many efficient cause processes can instantiate a single formal cause relation). Similarly, explaining human behavior (in various levels of aggregation: individuals, pairs, groups, and larger structures) in terms of *goals,* that is, driven by an *end,* adds considerable explanatory power, in particular for the (rather typical) cases where a goal can be reached in many different ways. Any account of these different paths toward an end in terms of only efficient causality would fail to identify the goal orientation.

Viewing a process in terms of sequences of events provides space to consider all four kinds of causality: efficient, formal, final, and material. Efficient cause can be modeled in terms of variables defined over events, formal cause in terms of event configurations (such as routines, procedures, practices, scripts), and final cause in terms of narrative structures that capture the goal orientation (purpose, ends) of a sequence. Material causes can be expressed in terms of constrains that the physical environment (e.g., architectural features) impose on actions and sequences of actions.

A pivotal difference to the variable-centered method is that event analysis does not start by framing the world in terms of variables, that is, fixed entities with varying attributes. Instead, event analysis "... conceptualizes development and change processes as sequences of events which have unity and coherence over time" (Poole et al., 2000, p. 36). While variable- and event-centered analysis can be combined (see below), conceptually they are quite different, and these differences are important to keep in mind (Mohr, 1982).

What counts as an event is basically up to the researcher, constrained by theory and informed by research goals; events are not "raw data," or incidents. In particular, events need to be defined dependent on the identification of the *central subject* under study because *entities participate in events* (for a more systematic treatment of the process of defining events, or colligation, see Abbott, 1984). The central entity in event analysis is some kind of" actor," but the "actor" does not have to be a person; it can also be a group, an organization, a nation, an idea, a technology—dependent on research question and level of analysis. I will not go into more details with respect to event coding here, because this kind of content analysis is well understood and has recently been the subject of methodological reflection in CSCL (Strijbos et al., 2006; Wever, Schellens, Valcke, & Keer, 2006). Although I gloss over these issues, it needs to be kept in mind that the conceptualization of what counts as an event and what event types to distinguish and the measurement of the occurrences of an event—which is a theoretical structure, a concept, hence not "identical" with its occurrences—play a critical role in the research process because they determine to a large extent the quality of the analyses and reflections that build on observations of events.

In our hypothetical CSCL study scenario, the main entities are individuals and groups. That implies then that events are constrained to those incidents in which either individuals or groups can participate. For our scenario, a process researcher would focus on the sequences of activities, incidents, crises, or stages that unfold in the groups over the duration of the semester. An explanation for an observed chain of events would take the form of a narrative that explains how event e(t) is related to events e(1) ... e(t-1) in terms of the actors' goals, motives, moves, and so forth and would keep track of how events happening outside the groups might affect them. The process is conceptualized here as a *developmental event sequence*, not a change in values of process variables. The research process yields a kind of narrative for each case, a case being a single person or a group, dependent on the level of analysis chosen.

Causation and Generalization in the Event-Centered Approach

While there can be little doubt that the event-based ontology of process and change has merits, it is less than straightforward to employ it as an explanatory device: In what sense can we say that a sequence of antecedent events can explain a certain state of the world? In other words, how can we establish the claim that a chain of antecedent events causes a target event? Questions of causation are tightly linked to generalizations.

Causation: Covering Laws Versus Narrative Structures

A major advantage of the quantitative-experimental, variable-based approach is that generalizing is straightforward, and testing for the validity of the generalization is well understood. In a sense, generalizations are built in right from the start, as soon as variables are used and as soon as explanations take the form of quantitative relations between antecedent and dependent variables. Furthermore, the General Linear Model sees the value of a particular variable y as a function of a set of antecedent variables x_1 to x_n, plus an error term: $\mathbf{y} = \mathbf{Xb} + \mathbf{e}$ (with **y, b,** and **e** being vectors, **X** a matrix with dimensions number of cases *(m)* * number of antecedent variables *(n)*). While the value of y for each case may vary, dependent on the values of the antecedent variables x_1 to x_n (captured in the vector **b**), the relation between y and the antecedent variables is the same for all cases. This is, of course, nothing else than a particular mathematical form of the *covering law* principle that sees a particular observation as explained if (and only if) this observation can be derived from a general law (in the quantitative realm: if the value of a particular variable for a particular case can be expressed as a function of a set of antecedent variables).

How do we establish causality in the event-based case? In this case, we can explain the event y as being *brought about* by a sequence of events, but this kind of explanation is obviously very different from employing a covering law. In particular, the causality at work here is not of a hypothetico-deductive or inductive-probabilistic covering law model type, but one of action causality (Abell 2004). This type of causality can be invoked when changes in the world are linked together by (human) actions. To the extent that one has evidence that a state of the world is transformed through the direct or indirect evidential action(s) of individual or collective agents, the causality in the particular case has been observed (Abell 2004, p. 293). Instead of a covering law, a *narrative structure* is invoked in order to establish causality. This kind of explanation is typically not used in a predictive manner, but the narrative formulation takes place after the transformation of world states is observed.

As Abell (2004) observes, the pivotal difference between the covering law model and the narrative structure one (or between nomothetic and idiographic causality) is that in the covering law case, proper explanations are only possible *after* generalizations, and comparisons have been performed, whereas in the narrative account, the explanation (for a specific case) comes *first,* followed by attempts to generalize to other cases (if and when the researcher is inclined to do so).

The issue of single-case causality has received extensive analysis (for an overview see Danto, 1985) that has led to a certain consensus among philosophers of science that singular causes might exist. More problematic than this ontological claim is the epistemological aspect (Abell, 2004, p. 294): How can we ground claims that we *know* they exist? In other words, how can we distinguish, for a single case, between a *consequence* and a mere sequence? Before that: Where does a consequential chain of events begin? It turns out that answering such questions typically requires referring to generalizations.

Hence, even in cases where the covering law model is (for good reasons) not accepted on ontological grounds, it is difficult to avoid generalizations and case comparisons altogether when one wants to establish claims regarding causal connections between events. Different from the variable-based approach, for the event-based approach generalizing does not come "automatically," and it is not as "straightforward." In particular, a dimension or metric, a distance measure, needs to be established along which to generalize from single sequences to patterns.

Generalizing by Pattern Extraction

Abbott (1990) provides an overview of methods useful for finding patterns in sequence data, distinguishing between methods employing or not employing *inter-event distance measures.* An example for the latter is calculating a simple Spearman rank correlation coefficient as a measure of the resemblance of one sequence to another. Repeating this for all pairs of observed sequences yields an *inter-sequence* distance matrix that can then be subjected to any standard classification technique, such as cluster analysis, to identify groups of sequences. Calculating the correlation coefficient as a direct measure of similarity between two sequences is, however, only meaningful for *non-recurrent* sequences in which every event is observed once and only once. Furthermore, as permutation statistics, Spearman rank correlation coefficients and similar measures have problems with extensive ties and missing events.

The already mentioned Markov modeling method is an approach to identify patterns in sequences that can be applied to *recurrent* sequences without employing any notion of inter-event distance. We have described its main assumption already—sequences are explained as random realizations of an underlying stochastic process—and need to mention here that in order to estimate the parameters of a Markov model, large data sets are needed (Kemeny & Snell, 1976).

However, most pattern searching methods for sequence data build on an inter-event distance matrix. There are three general ways to measure inter-event distance (Abbott, 1990). Firstly, one can use temporal distance between events across cases. This is often done for non-recurrent sequences. Secondly, one can use categorical resemblance and measure inter-event similarity analogous to kinship in a family tree. This can be done for recurrent sequences, where temporal distances are problematic to use as a distance measure, but requires, of course, that a (hierarchical) category system for event coding exists and can be reliably applied. The third type of distance measure builds on sequence transformation costs, using so-called *optimal matching* or *alignment* techniques. These can be applied to recurrent sequence data and have seen widespread use in (molecular) biology (Miura, 1986). The main idea is straightforward: For any two sequences, the distance between the two is determined by calculating the "cost" of transforming one (by insertion, deletion, and substitution) into the other. Different costs can be associated with the three types of transformations and/or with the event types subject to the transformation. Also, the total costs of a sequence transformation can be combined algebraically in different forms (e.g., total, mean, etc.). In any case, the resulting distance matrix can be used for classification (e.g., clustering) as well as scaling (e.g., multidimensional scaling) to identify families of sequences and dimensions of differences, respectively (Abbott & Hrycak, 1990).

Pattern extraction is one way of generalizing from particular event sequences while sticking to an event ontology: The generalization is accomplished without using variables, that is, attributes of an event. I want to introduce another approach—process modeling—that can be used for the same purpose, but is in interesting ways different from pattern analysis: It can deal with information about concurrent events (parallelism), and it employs two levels of description, a *model* of a process and *instances* of the model.

Generalizing by Process Modeling

Process models are interesting conceptually because they describe processes holistically; incorporating a priori assumptions about the form a process and all its instantiations can take. This makes process models suitable to describe *designed* processes, with the design affecting process enactment through prescriptions (e.g., collaboration scripts) and/or through constraints built into the collaboration software (e.g. an argumentation ontology, or specific features in the user interface). Process models are interesting; furthermore for practical reasons, as they can under certain circumstances be identified automatically from log data.

A process model in the meaning intended here is a formal model, a parsimonious description of all possible activity sequences that are compatible with a model (note that I use capitals to distinguish process modeling/models from other forms or modeling process, such as mathematical ones). Processes can be modeled in many forms, for example, using a system dynamics formalism for continuous process models. The class of process models that I want to concentrate on here pertain to the large class of discrete event systems (Cassandras, 1993). Finite state machines are one type of modeling language that can be used to describe and analyze discrete, sequential-event systems (Gill, 1962). Another one is the language and theory of Petri nets (Reisig, 1985) which present the advantage of modeling concurrency in addition to sequentiality.

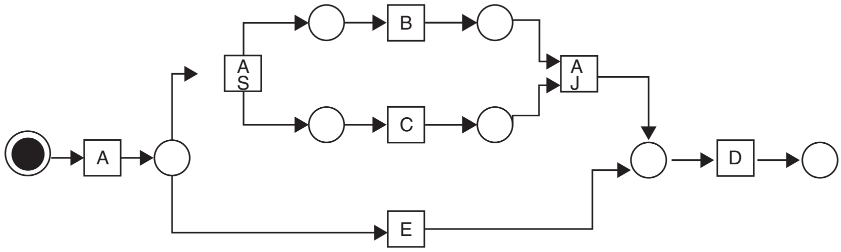

Fig. 10.3 Example for a Petri net description of a process

Petri nets can be mathematically described as bipartite directed graph with a finite set of places P, a finite set of transitions T, both represented as nodes (round and rectangular, respectively), two sets of directed arcs, from places to transitions and from transitions to places, respectively, and an initial markup of the nodes with tokens (usually representing resources). The Petri net shown in Fig. 10.3, for instance, expresses the fact that all process instances start with A and end in D. It also expresses the fact that the only predecessor to B is A, the B can only be followed by D, and that possible predecessors for D are B, C, and E. Furthermore, it shows that B, C, and E can be executed in parallel, or in any order. The black token in the initial node represent a token, which enables the transition A to be fired. Petri nets are nondeterministic, but a transition can only be fired if all the predecessor nodes have at least one token. (Two "technical" transitions are included in the net, and *And Split* (AS) and an *And Join* (AJ) in order to express formally the parallelism between activities B and C.)

Process model representations that take the form of Petri nets and similar formalisms have several interesting features. For instance, since they have formal semantics, they can be used to determine computationally if a specific activity sequence is commensurate with a model or not; like a grammar, a model can "parse" an activity sequence. For the same reason, one can use them to simulate potential (nonobserved) model behavior computationally and to compare different models with respect to certain formal parameters. The fact that they come with a graphical notation can be exploited for learning purposes: The graphical representations could be made an object for comparison and reflection for the group members, that is, serve as a mirroring or feedback device (Kay, Yacef, & Reimann, 2007).

In terms of the terminology introduced in this paper, process models (e.g., expressed as a Petri net) constitute a holistic view of a process: A process has a beginning and an end, it comprises events (activities), and the possible event/activity sequences are subject to more or less numerous constraints. Even a simple Petri net is a basic but powerful language to represent, for instance, the logic of a group script. While Petri nets are one out of many possible formalisms to express a process succinctly, they have another advantage: They can be automatically discovered from performance data.

A specific class of data mining methods can be applied in situations where we can expect that a group realizes a multistep process over time. This would be the case, for instance, when the group behavior is controlled by a script (Dillenbourg & Hong, 2008; Kollar, Fischer, & Hesse, 2006) or when the nature of the task suggests a specific sequence of activities, such as phases of a decision-making process (Poole & Roth, 1989). Process model mining (or process mining, for short) assumes that (a subset of) observed activities can be related to one or more processes or in other words that (a subset of) observed activities constitutes an instance of a process. Collaboration scripts frequently used in CSCL, for instance, can be seen as processes, and the activities performed by students enacting the scripts being the process instance. Another example: normative models of group decision-making can be seen as constituting processes, the enacted decision processes being instances thereof.

Process mining can serve a number of purposes, among them: (a) Discovery—no a priori model exists. Based on an event log, a model is constructed; (b) Conformance—an a priori model exists.

Fig. 10.4 An event log example (from Van der Aalst & Günther, 2007)

case id	activity id	originator	time stamp
case 1	activity A	John	9-3-2004:15.01
case 2	activity A	John	9-3-2004:15.12
case 3	activity A	Suc	9-3-2004:16.03
case 3	activity B	Carol	9-3-2004:16.07
case 1	activity B	Mike	9-3-2004:18.25
case 1	activity C	John	10-3-2004:9.23
case 2	activity C	Mike	10-3-2004:10.34
case 4	activity A	Suc	10-3-2004:10.35
case 2	activity B	John	10-3-2004:12.34
case 2	activity D	Pete	10-3-2004:12.50
case 5	activity A	Suc	10-3-2004:13.05
case 4	activity C	Carol	11-3-2004:10.12
case 1	activity D	Pete	11-3-2004:10.14
case 3	activity C	Suc	11-3-2004:10.44
case 3	activity D	Pete	11-3-2004:11.03
case 4	activity B	Suc	11-3-2004:11.18
case 5	activity E	Clarc	11-3-2004:12.22
case 5	activity D	Clarc	11-3-2004:14.34
case 4	activity D	Pete	11-3-2004:15.56

Event logs are used to determine the extent to which the enacted collaboration corresponds to the model; (c) Extension—an a priori model exists. The goal is not to test but to extend the model, for instance, with performance data (e.g., durations of activities). Extended models can then be used, for example, to optimize the process (Van der Aalst & Günther, 2007).

We look here only at the discovery task because it is conceptually and computationally the most demanding one, although conformance checking is of obvious relevance, for instance, in the context of our hypothetical study. The input to process mining is an event log, as shown in hypothetical form in Fig. 10.4. The result of process mining is a process model, for instance, a Petri net as shown in Fig. 10.3.

The cases in the event log refer to different instances of the same process. Different cases can result from different groups enacting the same process or the same group enacting the process at different times. The example event log in Fig. 10.4 illustrates the latter case: A team formed by six members enacts a process composed of activities A–E five times. For example, if we look at the first enactment, it takes the form ABCD. The fifth enactment takes the form AED. The Petri net in Fig. 10.3 is a formal representation of the process logic underlying the activities depicted in the event log. For instance, it expresses the fact that all process instances start with A and end in D. It also expresses the fact that the only predecessor to B is A, the B can only be followed by D, and that possible predecessors for D are B, C, and E. Furthermore, it shows that B, C, and E can be executed in parallel, or in any order. It is assumed that two activities are parallel, or concurrent, if they appear in any order in the log.

An important difference between visualizations resulting from process mining (as in Fig. 10.3) and visualizations such as an uptake graph (Suthers, 2006) is that the former are constructed automatically, whereas most visualizations used in qualitative research, such as uptake graphs, are constructed manually. Generating graphical process representations automatically has the obvious advantage of saving researchers' time and in addition opens up the possibility to use them as a resource in the hand of teachers and teams. However, the transformation of input data from a log file into a meaningful process representation can, at this stage, not be fully automatized unless the event data come from a highly structured workflow environment. For the kind of data typical for CSCL research, in most cases various steps of data cleaning, event identification performed by human raters, and tuning of parameters of process mining algorithms are required. Furthermore, for "real" CSCL data process, model types such as Petri nets with a formal semantics will regrettably not be suitable, among other reasons, because they are overly deterministic. One will have to employ heuristic methods, which are more complex both algorithmically and with respect to interpretation of results (for an example involving the analysis of chat data, see Reimann, Frerejean, & Thompson, 2009).

These practical obstacles notwithstanding, process modeling in the sense introduced here can be an interesting component in the methodological arsenal of the CSCL researcher because it combines a holistic view of a process with graphical representations on an algorithmic basis (with at least in some cases clear semantics). When used in an inductive, process mining mode, it adds to the repertoire of sequence mining methods applicable to CSCL data (Kay, Maisonneuve, Yacef, & Zaiane, 2006), but the approach can also be used to formulate process models and test them in a more deductive fashion, typical for experimental studies. For those CSCL researchers particularly interested in collaboration scripts, process models offer ways to formulate scripts as well as to computationally assess, based on log data, to what extent scripts have been enacted.

Combining Variable-Centered and Event-Centered Methods

The variable-centered approach works well for research questions that involve relationships among variables. An event analyst has nothing against variables, as long as they are not seen as the *only* way to describe and explain change. I already mentioned that stochastic event sequence analysis can incorporate information that takes the form of values of variables by employing nonhomogeneous Markov models. However, the potential for method integration is not exhausted there. While process analysis makes use of stochastic modeling methods because they use event type directly and thus preserve the nominal character of events and the integrity of event sequences unfolding over time, it can also employ *event variables*. Event variables are quantitative aspects of events, such as duration and intensity, or any other quantitative dimension that can be associated with an event. For such variables, variants of time series analysis can be used. Also, variables can be used in process research that describe the *characteristics of event sequences,* such as their periodicity, and these variables can figure as independent or dependent variables in theories of how such characteristics affect outcomes or are affected by other factors, respectively.

Since event analysis is more of a generalization of, rather than an antagonist to, the variable-centered method, experimental design with its meticulous control of external variables can be integrated. This is important for CSCL when we are interested in experimental trials of pedagogies and technical tools. There is no reason why such treatments should not be realized and included in process analysis, both in its narrative part and in the statistical analysis. Variables can represent contextual factors and/or experimental conditions. What event analysis reminds us, though, is that we should not harbor overly simplistic assumptions as to the causal relations between "treatments" and groups' behavior, in particular when groups interact with technology over longer stretches of time.

Conclusions

Starting from the observation that the analysis of change processes—in individuals in the form of learning, in groups in the form of participation and knowledge building—is a central concern for CSCL and that CSCL researchers have privileged access to detailed change data, we have noticed a lack in the use of (formal) methods that take the core dimension of change—time—into account. This is a particular concern in light of the fact that the majority of studies conducted in CSCL deal with change processes that have a duration of weeks and months. If individual and group processes are analyzed on such a scale without taking into account history, sequence, dynamics (in short time) then many of the resulting findings are of limited value. I argued further that for studies that aim to analyze change unfolding over days, weeks, and months, the quantitative method dominant in the social and learning sciences—variable-centered variance theory—is of limited value, not only because of the problems arising from "controlling" extraneous variables over longer stretches of time but more importantly because of problems with the fundamental notion of variable and process. Methodologies that focus solely on order in short-term interactions, such as Conversation Analysis, are also not applicable to the analysis of processes that unfold over long-term, and fragmented, forms of interaction.

Therefore, I introduced a more general process approach that builds on the notion of event and narrative explanation. CSCL research can gain from an adoption of a wider range of process methods in a number of ways. By the adoption, group process research gets a sound methodological foundation, and descriptive and experimental approaches can be better integrated, and insights informative for design can be derived. As has been the main argument on these pages, the variable-centered method, dominant in most experimental learning research, is not the only method for conducting (formal, quantitative) process research in CSCL. It makes many restrictive assumptions on the kind of data useful for analysis (namely variables only) and on the kinds of causation allowed to explain change. Adapting the more general stance to process analysis described above, we gain a more widely applicable yet by no means less rigorous method to analyze group processes.

Event analysis holds the potential to provide a methodological link between those researchers in CSCL who are producing descriptive, "thick," interpretive accounts of observations on learners' computer-mediated interactions and those in the research community who work experimentally and quantitatively. The link results mainly from the fact that the event-centered approach makes extensive use of event descriptions: They enter into narrative accounts and, optionally, into statistical analysis without losing their distinctiveness. Hence, independent of the research orientation (descriptive, experimental, design-oriented), activities such as defining, identifying, distinguishing events and event sequences, as well as providing qualitative, narrative accounts of events, and sequences are part of a common set of research activities and become shareable. The fact that there are many common elements to the research "work" across different epistemological orientations is better exploited in the event-view of process than with the variable-centered perspective alone.

By the same token, the event-centered method can contribute substantially to design-oriented research. A comprehensive, detailed descriptive account of how individuals and groups interact with technology over time is an important component to inform instructional and software designers in the early stages of the development process, and it provides opportunities in the trial phase to gauge for (positive as well as negative) side effects of introducing methods and technologies. An example for the value of employing (qualitative) process studies for information technology design is the research on structuration and appropriation processes (Poole & DeSanctis, 2004). But it needs to be said that this line of research has less implications for interface design than for organizational design and change management.

Analyzing the effects of specific tool and design decisions over longer stretches of time is also important for a realistic assessment of costs and benefits; for instance, Zumbach and Reimann (2003) observed that providing feedback to group members on interactional aspects was much more effective in the early stages of groups' lifetime than later and that, hence, this information should be phased out over time in order to reduce the cognitive load (the "costs"). Still, the contribution to design, in particular to "interface" design, is the least satisfying aspect of the strategy for method combinations suggested here. While researchers both in the nomothetic and idiographic tradition might appreciate some of the suggestions, the Great Unified Methodology for CSCL that pays due respect to all three epistemic orientations—nomothetic, idiographic, and design-perspective—is not identified here.

While there is ample concern for sequence data analysis in psychology (and to some extent in CSCL research), the analysis of long-term change processes is mainly taking place in disciplines such as organizational research and history, as well as developmental psychology. However, understanding organizational change processes and how they affect and are affected by collaborative technologies will become very important when (and if) CSCL follows the proposal that CSCL needs to concern itself more with processes that take place on a *meso level,* a level "...intermediate between small scale, local interaction and large-scale policy and institutional processes" (Jones, Dirckinck-Holmfeld, & Linstroem, 2006, p. 37). In general, when collaboration tools are used over extended periods of time, as they increasingly are due to the ubiquity of technology for collaboration and learning, then knowledge about how our technologies and tools affect individuals and groups over time becomes essential. As we move out of the laboratory and provide people with tools for their daily use, some of the most interesting processes are those that unfold over time (such as appropriation moves, Poole & DeSanctis, 2004). They are not observable in the usability lab or the short-term study looking into second-by-second interactions and immediate (learning) effects.

Researchers in the learning sciences, education, and psychology know of the pivotal role of time and process in their areas of research. Logistical hurdles have been reduced to a significant extent, certainly in CSCL, where recording collaboration automatically is the rule rather than the exception. This does by far not solve all questions of data acquisition over time, but it provides a good basis for progress (Markauskaite & Reimann, 2008). Problems remain in research training: The almost exclusive focus on variable-centered methods in quantitative training and the almost total lack of concern for formal analysis of qualitative data are both not productive. Problems remain in the area of research dissemination and publication. Editors and reviewers of the leading journals need to be aware of methodological alternatives to canonical quantitative and qualitative research, and be perhaps more critical when evaluating claims regarding the analysis of "process." Longitudinal research designs, including design-based research, are hard to fit into the conventional journal paper format, in particular when involving case studies, data in multimedia format, and narrative accounts. We cannot let it come to the point where the last step in the research process, the formal publication, blocks innovation in research methods and strategies. Publishers need to extend their services and need to extend the very notion of what it means to "publish," or they will be increasingly sidestepped. Problems remain regarding the adequacy of modeling methods for dealing with the complexities of human communication, cognition, and group behavior. However, different from the first two problems areas, these are "productive problems": They drive the research process forward.

Time is indeed precious. Too precious to be ignored or not treated adequately when formulating and testing theories of working and learning collaboratively. But the time of CSCL researchers is also precious; process studies are very work intensive; thus any method that can help us to share the workload and to conduct research cooperatively across epistemic interests and paradigms, without forcing us to gloss over fundamental differences, should be welcomed by the field. As a next step, shared online collections of (annotated) sequence data could be created that can be analyzed from multiple perspectives and with various methods or tools. The time gained might be most profitably spent on developing and testing process models and theories, of which there is a genuine lack in CSCL. While this paper has little to say on substantive theories of change in (learning) groups, it is obvious that existing process models in CSCL, which are predominantly describing short-term interactions, will need considerable theoretical extensions to connect with theories of long-term change.

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Investigation 11. The Multilayered Nature of Small-Group Learning: Productive Interactions in Object-Oriented Collaboration

Crina I. Damşa

Abstract

This article presents a study of small-group interaction in the context of collaborative learning in undergraduate education. The student groups participated in collaborative projects, which involved setting up, conducting, and reporting on empirical research studies. This study sheds light on the nature of productive interactions, the joint efforts to co-construct knowledge, and the shared epistemic agency expected to emerge when groups are addressing ill-structured, complex problems in a collaboration over time. In-depth qualitative analysis and descriptive statistics were used to analyze and interpret interaction data and developing knowledge objects (i.e., research reports) collected during a 20-week project period. The findings show that productive interactions can take different forms, with discourse-based and object-oriented being the most relevant patterns arising. In the latter case, the emergent knowledge objects also influence the course and productivity of the interaction. Finally, groups manifesting shared epistemic agency produce knowledge objects more complex and suitable to the problems addressed. These findings contribute to a better understanding of the collaborative learning process that includes work on knowledge objects over time. The implications for the educational practice and further research point toward the need for a better understanding of the way groups function when challenged to address complex problems and to participate in knowledge production, how these processes can benefit learning, and what is needed in terms of pedagogical and technological support, to enable students to be more than mere course-takers but also producers of knowledge.

Keywords

Knowledge co-construction · Knowledge objects · Learning in higher education · Productive interaction · Shared epistemic agency · Small-group collaboration

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C. I. Damşa (✉)
Department of Education, Faculty of Educational Sciences, University of Oslo, Oslo, Norway
e-mail: crina.damsa@iped.uio.no

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In the context of emerging changes in the knowledge-based society, students in higher education are expected to be able to address ill-structured and open-ended problems, conceive new ideas, show inquiring attitudes and proactive behavior, and capitalize on collective expertise (Goodyear & Zenios, 2007). Learning in small groups that focuses on solving open-ended problems and on managing the collaborative process has been proposed as a way to expose and enculture students to complex learning situations that stimulate engagement in collaborative knowledge production.

However, conceptualizations of collaborative learning (e.g., Hmelo-Silver, Chinn, Chan, & Donell, 2013; Stahl, 2009a) and empirical studies (e.g., Baker, 1999; Barron, 2003; Hmelo-Silver, 2004; Mercer, 2002) that have unfolded over the years have not addressed the details of learning in interaction that leads to knowledge production and challenges students to engage in sustained collaborative efforts. While some research studies on collaboration have provided substantial insight into whether and when interaction proves more effective than working alone (e.g., Furberg & Ludvigsen, 2008; Janssen, Erkens, Kirschner, & Kanselaar, 2010), others have emphasized the role of different variables in mediated interaction (cf. Cress, Held, & Kimmerle, 2013; Slof, Erkens, Kirschner, & Helms-Lorenz, 2013) or focused on the procedural characteristics of the process, such as social aspects, conflict, or planning (Barron, 2003; Engle & Conant, 2002; Remesal & Colomina, 2013). Fewer studies have explicitly addressed the unfolding (in time and space) relationship between the participants' ongoing interaction (Krange, 2007; Sarmiento-Klapper, 2009) and the emergence of the knowledge involved.

The rationale underlying this empirical investigation can be found in sociocultural perspectives of learning and development, viewed as a process of *co-construction* of knowledge that arises from interaction (Valsiner, 1994). This is a process that unfolds in time, and it is shaped by individuals' knowledge, active engagement, and the intersubjectivity created during interaction. Accordingly, it is by social interaction that individuals align their existing ideas to create new meaning and understanding (Ludvigsen, 2010) and through interaction between participants and resources that knowledge comes into use and is materialized into knowledge objects (Paavola & Hakkarainen, 2005). From this perspective, knowledge emerges as an interactional accomplishment based on a joint construction process and materialized into shared knowledge objects—"frozen" knowledge. In this context, it appears crucial to gain a deeper understanding of the learning process organized as collaboration around shared knowledge objects, which requires active engagement and participation in this interactional setting and in the joint construction of knowledge. Research needs to address the complex dynamics of this process, which involves acknowledging the connection between these different layers, i.e., interaction, emerging knowledge (objects), students' active participation, and their combined dynamics.

The aim of the study is to shed light on the productive interactions thought to occur when university students collaborate in small groups to learn to set up, conduct, and report on research. In particular, it examines interactions that are productive during long-term collaborative research projects, with a focus on how these interactions unfold, whether the interaction proves productive in relation to the emerging knowledge objects (in this case, research reports of collaborative research studies), and learners' active participation—agency—in this collaborative work. Ultimately, the aim is to gain an understanding of the interconnection between the aspects involved in the object-oriented collaborative process and how this can shape and contribute to the learning process.

To this end, the study builds on the conceptualization of learning as a collaborative process of knowledge co-construction. It carries out an in-depth and detailed analysis of higher education students' collaborative group activities and partly of their products. The following research questions will guide this investigation:

1. What are the characteristics of productive interactions in the context of group object-oriented collaboration?

2. How are productive interactions and knowledge object development interconnected?
3. How is shared epistemic agency expressed and related to the groups' object-oriented collaboration?

The article begins with an examination of theoretical and empirical studies related to the notion of productive interactions and knowledge objects. Next, it constructs a framework that sets the theoretical basis for understanding the concepts addressed herein and for conducting the empirical analyses. An analysis of empirical material collected from student groups follows. The article concludes with a summary and a discussion of findings, focusing on the interconnection between the aspects under investigation.

Theoretical and Empirical Perspectives

Learning as a Process of Co-construction of Knowledge

The main point of departure for the conceptualizations included in this study involves the sociocultural approach to learning (Vygotsky, 1978; Wertsch, 1998) and sociogenetic ideas (Valsiner, 1994; Valsiner & van der Veer, 2000). Generally, sociocultural approaches emphasize the interdependence of social and individual processes in the co-construction of knowledge. This view of learning and development rests on a number of premises directly relevant to the current conceptualization. One core premise holds that we achieve understanding and knowledge through (social) interaction. Knowledge is constructed as part of the interdependency that involves people interacting with peers, tools, or objects from their environment, primarily through communicative actions (Linell, 2009) and in the context of a process that spans time and space (Stahl, 2009a; Valsiner & van der Veer, 2000). This view purports that learning and development are rooted in social practices; the process is supposed to start in the intersubjective, external setting. The internalization of ideas, meanings, and knowledge begins as an aspect of collaborative interaction, and it successively transforms into a phenomenon of its own. For this first stage to happen, language or other mediating means are needed to "freeze" the meaning of an internalized event. This results in a process that triggers development or results in (cognitive) artifacts, which are an "internalized form of culturally developed artifacts" (Stahl, 2003, p. 7). One aspect that the classic sociocultural writings seem to have dealt with in a less clear fashion is that of externalization. Through externalization, the results of the internal transformations of the social input (into thought, cognitive artifacts, etc.) are communicated to others, who then receive and transform such messages in their personal ways. It places the internalized structures back into the interpersonal space, through a bidirectional process. Accordingly, the individual is in an active process of relating to the environment (physical, social, and cultural), and the construction of knowledge is an outcome of that process (Valsiner & van der Veer, 2000). In this context, knowledge becomes both an outcome and a mediating element in the interactional process. This stance relates directly to another sociocultural premise, which poses that human action is mediated. Hence, interaction and communicative action imply the use of tools, artifacts, or objects as mediational means that embody knowledge and experiences accumulated over time. Wertsch (1991) indicated how individuals use and act upon meditational means as being fundamental for understanding, knowledge construction, and learning. These means can also take different roles: in production, artifacts and objects can be outcomes of interaction; when used in the context of interaction, they can function as tools. Furthermore, another particular feature of these mediational means is their nature: not only physical artifacts but also especially those of an intellectual nature (Säljö, 2004), such as language, concepts, and structures for reasoning, have mediational value. Wertsch (1991) insisted on the dynamic character of this process, strongly determined by the intersubjective nature of the process, by how this process is mediated by various means—especially by language and by the active participation of the individuals involved in this process. Knowledge emerges as an interactional accomplishment based on a combination of the individual contributions, collective processing and actions, and mediational resources involved.

Productive Interactions

Theoretical and empirical studies of interaction (e.g., Baker, 1999; Engle & Conant, 2002; Furberg & Ludvigsen, 2008; Mercer & Wegerif, 1999) have conceptualized productive aspects of interaction in slightly different ways, depending on the theoretical assumptions they build upon. A number of contributions addressing, either explicitly or implicitly, the concept of productive interaction are discussed below.

The sociocultural approach has developed a rather advanced conceptualization of the notion of interaction and how it could be productive, but empirical studies based on these ideas are emerging currently. Theoretically, the sociocultural approach postulates that humans exist and develop in *intellectual interdependence* and social interaction and that they co-construct their knowledge through this interaction (Valsiner & van der Veer, 2000). This viewpoint involves the belief that (social) interaction is a prerequisite for how knowledge is constructed and used. This interaction, situated in a historical, physical, and cultural context, commonly takes place on a regular basis at a micro-social level (Valsiner, 1994). The sociocultural approach claims that knowledge is embedded in interaction and, moreover, that the individual processes and structures can be traced to their interaction with others. Productive interactions are mostly described at the microgenetic level of knowledge construction as part of the more general social interaction processes and are connected to the moment-to-moment (social) interaction among individuals (Ludvigsen, 2010).

Empirically, few studies have addressed productivity in interaction from this perspective and mainly emphasized the dialogical aspects of the interaction rather than how the knowledge emerging from the interaction is being materialized; however, connections with the outcomes of the dialogical interaction have been made at the level of the interpretation. Mercer (2002) and Mercer and Wegerif (1999) elaborated on the concept of *exploratory* talk, referring to a communicative process for reasoning through talk. Accordingly, such talk occurs when "partners engage critically but constructively with each other's ideas. Relevant information is offered for joint consideration. […] Agreement is sought as a basis for joint progress. Knowledge is made publicly accountable and reasoning is visible in the talk" (Mercer, 2002, p. 16). Furthermore, it recognizes peers' rights to participate and contribute toward the shared goal, activity, or outcome. The term "interthinking" (Mercer, 2000) encompasses this notion of people using the language for social and cognitive purposes, such as developing ideas together.

The notion of *constructive interaction* has been used to conceptualize, within social-cognitive views, the type of interaction with peers that supports learners' better understanding of concepts. This tradition builds on a richer set of empirical studies that contribute to both a better understanding of how interactions can be productive (even if that is not explicitly stated as the core of this conceptualization) at the verbal level and in delineating ways to analyze collaborative encounters. Miyake (1986) developed the notion of constructive interaction as an element of the pedagogical design that encourages learners to talk to each other while attempting to understand specific phenomena and methods of research, but the study did not examine the characteristics of this process. Later studies approached the idea of constructive interaction as an aspect of *conversational interaction*. Roschelle (1992) and Teasley and Roschelle (1993), in their studies of joint problem space, considered conversational interaction constructive when it enabled students to construct increasingly sophisticated approximations of scientific concepts through the gradual refinement of ambiguous, figurative, and partial meanings.

In studying collaborative argumentation, Baker (1999) developed an account of constructive interactions and identified two aspects that can be viewed as productive (or constructive). The first involves the productive transformations that lead to the co-construction of meaning, understanding, solutions, or knowledge. More specifically, in these interactions, "new meanings or knowledge are co-elaborated, and/or fulfill some specific (constructive) function with respect to cooperative activity" (Baker, 1999, p. 179). Baker emphasized the communicative aspects and how interaction leads to knowledge or understanding through the addition of new knowledge or understanding to eliminate confusion. The second aspect refers to interaction being constructive to the extent that it contributes to a shared goal or cooperative activity through actions that go beyond individual contributions and serve a common purpose. Baker's analyses illustrated argumentative interactions, including the understanding of knowledge, the co-elaboration of meaning, or the filtering of flawed hypotheses. His findings showed that interactive pressure does not lead group peers to resolve verbal conflicts but to draw on different types of knowledge, to determine and differentiate concepts, to negotiate meaning, and to combine elements of solutions.

Attempting to increase the understanding of micro-interactional processes in collective achievements, Barron (2003) emphasized the importance of productive collaboration beyond the accomplishment aspect and the characteristics of interactions that lead to differentially productive joint efforts. She identified aspects influencing the productivity of interaction at the relational and metacognitive levels. Groups considered more productive coordinated and monitored individual contributions to joint work and dealt with issues of power, role status, and engagement. Rather than using cognitive aspects to depict productivity, Barron used the social-relational dimension as a reference point for the analyses (see also Damşa, Ludvigsen, & Andriessen, 2013).

Investigating productive disciplinary engagement during collaborative learning projects, Engle and Conant (2002) and Engle and Faux (2006) attempted to characterize the productivity of student engagement in interaction. Accordingly, students become engaged when they make significant contributions to a topic and when their contributions are coordinated among each other. Productive engagement occurs when progress takes place in students' knowledge, materialized in the use of more advanced arguments or more elaborate questions.

Of the different concepts examined here, that of productive interactions brings together ideas of interaction as a mechanism for knowledge construction. Although varying in approach and basic assumptions, the studies discussed above have contributed, too, to a conceptualization of the notion. Thus, productive interaction refers to knowledge co-construction within the context of a knowledge domain, entailing both (joint) actions directed toward shared goals and increased shared understanding of concepts, but also actions that contribute de facto to the construction and progress of the (shared) knowledge objects. Due to this latter feature, productive interactions can be viewed as different from dialogical interactions because they go beyond the level of shared accomplishment at a dialogical level (i.e., problem identification, shared understanding of knowledge, and joint plans of action). It reflects one aspect of the knowledge co-construction that had been less explored and which has the potential to shed light on the innermost mechanisms of the process and how that entails learning.

Knowledge Objects

The investigation of dialogical aspects of the interaction has been mainly the focus of studies on collaboration and collaborative learning. In recent years, various studies (see also Nicolini, Mengis, & Swan, 2012; Stahl, 2009a) pose that it is increasingly important to take into account the knowledge emerging from this interaction. The notion of *knowledge object* emerges as instrumental here, to depict this aspect of the knowledge that is co-constructed and materialized.

Attempts to define, more generally, the concept of *object* did not lead to clear-cut, unambiguous, and indisputable definitions. The sociocultural perspective views the object as an anchor for an activity (Engeström & Sannino, 2010; Leont'ev, 1978) and emphasizes that collective action is inherently object-oriented and that the pursuit of some type of object motivates collaborative work (Kaptelinin, 2005). The object defines the activity and becomes the "sense-maker" (Kaptelinin, 2005, p. 12), which gives meaning to this activity and the values involved in the activity. What this perspective underscores is that, because of their collective origins, objects are, by definition, partially shared, emerging, and sometimes fragmented. Sociotechnical perspectives and interactionist sociology have focused on the role that various objects (technologies, artifacts) play in organizing work in general and collaboration in particular. From this perspective, objects have a binding role between individuals, groups, and communities (Nicolini et al., 2012), facilitating cross-disciplinary collaboration. Some studies (cf. Engeström & Sannino, 2010) have been concerned with the dual nature of the object. The object has, thus, both projective and objective value, meaning that it represents both the goal to be pursued and the material outcome to be achieved through the activity. Carlile (2002) referred to their role as boundary objects that individuals from different domains can work with, i.e., create, measure, and manipulate.

In this context, the notion of *knowledge (or epistemic) object* is of main interest. The notion of an epistemic object has been defined primarily within the context of knowledge work in scientific communities (Knorr-Cetina, 1997, 2001). It builds on Rheinberger's (1997) conception that the capacity of objects to support collaboration derives from them being experienced as epistemic things; objects become epistemic when they embody what one does not know yet. These are "material entities or processes […] that constitute the objects of inquiry" (Rheinberger, 1997, p. 28). In line with this, Knorr-Cetina (2001) emphasized the difference between objects as instruments, which are objects that are ready to use, a means to an end, and always available, and knowledge objects, which are problematic and open to transformation and further exploration.

Traditionally, a distinction has been made between objects and *artifacts*, with objects referring to the objective of activity and artifacts to the tools that mediate the achievement of these objectives (Ramduny-Ellis et al., 2005). In learning science research, the notions of object and artifact have been used interchangeably. It was the concept of (knowledge or cognitive) artifacts that received attention. Bereiter's (2002) elaboration on the notion of *conceptual artifacts* refers to how knowledge work in general takes place, how knowledge is produced, and the idea of knowledge building—as a form of knowledge production and learning in collaboration (Bereiter, 2002). With regard to the nature of these artifacts, Bereiter considered that they belong to a realm that encompasses entities such as problems, theories, ideas, concepts, conjectures, interpretations, proofs, criticisms, and the like. From his perspective, an idea, concept, or theory is real (Bereiter, 2002). Paavola and Hakkarainen (2005), in their elaboration of learning through knowledge creation approach, emphasized Bereiter's statement that human work focuses increasingly on knowledge objects rather than physical things, which characterizes knowledge work. Furthermore, Bereiter also considered that artifacts play a seminal role in the advancement of knowledge, in which they have multiple values: they are instrumental (i.e., they are used to create other artifacts), they are historical (e.g., they embody knowledge created in time), and they can be the outcome of knowledge work (e.g., they can be shared, articulated, and extended by shared efforts and by mobilizing collective cognitive resources). In his analysis of the mechanisms of small-group interaction during collaborative problem-solving, Stahl (2009b) related his conceptualization of the knowledge objects (or cognitive artifacts) to the processes of internalization and externalization discussed in the previous paragraph. Accordingly, he viewed objects and artifacts as carriers of (co-constructed) meaning that emerges through consistent use in interaction by individuals engaged in activity together. This meaning "emerges in external, observable, intersubjective world of other people and physical objects" (Stahl, 2003, p. 6). Through repeated iterations of the processes described, an object/artifact emerges and combines meaning and knowledge with physical existence.

Within the knowledge-building framework, some empirical studies have examined the role of conceptual artifacts in the process. Most relevant are those of Van Aalst and Chan (2007) and Lee, Chan, and van Aalst (2006), who investigated how digital portfolios scaffold the collaborative inquiry of high school students using the Knowledge Forum technology. The findings point to the formative value of the portfolios, which represented not only knowledge products but also the materialization of students' developing ideas and a form of scaffolding that helped students recognize and make sense of productive discourse. However, the collaborative aspects of knowledge building were again represented only by the analysis of peer discourse and not by active involvement in creating it. In the research on small-group learning, a number of studies dealt with the notion of *proposal* in virtual math teams (the VMT project) and how that influences or contributes to group work (Stahl, 2009c). Proposals can lead to group actions aimed at the clarification of deictic (linguistic) references and then to the discussion of a topic that eventually becomes shared by the entire group. Stahl (2009c) maintained that proposals contribute to a group's object orientation, with mathematical objects being the topics that are negotiated and co-constructed throughout the temporality of the discourse based on different individual contributions. Mathematical objects, ranging from a mathematical sign (Medina, Suthers, & Vatrapu, 2009) to an idea generated through a proposal (Fuks & Pimentel, 2009) to a visualization created by technological means (Çakir, Zemel, & Stahl, 2009; Charles & Shumar, 2009), were viewed as more tangible than problems, which are created, maintained, and transmitted through discourse.

While these studies disclose rather advanced conceptualizations of the notion of knowledge objects, at an empirical level, there has been no extensive documentation and analysis of small-group learning that revealed in detail how knowledge objects are constructed and how they emerge from the interaction. In the context of learning activities that aim to challenge students to go beyond being mere course-takers, it is important to have an insight into what is known of how students work together to construct and develop knowledge products. As the studies analyzed above showed, there are insights into the roles objects can fulfill in collaboration (tool/instrument, end product, object of inquiry), but there is little known about the process that takes place when objects are being constructed during the interaction.

Shared Epistemic Agency

Efforts directed at jointly co-constructing knowledge require active participation and a combination of individual and collective contributions. Active participation in interaction allows students to go beyond individual efforts (Scardamalia, 2002), to become engaged in knowledge construction at the collective level (Charles & Shumar, 2009), and to contribute to the shared goals. The assumption that the current study elaborates upon is that agency in collaborative contexts involves a social element that is enhanced during group work. From a sociological viewpoint, Emirbayer and Mische (1998) considered agency to be characterized by experience-based social participation, involving acts of negotiation on the course of future actions. The notion of *sharedness* in agency presupposes intersubjectivity (Matusov, 2001) and interaction between participants; it emphasizes the potential of people to concretize choices made for a particular trajectory of action, not expressed in each individual member's activities or pursuits but in shared efforts at the group level.

Furthermore, central to agency in knowledge work is the productional aspect. Schwartz and Okita (2004) viewed agency as a system of production and people acting to witness their ideas embodied in concrete products. Their notion of productive agency implies that people produce ideas, artifacts, and objects as part of their agentic patterns, designating the epistemic-productional (Damşa, Kirschner, Andriessen, Erkens, & Sins, 2010) character of collaborative activities. Accordingly, epistemic agency does not reside within the individual's mind but rather emerges through participation in collective activities. Palonen and Hakkarainen (2000) added that epistemic agency is the concept that reveals students' understanding of the fact that it is not only the teacher who initiates inquiry or activities of knowledge construction but also the students who can initiate, conduct, and steer this process.

This stance places the focus on the joint action and the effects on the objects, resources, and those who engage in it. In a joint action, a wider range of concepts or resources is likely to be deployed on the (shared) object than would be the case for individual action.

An Integrative Analytic Framework

The theoretical perspectives and empirical insights presented above sketch the complexity of the phenomenon under investigation, which leads, consequently, to a challenge when devising an analytic framework to depict this complexity. When addressing this challenge, some particular aspects appear of importance. Namely, (a) it is essential to define, even in a preliminary manner, the nature of productive interactions, i.e., how they are different from other types of interaction and how they lead to knowledge construction; (b) the temporality involved in the interaction; and (c) the multiple (analytic) layers that comprise this process, e.g., interactions, knowledge objects, agency, and their interconnection. Being able to identify and illustrate each of these layers is just one aspect of this analytic challenge. Understanding how these factors are interwoven and how they are part of the learning process is another.

The review of studies on interaction showed various instances of how meaning can emerge through dialog, shared discourse, and conversational encounters. Examples of such frameworks and analytic schemas emphasized the reasoning process in social interaction processes (Sawyer & Berson, 2004; Sfard & Kieran, 2001), (collaborative) argumentation and meaning making (Baker, 1999; Weinberger & Fischer, 2006), procedural and relational aspects of interaction (Barron, 2003; Rummel & Spada, 2005), or deictic aspects of conversation (Lindwall & Lymer, 2011). Productive interactions, inter alia, not only comprise these constructive, discursive, and procedural aspects but also refer to something outside this conversational space. They entail the actual production of something—knowledge objects, for example—that embodies the understanding, meaning, or knowledge that has been constructed. Analytically, this involves sequences of collaborative actions moving from one state of the object under construction toward another in a direction that leads to the advancement of these objects. Each case and context defines the "productivity" of interactions in epistemic terms rather than some universal criteria and is expressed in terms of long-term participation and learning, beyond the interaction moment itself. An analytic approach that unifies these layers builds on the discourse-analysis tradition but attempts to go beyond it by adding an analysis of the products of the interaction.

It is in this context that the temporality becomes important. A temporal perspective is needed when attempting to elucidate the way the interaction unfolds and whether it is productive (Ludvigsen, 2010). The concept of *interaction trajectories* encompasses the idea of interaction unfolding in time. Sarmiento-Klapper (2009) states that in longitudinal interactions, temporal and sequential resources are central to constituting activity as continuous. Krange (2007) emphasizes that a trajectory perspective creates possibilities for determining how these momentary interaction elements build into continuity, how the interaction process evolves over time, and how participants capitalize on, first, each other's contribution to the joint effort and, second, on the various resources available. For the current study, the notion of temporality creates the framework for explaining the co-construction process from a more dynamic view that captures progress within the given time boundaries. The productive interaction and the related co-construction of knowledge objects are depicted as moment-to-moment events. The interactional moves can be identified as coherent and sequentially organized actions, displayed analytically as collections of episodes.

Finally, the *multilayerdness* is expressed through different aspects and holds a great analytic potential. One aspect is represented by the locus of learning, which can be at the individual, the group, or the community level, and expressed in analytic terms by the unit of analysis. This study follows conceptualization by Valsiner and van der Veer (2000), Ludvigsen and Mørch (2010), or Säljö (2004) acknowledging that meaning making and knowledge are constructed in a less-well-charted middle ground of the interaction, involving individual and collective input. Social interaction at the group level, expressed in language and actions, allows us to pin down the important aspects of the knowledge construction effort. The unit of analysis is not the individual or the group but the joint action (verbal or otherwise) directed at the co-construction and elaboration of the knowledge objects involved—in other words, the mediated interaction (Stahl, 2013). This mediation leads us to the second aspect of the process being multilayered, which comprises the elements depicted in the previous sections. It is the combination of the interaction (productive, as envisioned here), the objects that mediate this interaction (with different functions), and the agency of the group as a construct of individual engagement and collective commission. The way these are woven together is also related to the temporality of the whole process and to how these components combine while unfolding in time.

Concretely, to construct analysis instruments, this framework envisions these concepts (or layers) as follows. In addition to the productive interactions, which are defined at the start of this section, *knowledge objects* are conceived as an externalization of knowledge, "freezing" knowledge at certain moments in time. The objects embody knowledge that is not in the mind but rather is externalized in something (such as ideas or actions) that is accessible to the whole group and can be used to produce new knowledge. As an analytic stance, this study adopts the distinction between generalized objects of activity, which are historically developed, and *situational* objects (Jahreie, 2010), which are discursively constructed in the interaction of the learners. This position situates the shared knowledge objects at the center of the interaction process, either as instruments or as objects of inquiry, not only as end outcomes. It views the knowledge objects as rather open-ended projections oriented toward something that is not known for sure and, as a consequence, as generators of new conceptions and solutions (Miettinen & Virkkunen, 2005). As a result, working with these objects is a continuous process of transforming an object from its current state into a required end state. Finally, it regards the construct of *shared epistemic agency* as the capacity to enable a deliberate, joint, object-oriented interaction. This type of agency expresses different qualities of the knowledge co-construction process. The epistemic aspect refers to the active involvement of the group with knowledge and its materialization into knowledge objects. The aspect of sharedness implies that agency is not the expression of each individual member's activities or pursuits but is, rather, the expression of joint efforts at the group level. Furthermore, shared epistemic agency is seen as an emerging, recursive capacity that manifests itself and unfolds during the interaction.

Methods

Research Context

This article reports on a design-based research project (Collins, Joseph, & Bielaczyc, 2004) concerning learning in higher education. The project involved studying collaborative learning settings using a co-design approach. The initial iteration consisted of investigating collaborative groups in existing settings; the iteration presented in this article provided input for redesigning the collaborative activities and technology features. This iteration, which spanned the whole course period, employed the model of distributed project work (see Ahuja & Galvin, 2003) and was organized within the Bachelor Thesis, a 20-week course offered in the third and final year of bachelor degree study in educational sciences. The course aims to support students in integrating and applying previously acquired scientific research knowledge and in reporting on the research studies conducted during the course period. The course curriculum was redesigned with an emphasis on open-ended tasks and the co-construction of shared knowledge objects (Paavola & Hakkarainen, 2005). During an introductory workshop, the participants were introduced to concepts such as small-group learning projects, open-ended and ill-structured problems, object-oriented collaboration, and online technology, and they met two external clients invited to participate in the project.

Participants

Fourteen out of the 120 undergraduate students enrolled in the Bachelor Thesis course at a large Dutch university participated in this study. Direct access to the sample group was gained through a call to students and their teachers, with the participating students deciding to participate voluntarily—a mixed purposeful sampling approach, including typical case sampling (Creswell, 2007). Seven full-time and 7 part-time educational science students (2 men and 12 women; average age = 30.1, SD = 9.9) participated and are organized into 5 groups. All participants were in the final year of the undergraduate program. The two participating clients were recruited from a pool maintained by the supervising teacher, of external companies and organizations interested in involving and supporting students in their activities, through either internship or research projects. Both clients involved were private consultancy organizations in the field of educational innovation. Client 1 specialized in instructional design using online technology (e.g., games or mobile learning modules). Client 2 specialized in knowledge management and educational innovation services using virtual learning community (VLC), an online environment for educational activities.

Design Iterations and Pedagogical Scenarios

The design unit was the *pedagogical scenario*—a purposeful description of instructional and learning activities taking place in a certain context. The course coordinated by the participating teacher was redesigned following a set of design principles (see Sins, Bauters, & Damşa, 2008), as follows:

- *Collaborative projects* involving *social interaction* replaced individual assignments and projects.
- *Open-ended and complex problems* were introduced, requiring inquiry and active engagement with knowledge.
- *Shared knowledge objects* were requested as part of the solutions envisioned for the problems.
- *Technology mediation*, an online application that supports collaboration, replaced a course management system.
- *Interactive mentoring* and *supervision sessions* on an as-needed basis were introduced, instead of lectures.

The participating teacher was involved in the redesign of the learning activities. Student learning was enhanced by facilitating participation in object-oriented collaborative research projects. The student groups were provided scaffolding for organizing their research activities. They were encouraged to organize and manage their own projects by using skills accumulated in prior research courses.

Table 11.1 Overview of research phases

Research phase	Activities	Intermediate objects	Final knowledge object
Project initiation phase	Finding a client and negotiating a research project Preparing a project plan	Project plan	Research article Presentation slides
Research preparation phase	Describing the research problem Formulating research questions Creating a theoretical framework Identifying and describing research methods Searching for respondents	Research plan	
Construction phase	Constructing instruments (for collecting and analyzing data) Collecting data Analyzing data Interpreting results	Data collection and data analysis instruments Drafts reports of findings	
Delivery	Reporting on project and results Presenting the project and results	Article drafts Presentation slides	

During the project period, face-to-face sessions with the teacher were organized on an as-needed basis. Participants presented the final group product, a common research report, on a Bachelor Thesis congress day. The research project consisted of four phases: *project initiation*, *research preparation*, *construction*, and *delivery.* These phases, the corresponding activities, and the knowledge objects are presented in Table 11.1.

Collaborative Research Projects

The task, to collaboratively set up, conduct, and report on a research project, was presented to and discussed with all participants. Groups were formed at the beginning of the course period based on the students' interest in the research topics proposed by external clients. In the introductory workshop, the two clients presented a number of problem situations that they wanted examined. In the period that followed, students had a chance to discuss their preferences and form groups based on their interest in specific topics, chosen from the ones proposed by the clients. Once groups were formed, they were encouraged to talk with the clients to give the initially presented research problem a clearer shape. The teacher facilitated this dialog. Client 1 required research on the design and implementation of educational games in secondary professional education. Two student groups worked on this project. Client 2 requested an investigation of learner behavior in this environment. Three student groups chose to investigate different aspects of this topic. When the research topics were specified together with the clients and approved by the teacher, the groups could proceed with their research study.

Technology Support

The technological support for collaboration was provided through the online course management system Blackboard®. The system provided support for both managing the course and making course documents available, as well as for within-group collaboration. Course objectives and guidelines were posted by the teacher in the virtual course environment in specific online folders—*course documents*—and announcements were placed in the *announcements* space. A *discussion board* was available for posting and discussing matters relevant to all participants in the course. For the collaborative work, separate virtual spaces were created for each group. This space had a *file exchange* functionality, which allowed group members to upload, download, and exchange documents and materials and report versions. A *chat* functionality was available for synchronous communication. Groups also had access to regular email. By providing students with space to share their work on the joint documents, the intention was to stimulate and enhance their exchange of ideas and versions of the materials they had worked on, by going beyond the constraints of face-to-face meetings. Students were encouraged to provide feedback, annotate, and elaborate on one another's drafts. Chat was introduced with the explicit intention to stimulate and facilitate discussion of these materials, while group members were not located in one another's proximity.

Data Collection and Analysis

The design-based research approach was used as an overarching methodological framework. Within this, the empirical study was conducted as a set of case studies (Yin, 2003). It defines a *case* as the activities and the products of one group of students during the 20-week course period. A variety of data was collected to achieve triangulation (Yin, 2003). The data set consisted of field notes during meetings with clients and the teacher, interaction data (group discussions and e-mails), reflective data (group interviews), group products, and all the report iterations (which varied per group, from a minimum of 11 to a maximum 29 iterations). This contribution involves a cross-section of the data, drawing primarily upon group discussions, group products, interviews, and field notes. The data were chronologically ordered, and the recordings were transcribed verbatim in the original Dutch; excerpts in the article were translated by the author.

The *analysis* followed the conceptual avenues outlined in the analytic framework section above, which highlight productive interaction, knowledge objects, and shared epistemic agency as essential layers of the learning process conceived as knowledge co-construction. In addition, the actions and objects identified were followed in time, with a focus on how interactions generate new actions, which can consequently influence and affect the developing objects. This trajectory approach has the purpose of documenting and depicting how interaction unfolds and the incremental development of the knowledge objects that emerge from the interaction. Eventually, the analysis attempts to provide substantiation for establishing a connection between how this co-construction process takes place and students' learning.

The analysis focused on three discrete aspects. First, *group interaction* was examined using a discourse-analysis technique and descriptive statistics to create an overview of the type of verbal actions in the interactional space (see Sarmiento-Klapper, 2009; Stahl2009c). *Relevant* (or *theme-based) episodes* of interaction were identified in the data corpus, an episode corresponding to relatively bounded sequences of speech or encounters in the group discussion (Linell, 2009). The unit of the analysis was combined: the episodes indicated the general thematic orientation of the discussion, while the coding of the verbal actions (in the context of an episode/theme) indicated the individual but contextualized contribution to this collective discourse. A coding scheme developed in a previous study (Damşa et al., 2010), emerging from theory-based categories through iterative analysis of empirical data, was further refined and applied (Annex 1 displays a complete overview of the coding categories). It consists of three dimensions of action, *epistemic*, *regulative*, and *other* and reflected the types of actions that can be identified in interaction following the theoretical aspects deemed essential in the co-construction process. The first category is that of epistemic actions—comprising actions that involved knowledge and dealing with knowledge-related aspects (ideas, concepts, etc.); the second is that of regulative actions, which involves actions aimed at organizing the interaction, such as planning, coordinating, monitoring, and reflecting on the collaborative process. The remaining episodes were coded as other types of actions. These categories of actions are considered to reflect the gradual involvement of the group with knowledge, starting with identification of the problem, continuing with the brainstorming of ideas, then with the elaboration into object drafts, etc. An inter-rater reliability test was conducted by the researcher and another, independent person, who both applied the coding scheme to six randomly selected excerpts from two groups' discussion protocols. A sufficient inter-rater agreement between two independent coders was achieved (kappa = 0.80).

A second layer comprised a combined analysis of *interaction* and of the *knowledge objects* that emerged from and were developed during this interaction. Interaction-analysis techniques (Jordan & Henderson, 1995) were used for an in-depth examination of the relevant episodes. Key events (Webster & Mertova, 2007)—actions that triggered subsequent actions and led to a particular, relevant development regarding the shared objects (in discussions, emails, or object iterations)—were identified in the (conversational) episodes. Object development was analyzed in conjunction with these key events in the interaction. Object versions were elaborated upon immediately after an identified key event; a timeframe was used for a maximum of 1 week to identify such pairs of key events and object-oriented actions. The analyses of the object versions, inspired by document analysis (Bowen, 2009), focused on identifying changes in the object structure, volume, and complexity as a follow-up to the interactional encounters. Figure 11.1 shows how the analysis is unfolded. The circled section represents a sequence of data materials illustrating connections between the interactional elements, followed by actions upon the emerging object iterations.

Finally, the third layer, the groups' *shared epistemic agency*, was disclosed by qualifying (sequences of) actions identified during the interaction analysis. This took place through a search for regularities in the occurrence of actions that indicated deliberate, strategic, and reflective conduct. The previous two layers (interaction and knowledge objects) were central to the analysis. The identification and analysis of the shared epistemic agency had the purpose of showing how active participation and sustained engagement are important in achieving co-construction and how they can complement the other layers in the process.

In addition, the *quality* of the groups' final knowledge objects was determined by using a standardized evaluation form based on criteria established by the teachers of the course. This form allowed the grading of the groups' articles with grades ranging from one to ten on the dimensions of *content* and *writing quality*. The content dimension consisted of five elements: the synthesis of material from scientific sources, the elaboration of the research problem and questions, the elaboration of the research design and methods, and the indicated scientific and practical value of the research study. The writing quality dimension refers to the structure of the article, language use, punctuation, and the academic writing guidelines. Two independent evaluators graded each article, with a sufficient inter-rater reliability (kappa = 0.90).

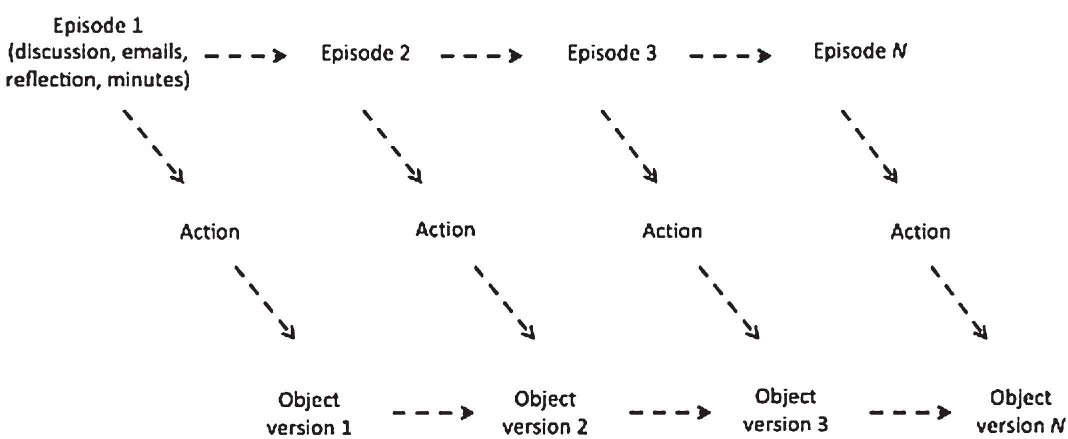

Fig. 11.1 Analysis model

Results

This section begins by presenting a general overview of the type of actions identified in the five groups' interaction upon the coding of the group discussions. It continues by illustrating interactional episodes that are considered productive and connects these to instances of knowledge objects developed by groups to explain different ways in which this productiveness is expressed in the object development. In addition, results indicating agentic conduct are discussed using a series of data excerpts from one group's interaction. The findings are summarized in a final subsection.

Overview of Interaction Types at the Group Level

The six coding categories of interactive actions provided a first insight into the type of interactions that were predominant in each group's collaborative work (Table 11.2).

The first notable finding is that, in Groups A and C, the most frequent actions were those aimed at creating a shared understanding of the problem, ideas, or knowledge. Sharing knowledge and information and regulative actions are the other types of actions that occurred rather often in these groups' interactions. Regulative actions occurred, too, but appear less frequent than in Group B's interaction, in comparison. This overview indicates a greater focus on actions that involve joint (discursive) activity with knowledge. Sharing ideas, information, or knowledge or discussing and negotiating the meaning of concepts and constructing shared understanding of these issues indicates that these groups had a strong epistemic orientation.

However, it is noted that discursive interactions, which serve as preparation for knowledge construction, are predominant.

Conversely, Groups D and E appear to have interacted most frequently through actions that led to the generation of ideas and knowledge. Both groups show a relatively high frequency of such actions, followed by actions aimed at creating shared understanding and those aimed at sharing knowledge and information. The rather low frequency of regulative and other types of actions indicate that these groups were more focused on the epistemic aspects of the interaction. This distribution of types of actions indicates that these two groups' activities were discernibly more concerned with working jointly toward generating knowledge, built on discursive interaction aimed at collecting information and creating a shared understanding of the knowledge gathered or emerging in the group. Regulative actions seem to have been performed to the extent needed to ensure that the group functioned efficiently, and priority is given to the productive types of action that contribute to advancing the knowledge objects.

Table 11.2 Frequencies of types of interaction

Category	Group A	Group B	Group C	Group D	Group E
1 Creating awareness	10	8	13	12	13
2 Sharing knowledge	20	14	18	18	15
3 Creating shared understanding	**27**	14	**29**	22	24
4 Generative collaborative actions	10	12	14	**29**	**31**
5 Regulative activities	23	**38**	15	12	9
6 Other	10	14	11	7	8

Finally, Group B's conversational interaction was concerned predominantly with regulative aspects of the collaboration. This means that the group often discussed the division of labor, the organization, and the coordination of the collaborative process and monitored the work performed by individual members. We also observe that actions in the category *other* (e.g., social chat) are just as high in frequency as the actions of sharing knowledge and creating shared understanding. The types of action identified as epistemic (creating awareness of problems, sharing knowledge, and generating knowledge) are identified in this groups' interaction but do not seem to have been the focus of their collaborative process. As shown in different episodes of their interaction, this group seemed to organize collaboration in which a division of labor and individual work, accompanied by coordination and monitoring of individual contributions, prevailed.

The quality of the final knowledge objects was assessed by the supervising teacher using the evaluation form. Groups that performed epistemic actions at the generative level more frequently, such as collaborative idea uptake and co-elaborating on ideas and object versions (Groups D and E), produced objects of higher quality—as opposed to the group that frequently employed a division of labor and relied on individual contributions (Group B). Groups A and C, which displayed mainly interactions that led to awareness and shared understanding of knowledge and problems, obtained grades in the middle range, lower than those of Groups D and E.

Productiveness Through Discursive Interaction

This section discusses interactional episodes from Group A's data. This group collaborated with Client 1, who was interested in gaining more insight into the use of gaming in secondary vocational education. The group examined the role and the added value of educational games used as learning tools in three vocational education institutions. They conducted observations of pupils during the use of a computer game and interviews after. They developed the interview protocol and adapted an observation scheme and then analyzed and reported their findings in a research report and in a plenary presentation to the teacher, their peers, and the client.

Once identified and labeled, the interaction sequences singled out for this in-depth analysis are linked to actual object development. The first excerpt (Log 11.1) originated in a discussion during the preparation phase of the research project, when the group members tackled the research question formulation. This group started the project by collecting information on the use of educational games in secondary vocational education. They discussed the information gathered in weekly face-to-face meetings. In the third project week, this group decided to start work on their research plan.

Log 11.1: Group A Face-to-Face Discussion (3rd Project Week)

1. Fleur:	"… Is it possible to brainstorm *on the research questions* this evening?	1-identifying focus
2. Eliza:	Yes, it seems a very good idea.	
3. Fleur:	It's funny, *I was reading those articles you sent* […]. That research is on a game, IT emperor, I actually don't know what that is. *That gave me ideas, we could research whether motivation for learning increases through playing a game*	2-sharing knowledge 3-explaining ideas
4. Fleur:	Yes, what are the obstacles when playing, that is a research question.	
5. Eliza:	Which factors…	
6. Fleur:	Wait a second, do we have to formulate a main question too?… because I didn't really understand that. *In the methodology course the question types were used* *wrongly all the time. Everybody calls them research questions.* I've got the idea that we make the same mistake. *Don't we have to clarify this before formulating the questions for our research*	1-stating problem 1-identifyig lack of knowledge

7. Eliza:	Yes, you are right, this must be clear for the three of us.	
8. Ted:	I agree. […]	
9. Fleur:	In any case, you have the main question and underneath.	
10. Eliza:	*…you have the research questions. So, main question and detailed research question. It is actually an itemization.*	3-creating explanations
11. Ted:	And that one you operationalize, in questionnaire questions, for example.	
12. Fleur:	So, do we need to have a main question as well? Or do we have one already?	3-re-framing problem
13. Ted:	Of course we need one.	
14. Fleur:	What could an educative game add to the learning process and to the motivation. Something in this direction?	4-generating ideas
15. Ted:	Yes, how can…	
16. Fleur:	…what can an educative game add to the learning process and to the motivation of students in vocational education."	4-elaborating ideas

Log 11.1 shows an example of an interaction sequence that illustrates how students attempt to create a shared understanding of concepts and ideas. During the discussion, group members realize that they lack a clear understanding of the research questions and of how to formulate these questions. One member of the group points to the problem—the different understandings or a misunderstanding of the concept *research question* (line 6). Others agree that they must clarify the incongruent understanding of the concept (lines 7 and 8) and decide to dedicate part of the discussion to this issue. They attempt to fine-tune their understanding of the concept. One group member provides her own understanding of the concept (line 10); another provides an elaboration (line 11). Another member offers the example of a concrete alternative (line 14), which the group continues to elaborate upon (line 16)

The discussion fragment shows that group members realize the importance of having a shared understanding of the concepts that they must apply before developing the knowledge object itself. In this interaction, the group makes progress on concept understanding through an exchange of insights, ideas, and knowledge sources. Creating a shared understanding of the concepts and giving these concepts concrete meanings in the context of their research help them to take a step forward and create premises to begin work on the shared object. This specific interaction instance illustrates this group's approach to object-oriented work, while their interaction, in general, was aimed at creating shared understanding and ideas or knowledge from sources and less at joint idea generation and elaboration.

Log 11.2 shows two versions of the shared object created by this group at different moments in time, i.e., before and after the group discussion episode presented above. The text in the column headed "Initial understanding and formulation" comes from a version that group members prepared the day before they met. The text in the column headed "Formulation after group discussion" is a section in a version produced by the group after the discussion shown in Log 11.1.

Log 11.2: Selection of Sequences in Object Progression

Initial understanding and formulation (2nd project week)	Group discussion (see Log 11.1) and elaboration of material after 2 weeks	**Formulation after group discussion** (4th project week)
"We can think of research questions like: a. What is the definition of a game? On Wikipedia there are simple ones: 'a computer game, is a game that is played on a computer'. It can be played on a computer, Playstation, PDA, mobile phone, mobile computer. b. Is an educational game an addition to the learning process? In which the motivation plays an important role? Reading this now I realize this is not the right formulation if we want to investigate statistically. Should it be a closed question? Other formulation: c. Does an educational game have an effect on the learning process, and hence, on the motivation of the students? Should we only talk about motivation, and that we look at the learning process through it? d. When is an educational game educational? When do people speak about educational games? Answer this question with a literature review, hence not necessary to be a closed question. e. How do students feel when playing games? This one too formulated as open question, answered with interviews? f. Which of the elements below do students appreciate more? Statistical analysis? Players and competition Making decisions, keeping control Goal aim, begin, end Learning goal		Main research question: What do educative games add to the learning process and the motivation of students? Based on this main research question we formulated the focus of our research in sub-questions: 1. What are the criteria for defining a game as educational? 2. How do students experience educational games in a learning/educational context? 3. Which elements of educational games motivate learners?"

One can detect rather murky ideas in the first column of Log 11.2. Explanations added by the creator of the text (in italics) indicate that these ideas are still in development and that the author feels uncertain about the direction to take. The explanations are very tentative; some questions are formulated, and the group discussion shows that some of the group members consider these suitable research questions for their study. In the selected discussion in Log 11.1, it is stated that research questions are not the same as questionnaires or interview questions. It occurs to all the group members that some of the questions in this preliminary document are actually formulated incorrectly. The discussion helps them to understand the difference between the types of questions and to create a shared understanding of how to formulate research questions. The text in the column headed "Formulation after group discussion" resulted from revisions applied in the week after this discussion and reflects a much better synthesis of the knowledge the group discussed about. This second version shows that the group understood the notion of research question and how that is supposed to express the topic of their empirical study, and not be part of an instrument used to collect data.

Log 11.3 follows the elaboration and work on the knowledge object that led to the last version of the research questions, as displayed in Log 11.2 above.

Log 11.3: Group A Discussion (6th Project Week)

1.	Eliza:	"… so, we formulated these questions, and I think it summarizes our ideas. Don't you think?	3-re-framing focus
2.	Ted:	Yeah, I think the part with the games is fine.	
3.	Fleur:	But we didn't include defining the games in it…	3-problematizing
4.	Eliza:	But it should be part of the answer. We discussed that, that we don t take it up in the questions, did n t we?	
5.	Fleur:	But the research questions, they show our focus, and isn't that what we are after, games in learning?	3-structuring knowledge

6.	Eliza:	True! But do we really need to add something on what games are?	
7.	Fleur:	I think we do. You can' t just ask about what games add to learning and how they motivate learning without explaining what they are.	1-identifying lack of knowledge
8.	Ted:	But don't we do that through the literature?	
9.	Fleur:	Well… that is possible. But we are not asking in the research questions. shouldn't we? I really think this is not good as it is now.	
10.	Eliza:	Hmmm. I think I am getting your point. but then we need to rephrase.	
11.	Ted:	No, we can use the literature to formulate a definition.	
12.	Fleur:	We need a question first, I think. Which we can answer through the literature. [.]	3-re-framing problem
13.	Ted:	Are you sure?	
14.	Fleur:	I think that s how it works. What do you think, El?	
15.	Eliza:	I am not sure. I think we should ask John [supervising teacher]"	

In the previous excerpt (Log 11.2), showing a section of the knowledge object at various stages of development, it can be noted that the group succeeded in synthesizing essential knowledge to formulate their research questions. This leads to progress in their object-oriented work in that the aspects that was rather unclear in the previous version (e.g., what research questions vs. interview questions are, or what is important enough to be incorporated into the research questions). However, in this excerpt, the conversation returns to the matters that have been addressed in previous discussions, such as the definition of a game, and whether it should be addressed in the research questions (line 3). The group has a good (and shared) understanding of what they are after in their research (line 7—what games add to learning and how they motivate it), but they seem to stumble over aspects that have not been clarified, even if they were addressed in other discussions. The discussion is concerned with agreeing whether or not to insert this in their questions (lines 6, 7, 12, 14) and the technical aspect of how to actually do this (lines 8, 11). The group seems confused and eventually adjourns discussing this aspect by introducing the alternative of consulting their supervising teacher (lines 13–15).

While the clear depiction of the research questions (in Log 11.2), as they emerged from previous discussions, indicates the group members' understanding of the research problem and topic, in this final discussion excerpt, they seem unable to capitalize on that progress. They materialize the shared understanding and ideas that they have clarified through their face-to-face discussion into a new version of the knowledge object (i.e., research questions), but they return to the same topic in their subsequent face-to-face meeting. While their discursive interaction seems to be productive in the sense that clarification and a shared understanding of ideas are taking place, it appears that it does not always lead to the group materializing it into more advanced versions of the knowledge object.

Productiveness Through Iterative Co-construction

The following episodes illustrate interaction instances in Group D's face-to-face discussions. This group collaborated with Client 2, who requested an examination of the role of feedback in a virtual action learning environment. Using an electronic learning platform, this client implements virtual action learning, which involves learners in solving and uploading assignments into the system and using other learners' directed feedback to revise their products. Group D decided in agreement with the client to investigate the role of peer-feedback on the learning of the participants in this environment. They collected log data from this virtual environment, products, and feedback on these products. Their project and findings were reported in a common research report and a plenary presentation at the end of the course period.

The general collaborative strategy of the group was characterized by frequent face-to-face meetings, during which both logistics and content-related issues were discussed. Most of the ideas brought forward during these discussions were provisionally elaborated on the spot and provided with feedback by the others. One group member took notes, while the other two continued the elaboration verbally. When not able to meet face-to-face, they wrote down their ideas and emailed them, asking for feedback. At the moment of this discussion, during the preparation phase, the group met to decide and elaborate on the research questions and main concepts to be defined in their research plan. These aspects, already tackled in the project plan, needed elaboration and specificity.

Log 11.4: Group D Face-to-Face Discussion (5th Project Week)

1. Alice:	“. Shall we try to organize our ideas about feedback, what we talked about before. some terms and definitions we need to understand so we know what we want to investigate… let’s get the questions.	1-identifying focus
2. Elly:	…oh, yes, the project plan, let’s get that document with the questions we already formulated. (Searching for the plan)	4 -idea uptake
3. Elly:	What do we call feedback?	
4. Jane:	Let’s first see., what is feedback for us, and what is feedback in the VLC.	3-problematizing
5. Alice:	Shall we just look what we wrote about that in the plan? [.]	
6. Jane:	So, we can indicate here that feedback can be given in different ways and that we focus on peer-feedback, suggestions for improvement and rating from peers.	4-generating ideas
7. Elly:	Yes, then we can elaborate. Let’s write that down. (Typing)	
8. Elly:	OK, what is feedback?	
9. Alice:	Feedback is. how is it defined in those sources?	
10. Elly:	I don’ t have them, but I remember. linking back the results of the collaboration.	2-sharing information
11. Jane:	We must first write the definition of feedback.	
12. Elly:	But don’ t forget we focus on peer-feedback.	4-re-framing
13. Alice:	But linking back the results of collaboration is too vague.	
14. Jane:	The reaction,. or response then.?	
15: Alice:	Yes, response, it is response on a., you could say, product, from a peer?	4-idea up-take
16. Elly:	…inside de VLC…	
17. Jane:	Yes, don’t make it too complicated. Suggestions for improvement for the product in VLC by peers.	4-elaborating ideas
18. Alice:	OK. (Typing)…”	

One group member identifies a focus for the discussion and underlines the importance of a good understanding of the domain, the questions, and the main concepts as a condition for setting up a good research study (line 1). They retrieve the project plan that they created in earlier stages as a source of and support for discussion (lines 2 and 5). The interaction sequence continues by structuring the talk on the concept in discussion—*feedback* (line 3)—and framing this concept (line 4). The group uses ideas from the initial object to elaborate collaboratively on the new object iteration (line 5). One group member points out that the concept needs specification, and the group reframes it (line 12). The ideas generated are written down and then taken up by the other group members (lines 15 and 16). The group starts elaborating on these ideas (line 17).

This excerpt illustrates a different aspect of productive interaction. This group’s strategy goes beyond creating a shared understanding of concepts and individual task performance.

Instead, they attend to generating ideas and negotiating them. Moreover, the entire group then takes up these ideas and elaborates upon them, and the knowledge object gains shape as they document these ideas. This interaction can be labeled productive due to the visible progress of the knowledge object.

To illustrate this progress, Log 11.5 shows a section of the shared knowledge object created by Group D during the aforementioned discussion and beyond. The comparison between a section of the initial version (the project plan) and the elaborated version in the newly produced object (research plan) illustrates the productive value of this interaction sequence.

Log 11.5: Fragment of Content of Shared Knowledge Object Iterations

Initial object content (4th project week) "Research questions: […] Possible sub-questions –What is feedback? –Which influence does feedback have on the learning process? –Does the way feedback is given have an influence on the learning process? –Does feedback have an influence on motivation for learning? –How is feedback given and received?	Group discussion (see Log 11.4)	**Co-elaborated object (6th project week)**. Necessary definition: –How is feedback defined in the context of the virtual learning community? Definition: giving and receiving suggestions for improvement on the products or artifacts to and from course-peers. (Definition of peer-feedback needs to be looked up in the literature and will be processed here.) Research questions and ideas for investigation: In which way is peer-feedback given inside a VLC? The suggestion for improvement can be given in different ways; there is no fixed format or example of how it should be done. These different ways are dependent on the prior knowledge of the learners, age, motivation, gender, personal interests, self-confidence, reading and writing skills, and learning and interaction style."

The research questions shown in the column headed "Initial object content", which presents material from the initial stages of the process, are reframed and elaborated in the column headed "Co-elaborated object." This latter column displays material from the co-elaborated object after the discussion illustrated in Log 11.4. This example indicates the progress in the conceptual complexity of the group's shared knowledge object during this interaction. During the discussion, the concept of feedback is further specified and reframed as *peer-feedback*. The group discusses and defines this newly introduced concept using information from sources (line 10, Log 11.4) regarding the specific context of their research (the VLC) and individual ideas. They create definitions and explanations that deepen the meaning of the concept, as shown in a more elaborated version in the third column.

Following the revision and elaboration of the research questions, as partly illustrated in Log 11.5, the group moved on to the next step in further developing the research plan and design. Log 11.6 shows an instance of interaction from the week following the elaboration of the research questions.

Log 11.6: Group D Face-to-Face Discussion (7th Project Week)

1. Alice:	Right, we are this far. Good job on the research questions.	
2. Jane:	Yes, we ve gotten nicely on the way. [.] I looked up the information we needed, on peer-feedback.	2-idea uptake
3. Elly:	Me too, found interesting stuff in the articles we collected. Useful leads by John (au. *supervising teacher).*	
4. Jane:	Got some idea on how to proceed here. remember the issue with feedback versus peer-feedback?	1-identifying focus
5. Alice and Elly:	Yes.	

6. Jane:	I think we contextualize it very clearly. Like, I would say this is the type of environment, these are the features, these are the activities envisioned, and feedback is part of the learning design.	3- structuring ideas 4- generating ideas
7. Alice:	Sort of. pedagogical design, you mean?	
8. Jane:	Yes, something like that.	
9. Alice:	Then we can define feedback, using the literature, but then explain that here we have peer-feedback at play, and what the differences are. Like, what we started writing on last time.	4-co-elaborating ideas
10. Elly:	Yes. We can, actually, take each way of giving feedback, like positive, negative, constructive, etc., and explain how that works with peer feedback.	4-generating ideas
11. Jane:	Yes, but don’ t forget that our focus is on how peer-feedback correlates with participation, motivation, and others.	3-reframing focus
12. Elly:	Yes, but that is the next step, right? First, we have to deal with this feedback concept.	
13. Alice:	True, on the same page here.”	

The excerpt starts with the group members acknowledging the work done on the research questions (line 1). Then, they start discussing the next step in their elaboration of the research plans, which is to operationalize the key concepts (line 2). They connect this discussion to points touched upon in the previous discussions (i.e., the distinction between the *feedback* and *peer-feedback* concepts, line 4). Group members indicate that they collected information on this matter (lines 2 and 3) and proceed to discuss strategies for elaboration. In line 6, Elly proposes an alternative, which is taken up and elaborated further by Alice in line 9. The group members take up ideas from the previous discussions (e.g., on the type of feedback) and generate new ideas to devise a way to pursue the elaborations (lines 9 and 10). Jane reminds the group about their research topic and focus, which should be kept in mind, but they all agree on the order of actions they have to pursue.

This excerpt illustrates how the group capitalizes on their previous discussions and understanding of concepts and used object drafts they had worked on as a starting point for their upcoming discussion. They explicitly acknowledge the point that they have reached in the process (research questions are now elaborated) and their achievement in this regard. They quickly strategize and continue their discussion on the next task that awaits them, the operationalization of concepts. The interaction is focused on content, and the group members very closely build on both previously constructed knowledge and each other’s ideas. They seem to have a natural way of taking up and elaborating on each other’s ideas generated during the discussion.

Overall, this group has devised a strategy for collaboration and work on the object, also illustrated partly in this excerpt. They first discussed concepts and strategies, created shared understanding when that was possible, together wrote first drafts, looked up sources, and collected information, processed it in the elaboration of the drafts, and discussed the elaborated drafts in their following meetings. They worked in a targeted way, and their discussions were content-oriented. They used their discussions as a starting point for elaborating ideas in writing and rarely left the meetings without writing down the ideas and elaborations (in draft form) that emerged and gained shape during the meetings. Elaborations of the object drafts pursued individually were always discussed in the group in the face-to-face meetings.

Expression of Shared Epistemic Agency

How shared epistemic agency is expressed is illustrated here using Group D's data, in implicit contrast with the collaboration of Group A. How this capacity manifested itself is not straightforward but intertwined in a subtle manner with the groups' interaction and object-oriented work. The two excerpts below are selected from a face-to-face group discussion and the group interview at the end of the course period, respectively. Log 11.7 displays a face-to-face discussion episode in the preparation phase of the research, following a week after the elaborations and work on the research plan (showed in Logs 11.4 and 11.5). The discussion reflects the interaction at the point where the group encountered problems with regard to the operationalization of concepts and the mapping of the context for entrance points for the empirical investigation.

Log 11.7: Group D Face-to-Face Discussion (9th Project Week)

1. Jane:	". I've gone through our list of concepts and I think we are on track with the operationalization.
2. Alice:	Yes, beside that issue with which aspect in the VLC connects to which concept in our framework.
3. Elly:	This thing really annoys me, cos we can t move on. [.]
4. Jane:	I think we are far enough now. The way I understand it is, we have defined peer- feedback as (reading out loud definitions from the written texts). Then we listed the key concepts (enumerates concepts) and now we have to operationalize and make some connections.
5. Alice:	Yes, for example, how does positive or negative peer-feedback have an influence on presence or activities in VLC. My hypothesis is that the more negative the feedback, the longer the presence.
6. Jane:	But where did you get that from?
7. Alice:	It's logical, isn' tit?
8. Elly:	You can't just invent something, it needs to be grounded. We had that in the methods course.
9. Alice:	Yes, but it's kind of common sense. Also, this issue with the client being a little vague, we have to make it more concrete.
10. Elly:	Could be. but we have to do it by the book. Like. ehm, we have our research questions, based on literature, right? We use that to work out the hypotheses. Then we have definitions of concepts, now we operationalize the concepts.
11. Jane:	Wait. we should write down this one, as Alice formulated it, then we all go after information in the articles we have.
12. Elly:	Yes, smart! I think we can all write down the supporting or counter arguments, we exchange and discuss them when we meet again.
13. Alice:	Ok, can be done. Shall we note down what we have for now and what we plan to do?
14. Jane:	Yes. (Retrieves the research plan document and starts typing)"

In this excerpt, the discussion revolves around a problem the group has struggled with for a while. They had identified the main theoretical concepts to work with, but the complexity of the virtual learning environment they were studying and the rather broad expectations from the client made this task difficult. In this episode, they are suggesting some possible hypotheses and alternatives for solving this problem (e.g., line 5). While approved as a strategy, the solution proposed by Alice is criticized by Elly (line 8), who explains some of the criteria and the rigor of the research methodology their study must comply with. It seems that they have a good theoretical knowledge of the empirical context, but they lack knowledge of how to bring them together into a coherent and sound research plan. They appear aware of this issue, and while they emphasize the need to meet these criteria, they start devising a strategy to address the problem. It resembles their usual collaborative strategy, but it is now spelled out explicitly, with the steps to be followed planned and written down.

This final excerpt is selected from the ending interview with Group D and focuses on the episodes of the interaction and work revolving around the problem that the group encountered regarding the operationalization and connection with the empirical context (presented also in Log 11.6).

Log 11.8: Ending Interview, Group D

Interviewer:	"…Do you remember the discussions regarding the operationalization of concepts?
Alice:	Oh yes, that was a tough one. I mean, at that point in time. Because we had some other moments like that, but we managed them.
Elly:	That one was one of the moments when we felt that we don't understand what we are doing, that we don't have the knowledge and skill needed to tackle this.
Interviewer:	And how did you manage it?
Alice:	We were a little confused, at the beginning. We didn't know how to make the connections, conceptual and, ehm. methodological.
Jane:	But then we discussed the problem, and figured some point where where we could start. And what we would need to do.
Alice:	Yes, we first looked up some more information in articles, then exchanged materials, then we met and talked again. We wrote up a first version, like first operationalization and ideas, and Elly refined that at home.
Elly:	We asked for a supervision session and we asked John to take a look. We wanted to be sure we didn't go totally the wrong way.
Alice:	Yes, and it was ok-ish, the way we started. After that we finished up that section and could start working on the instruments.
Elly:	I found it difficult and frustrating, but I think we learned a lot.
Jane:	Yes, we surely had a break through there, got a better idea of how research works."

This interview section was aimed at understanding how students experienced the operationalization of the problem previously discussed. As it becomes evident, they were very aware of the problem and assigned importance in solving it thoroughly. They indicate that lack of knowledge and experience in conducting research has caused them confusion and frustration, but their explanation of their strategy also shows that they have approached the situation in a very rational and thorough fashion. They identified their shortcomings with regard to research and outlined their strategy for tackling the problem. While they clearly were at an impasse, as they indicate themselves, they did not consider giving up or relying on the supervising teacher and other authoritative instances. They devised a procedural strategy and a first draft of what they thought it should contain, which indicates their decisiveness and engagement in pursuing the task. Only after developing this outline did they ask for confirmation of their strategy and co-constructed content from the teacher.

How the group approached this problem and engaged in addressing it allows us to depict how shared epistemic agency is expressed in the context of interaction. This group expressed its agency through deliberate choices for gaining a good understanding of the problem, analyzing possible alternatives, searching for additional knowledge, and constructing knowledge that could represent a solution to this problem. In-depth discussion, the use of theory-based arguments, and concrete actions aimed at concrete knowledge solutions illustrate the epistemic aspects of agency. Envisioning a strategy to address the problem jointly, i.e., preparing alternative solutions and informing each other, continuously discussing the alternatives, and, finally, co-elaborating the final version, illustrates the shared aspect of agency.

Integration of Findings

The first two research questions asked were as follows: *What are the characteristics of productive interactions in the context of group object-oriented collaboration? How are productive interactions and knowledge object development interconnected?* Productive interactions emerged in different ways and in varying extent in the five groups' activities. As shown in the overview of coded interactions, three interaction patterns emerged from the data. First, Group B's collaboration was dominated by interaction at the regulative level, with actions focusing more on procedural aspects of the collaboration, and characterized by the frequent division of labor. This group finalized their project and passed the evaluation, which indicates that their interaction functioned from a process management viewpoint. The question that emerged is whether this interaction can be considered productive from an epistemic viewpoint and whether this group interacted sufficiently at this level to arrive at co-constructed knowledge. The interaction was more *individual-based* and process regulation-oriented. The assessment outcomes indicate that the conceptual elaboration and complexity of their research report was rather low. Second, the interaction of Group A appeared to be characterized by much discursive interaction, which resulted in an awareness of lack of knowledge, sharing knowledge from sources, and creating a shared understanding of ideas, knowledge, or identified problems that occurred during the work on the research plan. As shown in the analysis of Group A's excerpts, this led to the group reaching a common understanding of knowledge, negotiating explanations and definitions for concepts, and (re)framing ideas and problems. In various situations, creating a shared understanding of concepts (Group A) appeared crucial for the groups to move their work forward. This interaction was intensive and knowledge-laden, with the group's conversation being dominated by epistemic orientation and fewer regulative actions compared to Group B. It can be characterized as a productive but rather *discourse-based* interaction. Finally, as displayed by Group D, interactions involving generative collaborative actions, resulting in knowledge co-construction, were identified. These comprised discursive actions that led to shared understanding and knowledge but also generating of new ideas, collaborative idea uptake, co-elaboration, and the materialization of ideas into object versions. Group D's data shows that this groups' interaction was not limited to discussions of ideas and concepts but also involved group members bringing in new ideas, with supporting material, elaborating and co-elaborating on these ideas and alternatives for further actions, and strategizing on co-construction of the knowledge object, its quality, and the related processes. These types of interactions were more object-oriented and illustrative of productive interaction. Figure 11.2 below graphically represents these last two patterns of interaction, as illustrated by the collaboration of Groups A and D.

Group A's interaction trajectory shows a tendency toward discursive interaction, mainly aimed, as described above, at a shared understanding of knowledge. While this interaction was productive, the materialization of concepts and ideas into drafts to support them in being carried across sessions and enhancing joint elaborations was less frequent. The interaction was more verbal, fewer draft objects were developed, and the object drafts appeared not to play an important role in the interaction. The knowledge content elaborated in the object was shared among the participants to a much lesser degree. For Group D, regularly discursive interaction (face-to-face meetings and online conversations) was the basis for the joint object construction. Concepts, ideas, and strategies were discussed in the group, textual versions were discussed and amended, and co-elaboration occurred. Figure 11.2 shows that the number of draft versions of the text was notably higher than in Group A and that the majority of these drafts emerged and were elaborated upon following discursive interactions in the group meetings. This shows a better and more sustained integration of conversational interaction with the concrete co-construction and co-elaboration of the object. It is a shared approach in which productiveness was expressed at both the discursive and the object-development levels. In addition, the type and frequency of interactions indicating the co-construction of knowledge objects are reflected in the quality of the knowledge objects developed by the groups.

The final research question asked, *How is shared epistemic agency expressed and related to the groups object-oriented collaboration?* The emergence and expression of shared epistemic agency in the context of collaborative research projects was illustrated in the collaboration of Group D. This group displayed a high awareness of the problem, engaged in sustained discussion to clarify where the problem originated and thought together about possible strategies to solve it, and organized joint work to apply these strategies. This sustained engagement in collaboration and the pursuit of suitable solutions for developing the knowledge object is a reflection of how the group achieved shared agency, in

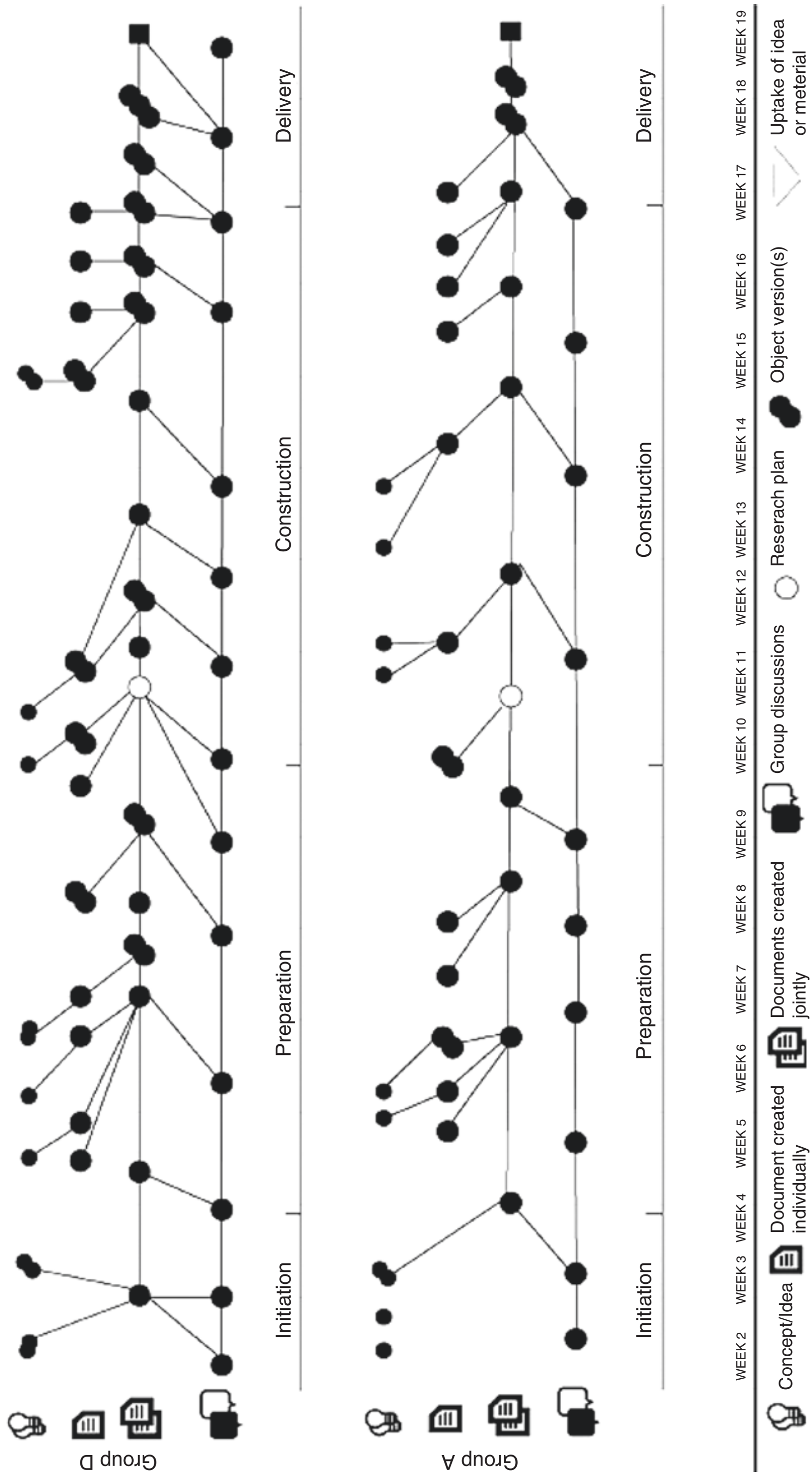

Fig. 11.2 Patterns of object-oriented collaboration

both epistemic and regulative terms. In addition, it supported an interaction that proved productive for the group in that they devised, constructed, and elaborated their shared ideas toward a complex and (from a methodological perspective) correct solution. The analyzed instance showed how individual members worked together in a joint effort to clarify both conceptual and procedural issues. The expression of agency here is characterized by individual input being weaved in together with this joint effort, which involves negotiation and supports a wider range of concepts or resources being deployed for the work on the (shared) object than it would in the case of individual action.

Discussion

This study aimed to gain an insight into the nature of *productive interaction* during *object-oriented collaboration* and how both elements contribute to the development of knowledge objects. It also examined the way *shared epistemic agency* is expressed in this process. The study's main contribution is the empirical substantiation it provides to illustrate the different layers of object-oriented collaboration and their interconnection. The study is built on the assumption that developing knowledge objects in a process of collaboration requires some form of productive interaction and that shared epistemic agency can fuel and steer this interaction. Using sociocultural perspectives as the main theoretical framework allowed the depiction of the productive aspects of collaboration, which translate to the need of human beings to express themselves by producing ideas and knowledge in interaction with others. From this perspective, productive interactions are conceived as communicative encounters between collaborating individuals, which lead to a shared understanding of concepts and ideas, the co-elaboration of the ideas into knowledge objects, and the sustained advancement of those knowledge objects.

This study provides an empirical contribution to the elaborations of the notion of productive interactions. It builds on and attempts to extend, among others, Baker's (1999) concept of constructive interactions and Mercer's (2002) view of exploratory talk, which highlight critical but constructive engagement with one another's ideas. However, while Baker considers that knowledge (re)construction is equal to negotiation, the current study takes Baker's elaboration one step further by proposing and illustrating a series of actions that make an interactional encounter ultimately productive and in a more tangible manner. The interactions identified are considered productive in the sense that, first, they create the grounds for co-elaboration and co-construction of new knowledge objects and, second, the interactions in the category of generative actions do in fact lead to the emergence of new knowledge and to the visible progress of the knowledge objects. The different types of action that make up these productive interactions and their occurrence are, nevertheless, interwoven. In the case of the two groups examined in depth, the analyses show how Group A achieved shared understanding through the verbal interaction of group members; at this level, such interaction can be considered productive. But the group did not achieve a deeper level of joint idea elaboration or materialization of their conversational accomplishment in the object drafts in the same way that Group D did. The latter succeeded in finding a balance between discussing concepts, ideas, and strategies and materializing those into object sections, drafts, and versions through a joint approach. Ideally, this is the type of interaction that collaborative work should elicit and facilitate, and it has the dual potential to trigger mutual interdependency at epistemic level and to lead to a concretization of this accomplishment into tangible knowledge products.

Next, while the findings of the current study could be interpreted as being in line with the ideas and findings on interaction in discursive activities (argumentation, small-group collaboration, or exploratory talk), they also reveal a less explored side of collaborative processes; this attempts, namely, to establish and illustrate the role of the developing knowledge objects in the interaction and the link between these two layers of the process. This aspect of the findings relates to Baker's conception of a shared goal in the constructive process, but it is more concrete and material than a goal, and, also, to Barron's (2003) analysis of interaction in a relational space. But unlike Barron's study, which places a strong emphasis on the productivity of interactions within the relational space but makes no link to generate a knowledge solution, the interactions identified here are visible in the way the knowledge object evolves. Interestingly, Baker (1999) and Barron (2003) come very close to the idea of knowledge objects in the sense of conceptual artifacts (Bereiter, 2002), but neither of the two studies pursues this idea in depth. The current study shows that a knowledge object is concrete, i.e., it materializes the knowledge collected or produced by the group (Paavola & Hakkarainen, 2005) and has a more distinct value as the mediator of group interaction (Wertsch, 1991). The relevance of the knowledge object for the convergence of the interaction becomes evident in this context, since it triggers group members to explain their point of view, confusion, and misunderstandings and also their ideas, suggestions for action, and further elaborations of the object, as was the case in Group D's collaboration. Furthermore, the findings also illustrate a two-way relationship between the knowledge object and the interactional process. The knowledge object's structure and elaboration are determined by the interactions, especially those of an epistemic nature, and this was evidenced in Group D's interaction. At the same time, the way the knowledge object develops influences the content and the direction of the interaction. In this context, Group D also experienced that their interaction was strongly influenced by the way their shared object developed and by their confusion and lack of insight into how elaborations should be pursued.

Another contribution of this study concerns the emergence and expression of shared epistemic agency. Data that shed light on how discussion among group members triggers problems, but also a shared effort to find solutions, illustrates a knowledge object's potential to elicit more convergent, complex interaction at the epistemic level. Here, the notion of shared epistemic agency proves useful for explaining what drove the groups to engage in particular types of interaction and go about working on the knowledge object. This type of deliberate, goal-oriented approach characterized by a high level of awareness and engagement, as identified in Group D's collaborative work, is rather generic and is in line with other findings on agency (Charles & Shumar, 2009; Damşa et al., 2010; Schwartz & Okita, 2004). In addition, such action bears a close resemblance to what Engle and Conant (2002) labeled as disciplinary engagement performed in relation to a specific task within a particular discipline. However, the current study contributes to a better understanding of how agentic action of this nature impacts interaction involving the construction of knowledge and the way shared knowledge objects are co-developed. These findings are fed into the discussion on the complexity of the agency construct, highlighting two main aspects. The first concerns the epistemic nature of agency in this context, with the results showing that it can be triggered and fueled by concrete objects that materialize group production and form a basis for devising further solutions. This highlights the importance of the productive aspect of agency, as emphasized by Schwartz and Okita (2004), which is manifested here in Group D's sustained pursuit of ideas and solutions, an approach that required them to go beyond the usual problem-solving tasks and the outlining of research strategies. The second aspect refers to the intersubjectivity that makes shared agency possible. From this perspective, the expression of agency shown in these findings is characterized by the weaving together of individual input and joint efforts, which involves negotiation and supports the deployment of a wider range of concepts or resources for work on the (shared) object than would be the case for individual action. While this group displayed the capacity to address atypical situations and problems, the question arising in relation to those findings is whether all collaborative groups have and can express such shared epistemic agency.

Multilayeredness and Temporality

Most importantly, one of the most compelling assumptions in this study is the multilayered nature of learning, conceived as knowledge co-construction. As indicated at the start of the article, this multilayeredness can be viewed from a structural and from an analytic perspective, since all these aspects are closely related. The structural aspect has been discussed in depth in various interaction studies (see mainly Stahl, 2009a), and it raises the issue of whether collaborative learning relies on interaction as a way of simply combining individual cognitions and the implications that have for the unit of analysis. The analytic aspect, which this study attempted to investigate in particular, comprises the layers that are assembled in the co-construction process, namely, interactions, knowledge objects, and agency. In the context of the current study, the structural aspects relate to the notion of intersubjectivity (Matusov, 2001) and the manner in which interaction around a shared object can bring together the engagement and contributions of individuals, intertwined in a joint effort. As shown in the analyses, there is dynamism in the relationship between intersubjectivity and how it is enacted—that is, how individual group members arrive at joint thinking, strategizing, and action—and the embodiment of the knowledge into objects. Furthermore, the characteristics of the interaction and the way it takes place are, in an ingrained manner, connected to the knowledge objects that emerge from and are developed through the interaction; this relates to the aspect of multilayeredness previously mentioned. The students' interaction examined here focuses not just on the shared understanding of knowledge but also on the translation of this knowledge into tangible objects, which are advanced iteratively.

In this regard, one distinctive contribution of the empirical examination is its attempt to follow, along with the unfolding interaction, the knowledge that emerges and gains shape through the interaction. This analysis focuses on the *trajectory of the knowledge* from the moment it enters the interaction process (e.g., ideas and concepts) until it has materialized and is elaborated into the final objects produced by the groups. Few studies have traced knowledge in this way, and those that attempted to do so (Furberg & Ludvigsen, 2008; Krange, 2007; Sarmiento-Klapper, 2009) focused on the concepts' trajectories and did not examine their further elaboration. The results of the present study add to this body of research by showing how ideas and concepts identified as "important" are put forward in the group. The knowledge in its preliminary form was dealt with in different ways using an array of alternatives, some of which are displayed in the interaction patterns represented in Fig. 2. The results of the study add to the relevant body of knowledge by disclosing what happens to the knowledge once shared discourse within the group is achieved, at the point when those verbal elaborations have to be "frozen," and then become materialized. This examination was taken further by connecting it to the ways in which emergent knowledge is elaborated. The manner in which the groups shaped knowledge and engaged with it for a period of time was, in a sense, also representative of how they positioned themselves when addressing the open-ended problems that triggered their collaborative work. The interconnection between interaction and the emerging objects is one of the main aspects of intellectual interdependency (Valsiner, 1994) that makes productive collaboration possible. The objects created by the groups passed through those different functions while shaping the ongoing interaction. To conclude, a multilayered analysis provides the opportunity to address the interconnection between the various aspects of the co-construction process in a more diligent manner than is possible in the case of studies analyzing those layers independently.

Finally, the analysis of interaction and object development from a trajectory perspective allows the mutuality of this relationship to be unveiled and understood and the unfolding of the process to be made visible. The current results elaborate on the dialogical studies of interaction by showing groups engaging in trajectories that go beyond mere discursive interaction, go on to build on shared elaborations, and follow up on iterations. In this research, one way in which the productivity of the interaction manifests is through the sequence of actions in the interaction that leads to the co-elaboration of the knowledge objects. Given the complexity and length of the projects, organizing and attending to a sequential structure in which knowledge is not only generated and discussed but also taken and followed up, elaborated upon, and refined is of essential importance. The current findings suggest that materializing knowledge, whether in a preliminary or advanced form of elaboration, into situational objects (Jahreie, 2010) serves to preserve the continuity of the process. It also aids the progressive accumulation of conceptualizations and elaborations (Muukkonen & Lakkala, 2009) and contributes to the co-construction process by freezing the generated knowledge at particular moments during the process. As stated earlier, the knowledge object drafts played a catalyzing role in the groups' interactions, and that was also expressed in how the course of the interaction changed or adjusted with time, in order ultimately to become meaningful for the co-construction of the objects.

Implications for Research and Practice

From an educational-practice perspective, the idea that collaboration requires explicit orchestration finds resonance in this study's findings. Specific organization and instruction appear necessary for group-based work to be productive, and studies such as the one presented here provide input in relation to the design of such supporting structures. The main recommendation based on this study's finding concerns the important role of collaboration generating a shared, tangible outcome—in the case presented here, a knowledge object. Creating the conditions for students to discuss and elaborate on ideas, providing them with the space to explore, and encouraging an investigative attitude are important features of a design aimed at supporting productive interaction. In addition, the task should be formulated in such a manner that it requires students to capitalize on this interaction and to materialize their discussions, ideas, and contributions into objects that are dynamic in their development and emergence from the interaction. In turn, this type of collaboration might require specific type of guidance. This study hints that, from an instructional perspective, such interaction can be designed and supported by adjusting the nature and complexity of tasks, by tailoring the guidance for each group's needs, and by considering the aspects analyzed in this study such as interaction, object development, and shared epistemic agency when assessing the learning activity. As an important note, the emerging technologies designed for collaboration have considerable potential to provide support for this part of the process that leads to knowledge co-construction. When designed in a targeted manner, such technologies should involve the type of tools and functionalities that support joint work on knowledge content and allow following up and tracing the co-constructed knowledge in a consistent manner. From a research perspective, such technology can also allow the retrieval of the material produced and make analyses of its detailed evolution in time feasible.

Lastly, this study highlights a number of aspects that require further investigation and discussion. First, it provides a rather succinct insight into knowledge objects and of their development over time, but it does not comprise a comprehensive analysis of the process and developing objects. Additionally, in-depth investigations are needed to pinpoint object-mediated collaboration in terms of the nature of the knowledge objects and their semantic content and how those objects affect learners' actions.

Second, a methodological challenge lies ahead with regard to developing methods and instruments that allow a comprehensive multilayered analysis of the knowledge objects created and of group elaboration strategies. The findings in this study show how learning takes place on different planes and over time and is fueled by various resources, with researchers assigned the difficult task of unveiling the mechanisms of this complex phenomenon. Finally, this study also points up the importance of investigating pedagogical designs and technology to support productive interactions *and* collaborative object development. Such investigations should highlight ways to create improved pedagogical designs and technology that support students in their collaborative work, as well as ways to evaluate this type of learning by taking into account both the interactional process and its (emerging) outcomes.

Conclusion

This study attempted to step beyond merely analyzing interaction in collaborative learning; it also considered the interconnection of those interactions in terms of how they are mediated and intertwined with shared epistemic agency and how they lead to the co-construction of knowledge objects. As a result, it contributes to the field by providing a view of the phenomenon that emphasizes its multiple layers and which, through its complexity, requires a versatile investigation approach.

In closing, the study and its findings do not serve merely to underscore the nature and relevance of understanding how collaboration can be a natural part of learning but also highlight the need to shift toward a view of collaboration that acknowledges and emphasizes the value of productive interaction in the context of knowledge-driven, technology-supported learning contexts. While the elements, the mechanisms, and the layers in this process emerge as highly intricate and complex, in-depth understanding can contribute in shaping the learning process in its emergence and can also support students in their quest to be more than mere course-takers but also producers of knowledge.

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Appendix (Table 11.3)

Table 11.3 Analysis categories and dimensions

Dimensions	Categories (of actions)	Actions	Description
Epistemic	1) Creating awareness	Identifying focus Stating problems Identifying lack of knowledge	Naming the topic, subject, concept, discipline, etc. that represent the project focus Naming difficulties that impede the group from finding a solution to the problem they are solving or from elaborating on the solution they are working on Identifying gaps and missing knowledge in relation to various aspects of the problem or of the solution
	2) Sharing knowledge	Sharing information (from sources) Sharing knowledge from sources	Informing other members about sources of information Informing other members about the content of information sources and their possible use
	3) Creating shared understanding	Creating explanations to concepts or ideas Structuring new concepts/ideas Problematizing (Re)framing problem/focus	Explaining concepts or ideas using definitions and knowledge from sources Organizing concepts or ideas the group is discussing Questioning understanding and explanations of concepts/ideas Reformulating focus or problem
	4) Generative collaborative actions	Generating new ideas Negotiating new ideas Idea uptake (Co-)elaborating concepts/ideas (Constructive) use of feedback	Bringing in ideas that can contribute in solving the problem or elaborating the solution Constructing arguments in favor of the ideas brought in or challenging other group members to do so Building up on own other members' argument in order to provide explanations and elaborations Formulate explanations, arguments, and illustrations, or provide examples for the ideas discussed Use feedback provided by other group members or the teacher to elaborate on ideas
Regulative	5) Regulative actions	Planning: define goals and create joint plans Coordinating process Monitoring process and object progress Reflecting on individual and collective actions	Formulating goals for the group project activities and creating a plan of activities together Organizing activities within the group, dividing tasks, and assigning responsibilities Checking on the status of tasks that must be fulfilled and others' contributions Discussing about the progress of the group work and members' participation
Other		Other types of statements	Engaging in social talk unrelated to the task

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Investigation 12. The Joint Organization of Interaction Within a Multimodal CSCL Medium

Murat Perit Çakir, Alan Zemel, and Gerry Stahl

Abstract

In order to collaborate effectively in group discourse on a topic like mathematical patterns, group participants must organize their activities in ways that share the significance of their utterances, inscriptions, and behaviors. Here, we report the results of an ethnomethodological case study of collaborative math problem-solving activities mediated by a synchronous multimodal online environment. We investigate the moment-by-moment details of the interaction practices through which participants organize their chat utterances and whiteboard actions as a coherent whole. This approach to analysis foregrounds the sequentiality of action and the implicit referencing of meaning making—fundamental features of interaction. In particular, we observe that the sequential construction of shared drawings and the deictic references that link chat messages to features of those drawings and to prior chat content are instrumental in the achievement of intersubjectivity among group members' understandings. We characterize this precondition of collaboration as the co-construction of an indexical field that functions as a common ground for group cognition. Our analysis reveals methods by which the group co-constructs meaningful inscriptions in the dual-interaction spaces of its CSCL environment. The integration of graphical, narrative, and symbolic semiotic modalities in this manner also facilitates joint problem-solving. It allows group members to invoke and operate with multiple realizations of their mathematical artifacts, a characteristic of deep learning of mathematics.

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M. P. Çakir (✉)
Department of Cognitive Science, Middle East Technical University, Ankara, Turkey
e-mail: perit@metu.edu.tr

A. Zemel
The Department of Communication, University at Albany, Albany, NY, USA
e-mail: azemel@albany.edu

G. Stahl
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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Keywords

Group cognition · Interaction analysis · Dual-interaction space · Ethnomethodology · Indexicality · Mathematics education · Text chat · Visual reasoning · Common ground · Joint problem space

Computer-supported collaborative learning is centrally concerned with the joint organization of interaction by small groups of students in online environments. The term "collaborative learning" is a gloss for *interaction that is organized for the joint achievement of knowledge-building tasks* such as problem-solving in domains like school mathematics. Rather than using the term "collaborative learning," which carries vague and contradictory connotations, we coined the term "group cognition" to refer to activities where several students organize their joint interaction to achieve such collective cognitive accomplishments as planning, deducing, designing, describing, problem-solving, explaining, defining, generalizing, representing, remembering, and reflecting as a group.

We have argued in *Group Cognition* (Stahl, 2006) that CSCL interactions should be analyzed at the group level of description, not just at the individual or the community levels, as is done in other theoretical approaches influential in CSCL research. During the past 6 years, we have conducted the Virtual Math Teams (VMT) Project to explore group cognition in a prototypical CSCL setting and to analyze it at the group level. We have used our analyses of interaction to drive the design of the technology.

In this paper, we present a case study of an 18-minute-long excerpt from the VMT Project. We look at some ways in which the students organized their joint efforts. Our observations here are consistent with our impressions from more than a hundred student hours of interaction in the VMT data corpus. Many of the broader theoretical and practical issues surrounding the analysis here are addressed by CSCL researchers in a new edited volume on *Studying Virtual Math Teams* (Stahl, 2009b) in the Springer CSCL book series.

The issue that we address in the following pages is: *How do the students in our case study organize their activity so they can define and accomplish their tasks as a group within their online environment?* This is necessarily a pivotal question for a science of CSCL (Stahl, 2009a). It involves issues of meaning making, shared understanding, and common ground that have long been controversial in CSCL.

The problem of coordination is particularly salient in the VMT software environment, which is an instance of a dual-interaction space (Dillenbourg, 2005; Mühlpfordt & Stahl, 2007), requiring organization across multiple media, each with their own affordances. We have found that the key to joint coordination of knowledge building is sequential organization of a network of indexical and semantic references within the group discourse (Stahl, 2007). We therefore analyze sequential interaction at the group level of description, using ethnomethodologically inspired chat interaction analysis rather than quantitative coding, in order to maintain and study this sequential organization. Thereby, we arrive at a view of mathematical knowledge building as the coordinated production and use of visual, narrative, and symbolic inscriptions as multiple realizations of co-constructed mathematical objects.

While we have elsewhere presented theoretical motivations for focusing on *group discourse organization* as fundamental for CSCL, in this paper we foreground our *analysis of empirical data* from a VMT session. We derive a number of characteristics of the joint organization of interaction from the details of the case study. The characteristics we describe are to some extent specific to the technological affordances of the VMT environment, to the pedagogical framing of the chat session, and even to the unique trajectory of this particular group interaction. Nevertheless, the characteristics are indicative of what takes place—with variations—in similar settings. After the analytic centerpiece of the paper, we discuss *methodological implications* for CSCL analysis, including what it means to take the *group* as the unit of analysis. We then contrast our approach to leading *alternative approaches* in CSCL. This discussion focuses particularly on multimodal interaction in a *dual-interaction space* and on related conceptions of *common ground*, concluding with summary remarks on *sequential analysis*. The paper proceeds through the following topics:

- The problem of group organization in CSCL
- A case study of a virtual math team
- Implications for CSCL chat interaction analysis
- The group as the unit of analysis
- Other approaches in CSCL to analyzing multimodal interaction
- Grounding through interactional organization
- Sequential analysis of the joint organization of interaction

The Problem of Group Organization in CSCL

A central issue in the theory of collaborative learning is how students can solve problems, build knowledge, accomplish educational tasks, and achieve other cognitive accomplishments *together*. How do they share ideas and talk about the same things? How do they know that they are talking about, thinking about, understanding, and working on things in the same way? Within CSCL, this has been referred to as the problem of the "attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995), "building common ground" (Baker, Hansen, Joiner, & Traum, 1999; Clark & Brennan, 1991), or "the practices of meaning making" (Koschmann, 2002). We have been interested in this issue for some time. *Group Cognition* (Stahl, 2006) documents a decade of background to the VMT research reported here: Its Chapter 10 (written in 2001) argued the need for a new approach and its Chapter 17 (written in 2002) proposed the current VMT Project, which includes this case study. Since 2002, we have been collecting and analyzing data on how groups of students in a synchronous collaborative online environment organize their interaction to achieve intersubjectivity and shared cognitive accomplishments in the domain of school mathematics.

Knowledge building in CSCL has traditionally been supported primarily with asynchronous technologies (Scardamalia & Bereiter, 1996). Within appropriate educational cultures, this can be effective for long-term refinement of ideas by learning communities. However, in small groups and in many classrooms, asynchronous media encourage mere exchange of individual opinions more than co-construction of progressive trains of joint thought. We have found informally that synchronous interaction can more effectively promote group cognition—the accomplishment of "higher-order" cognitive tasks through the coordination of contributions by individuals within the discourse of a small group. We believe that the case study in this paper demonstrates the power of group interaction in a largely synchronous environment; the coordination of interaction in an asynchronous interaction would be quite different in nature as a result of very different interactional constraints.

In CSCL settings, interaction is mediated by a computer environment. Students working in such a setting must enact, adapt, or invent ways of coordinating their understandings by means of the technological affordances that they find at hand. The development and deployment of these methods is not usually an explicit, rational process that is easily articulated by either the participants or analysts. It occurs tacitly, unnoticed, and taken-for-granted. In order to make it more visible to us as analysts, we have developed an environment that makes the coordination of interaction more salient and captures a complete record of the group interaction for detailed analysis. In trying to support online math problem-solving by small groups, we have found it important to provide media for both linguistic and graphical expressions. This resulted in what is known within CSCL as a *dual-interaction space*. In our environment, students must coordinate their text chat postings with their whiteboard drawings.

A careful analysis of how they do this reveals as well their more general methods of group organization.

The analysis of our case study focuses on episodes of interaction through which an online group of students co-constructs mathematical artifacts across dual-interaction spaces. It looks closely at how group members put the multiple modalities into use, how they make their chat postings and drawing actions intelligible to each other, and how they achieve a sense of coherence among actions taking place across the modalities to which they have access. We base our discussion, analysis, and design of the affordances of the online environment on the methodical ways the features of the software are put into use by the students.

In another VMT case study (Sarmiento & Stahl, 2008), we have seen how the problem-solving work of a virtual math team is accomplished through the co-construction and maintenance of a *joint problem space* (Teasley & Roschelle, 1993). This figurative space that supports group interaction and the shared understanding of that interaction by the participants not only grounds the *content* of the team's discourse and work but also ties together the *social* fabric of the relations among the team members as actors. In addition, we saw that the joint problem space has a third essential dimension: *time* or sequence. The construction of the joint problem space constitutes a shared temporality through bridging moves that span and thereby order discontinuous events as past, present, and future (Sarmiento-Klapper, 2009). This can be seen, for instance, in the use of tenses in group-remembering discourses. More generally, the joint problem space provides a framework of sequential orderings, within which temporal deictic references, for example, can be resolved.

In this paper, we further investigate how a virtual math team achieves a group organization of its activities such that the group can proceed with a sense of everyone understanding each other and of working collaboratively as a group. We do this through a fine-grained analysis of the group's interaction in a VMT session in which they formulate, explore, and solve a geometry problem. Their work takes place in graphical, narrative, and symbolic media—supported technologically by the shared whiteboard, text chat, and wiki pages of the VMT environment. We pay particular attention to how graphical inscriptions, textual postings, and symbolic expressions in the different media are closely coordinated by the group members, despite the differences of the media.

We pursue a micro-ethnographic approach to analyzing the activities of the group members in their own terms. They set themselves a task, propose how to proceed step by step, and explain to each other how to understand their actions. We try to follow the explanations, which are available in the inscriptions, postings, and expressions—particularly when the sequentiality of these allows the complex references among them to be followed.

The establishment of group order in small-group interaction is always strongly dependent upon the media, which mediate interaction. In the case of VMT chats, there is an intricate set of technological media, including text chat, a shared whiteboard, a community wiki, and graphical references from chat to whiteboard. The central part of this paper explores the different characteristics of the VMT media by observing how the students use them. Of particular interest are the ways in which a group coordinates activities in the different graphical and textual media. From a math education perspective, it is also insightful to see how the visual and narrative understandings feed into the development and understanding of symbolic expressions.

By the end of the paper, we will see how the group organization of graphical, narrative, and symbolic resources in interaction continuously produce and reproduce the joint problem space of the group's effort. This coordination is revealed through sequential analysis, in which the consequence of one action in one medium following another in another medium is seen as mutually constitutive of the meaning of those actions. The sequential web of activity across the VMT media—woven by semantic and indexical references among them—forms the joint problem space within which problem content, participant relationships, and temporal progress are all defined in a way that is shared by the group. We can see the "indexical field" (Hanks 1992) formed by the group activities as the source of grounding that supports the intersubjectivity of the group effort. In contrast to psychological or psycholinguistic models of common ground, the fact that team members believe they have understandings in common about what each other is saying and doing is not a result of exchanging individual mental opinions, but is a function of the indexical organization of the group interaction.

The joint problem space—as the foundation of group cognition—is not a mental construct of a set of individuals who achieve cognitive convergence or common (identical) ground through comparing mental models anymore than it is a figment of some form of group mind. Rather, it is a system of interconnected meanings formed by a weaving of references in the group discourse itself (Stahl, 2007). In this paper, we analyze the methods the students used to co-construct this indexical field.

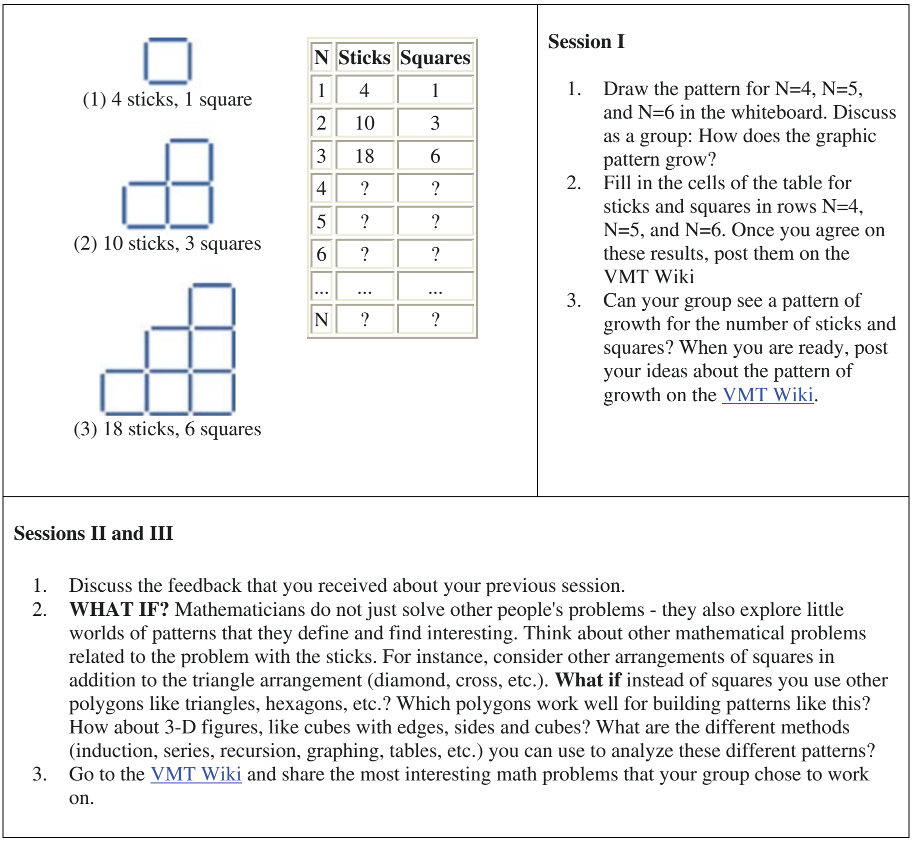
In our case study, the organization of group meaning making takes place across media—in accordance with the specific affordances of the different media. Furthermore, the grounding of the students' symbolic mathematical understanding can be seen as related to their visual and narrative understandings—or, rather, the various understandings are intricately interwoven and support each other. We trace this interweaving through our approach to the interactional analysis of sequential coordination at the group unit of analysis.

A Case Study of a Virtual Math Team

The excerpts we present in this paper are obtained from a problem-solving session of a team of three students who participated in the VMT Spring Fest 2006. This event brought together several teams from the USA, Scotland, and Singapore to collaborate on an open-ended math task on geometric patterns. Students were recruited anonymously through their teachers. Members of the teams generally did not know each other before the first session. Neither they nor we knew anything about each other (e.g., age or gender) except chat handle and information that may have been communicated during the sessions. Each group participated in four sessions during a two-week period, and each session lasted over an hour. An adult from the research project moderated each session; the facilitators' task was to help the teams when they experienced technical difficulties, not to participate in the problem-solving work.

During their first session, all the teams were asked to work online on a particular pattern of squares made up of sticks (see Fig. 12.1). For the remaining three sessions, the teams were asked to come up with their own shapes, describe the patterns they observed as mathematical formulas, and share their observations with other teams through a wiki page. This task was chosen because of the possibilities it afforded for many different solution approaches ranging from simple counting procedures to more advanced methods involving the use of recursive functions and exploring the properties of various number sequences. Moreover, the task had both algebraic and geometric aspects, to allow us to observe how participants put many features of the VMT software system into use. The open-ended nature of the activity stemmed from the need to agree upon a new shape made by sticks. This required groups to engage in an open-ended problem-solving activity, as compared to traditional situations where questions are given in advance and there is a single "correct" answer—presumably already known by a teacher. We used a traditional pattern problem (Moss & Beatty, 2006; Watson & Mason, 2005) to seed the activity and then left it up to each group to decide the kinds of shapes they found interesting and worth exploring further.

All the problem-solving sessions were conducted in the VMT environment. The VMT online system has two main interactive components that conform to the typical layout of systems with dual-interaction spaces: a shared drawing board that provides basic drawing features on the left and a chat window on the right (Fig. 12.2). The online environment has features specifically designed to help users relate the actions happening across dual-interaction spaces (Stahl, 2009b, chap. 15). One of the unique features of this chat system is the referencing support mechanism (Mühlpfordt and Wessner



(1) 4 sticks, 1 square

(2) 10 sticks, 3 squares

(3) 18 sticks, 6 squares

N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...	...	...
N	?	?

Session I

1. Draw the pattern for N=4, N=5, and N=6 in the whiteboard. Discuss as a group: How does the graphic pattern grow?
2. Fill in the cells of the table for sticks and squares in rows N=4, N=5, and N=6. Once you agree on these results, post them on the VMT Wiki
3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the VMT Wiki.

Sessions II and III

1. Discuss the feedback that you received about your previous session.
2. **WHAT IF?** Mathematicians do not just solve other people's problems - they also explore little worlds of patterns that they define and find interesting. Think about other mathematical problems related to the problem with the sticks. For instance, consider other arrangements of squares in addition to the triangle arrangement (diamond, cross, etc.). **What if** instead of squares you use other polygons like triangles, hexagons, etc.? Which polygons work well for building patterns like this? How about 3-D figures, like cubes with edges, sides and cubes? What are the different methods (induction, series, recursion, graphing, tables, etc.) you can use to analyze these different patterns?
3. Go to the VMT Wiki and share the most interesting math problems that your group chose to work on.

Fig. 12.1 Task description

2005) that allows users to visually connect their chat postings to previous postings or objects on the whiteboard via arrows (see the last posting in Fig. 12.2 for an example of a message-to-whiteboard reference). The referential links attached to a message are displayed until a new message is posted. Messages with referential links are indicated by an arrow icon in the chat window, and a user can see where such a message is pointing by clicking on it at any time.

In addition to the explicit referencing feature, the system displays small boxes in the chat window to indicate actions performed on the whiteboard. This awareness mechanism allows users to observe how actions performed in both interaction spaces are sequenced with respect to each other. Moreover, users can click on these boxes to move the whiteboard back and forth from its current state to the specific point in its history when that action was performed. Chat messages and activity markers are color coded to help users to keep track of who is doing what in the online environment. In addition to standard awareness markers that display who is present in the room and who is currently typing, the system also displays textual descriptions of whiteboard actions in tool-tip messages that can be observed by holding the mouse either on the object in the whiteboard or on the corresponding square in the chat window.

Studying the meaning-making practices enacted by the users of CSCL systems inevitably requires a close analysis of the process of collaboration itself (Dillenbourg et al. 1996; Stahl, Koschmann, & Suthers, 2006). In an effort to investigate the organization of interactions across the dual-interaction spaces of the VMT environment, we consider the small group as the unit of analysis (Stahl, 2006), and

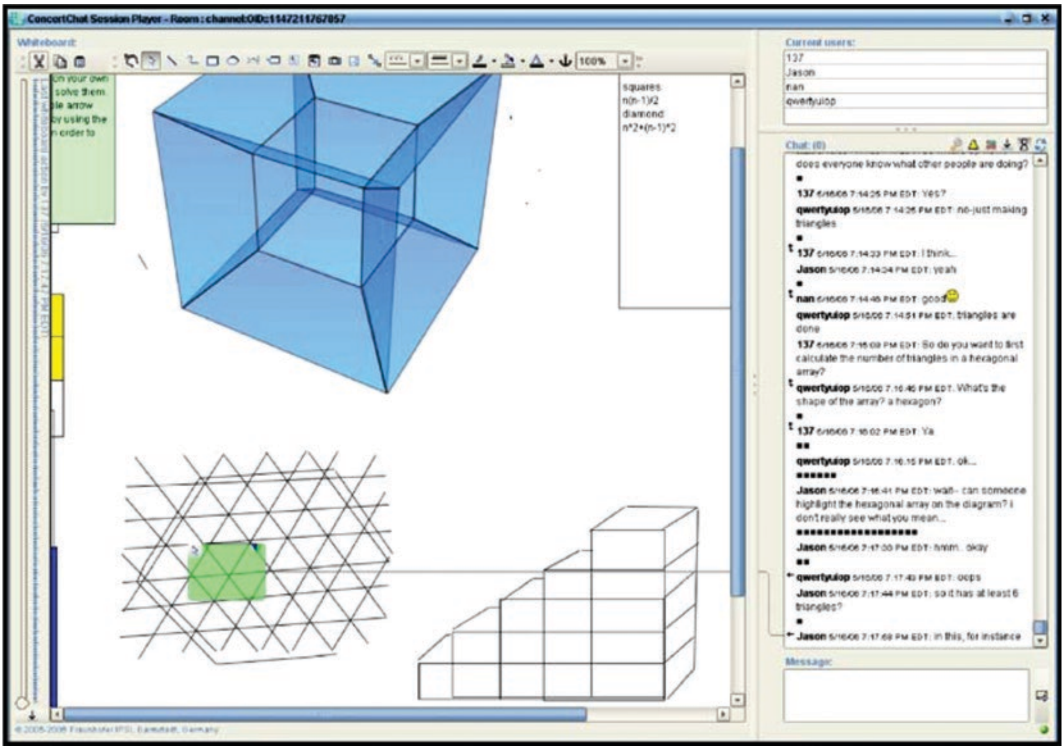


Fig. 12.2 A screenshot of the VMT environment

we appropriate methods of ethnomethodology and conversation analysis to conduct sequential analysis of group interactions at a microlevel (Psathas, 1995; Sacks, 1962/1995; ten Have, 1999). Our work is informed by studies of interaction mediated by online text chat with similar methods (Garcia and Jacobs 1998, 1999; O'Neill and Martin 2003), although the availability of a shared drawing area and explicit support for deictic references in our online environment substantially differentiate our study from theirs.

The goal of this line of analytic work is to discover the commonsense understandings and procedures group members use to organize their conduct in particular interactional settings (Coulon, 1995). Commonsense understandings and procedures are subjected to analytical scrutiny because they are what "enable actors to recognize and act on their real world circumstances, grasp the intentions and motivations of others, and achieve mutual understandings" (Goodwin and Heritage 1990, p. 285). Group members' shared competencies in organizing their conduct not only allow them to produce their own actions but also to interpret the actions of others (Garfinkel and Sacks 1970). Because group members enact these understandings visibly in their situated actions, researchers can discover them through detailed analysis of the members' sequentially organized conduct (Schegloff & Sacks, 1973).

We conducted numerous VMT Project data sessions, where we subjected our analysis of the excerpts below to intersubjective agreement (Psathas, 1995). This paper presents the outcome of this group effort together with the actual transcripts so that the analysis can be subjected to external scrutiny. During the data sessions, we used the VMT Replayer tool, which allows us to replay a VMT chat session as it unfolded in real time based on the time stamps of actions recorded in the log file. The order of actions—chat postings, whiteboard actions, and awareness messages—we observe with the Replayer as researchers exactly matches the order of actions originally observed by the users. This property of the Replayer allowed us to study the sequential unfolding of events during the entire chat session, which is crucial in making sense of the complex interactions mediated by a CSCL environment (Koschmann, Stahl, & Zemel, 2007).

In this case study, we focus on a sequence of excerpts obtained from a single problem-solving session of a virtual math team. We are concerned with how the actors contribute to the group meaning making as they proceed. This example involves the use and coordination of actions involving both the whiteboard and chat environment. It therefore served as a useful site for seeing how actors, in this local setting, were able to engage in meaningful coordinated interaction.

The team has three members: Jason, 137, and Qwertyuiop, who are upper-middle-school students (roughly 14 years old) in the USA. In the following subsections, we will present how this team co-constructed a mathematical artifact they referred to as the “hexagonal array” through a coordinated sequence of actions distributed between the chat and whiteboard spaces, and how they subsequently explored its properties by referring to and annotating shared drawings on the whiteboard. In particular, we will highlight how whiteboard objects and previous chat postings were used as semiotic resources during the collaborative problem-solving activity. This will show how chat and whiteboard differ in terms of their affordances for supporting group interaction. We will see how these differences are enacted and used in complementary ways by team members to achieve mutual intelligibility of their actions across multiple interaction spaces.

Availability of Production Processes

Log 12.1 is taken from the beginning of the team’s third session. The team has already explored similar patterns of sticks and become familiar with the features of the VMT online environment during their prior sessions. The drawing actions at the beginning of this excerpt were the first moves of the session related to math problem-solving.

Log 12.1

Line	Time	Chat handle	Chat message or <*whiteboard action*>
	7:07:52–7:11:00	137	<*137 draws a hexagon shape and then splits it up into regions by adding lines. Figure 12.3 shows some of the key steps in 137’s drawing performance*>
1	7:11:16	137	Great. Can anyone make a diagram of a bunch of triangles?
	7:11:16–7:11:49	137	<*137 deletes the set of lines he has just drawn*>
2	7:11:51	Qwertyuiop	just a grid?
	7:11:54–7:12:01	137	<*137 moves some of the older drawings away*>
3	7:12:07	137	Yeah…
4	7:12:17	Qwertyuiop	ok…
	7:12:23–7:14:07	Qwertyuiop	<*Qwertyuiop draws a grid of triangles in the space opened up by 137. Figure 12.4 shows some of the steps in Qwertyuiop’s drawing actions*>

At the beginning of this excerpt, 137 performs a series of drawing actions. 137’s actions on the whiteboard include the drawing of a hexagon first, then three diagonal lines, and finally lines parallel to the diagonals and to the sides of the hexagon whose intersections eventually introduce some triangular and diamond-shaped regions. Moreover, 137 also performs some adjustment moves—for instance, between the fourth and fifth snapshots in Fig. 12.3—to ensure that three nonparallel lines intersect at a single point and the edges of the hexagon are parallel to the lines introduced later as much as possible. Hence, this sequence of drawing actions suggests a particular organization of lines for constructing a hexagonal shape. (Figure 12.3 shows six snapshots corresponding to intermediary

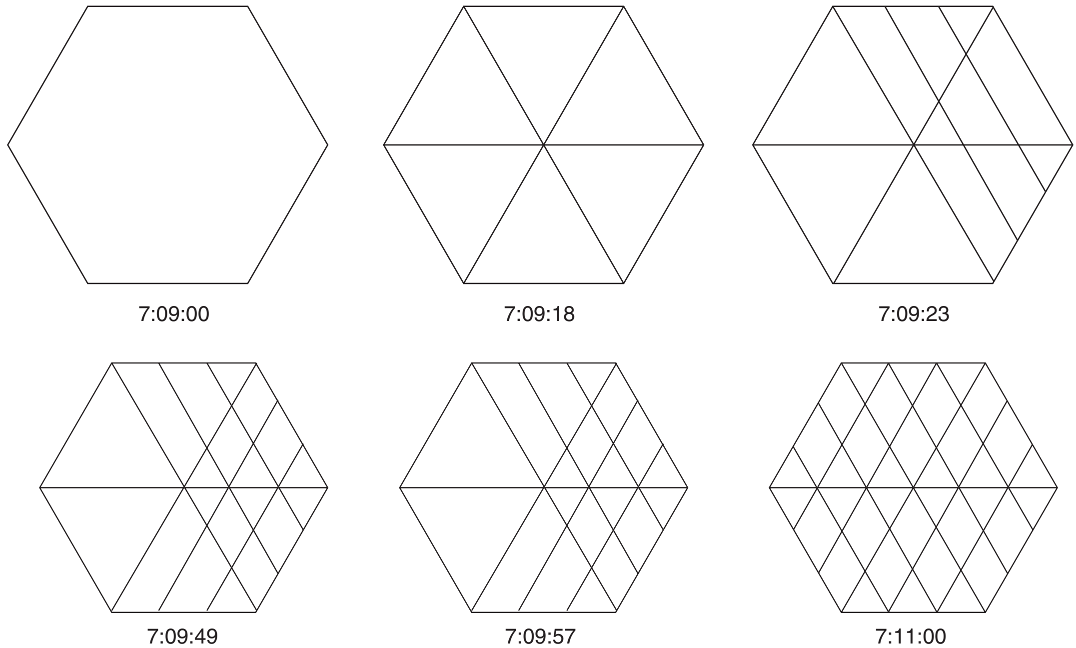


Fig. 12.3 Six stages of 137's drawing actions obtained from the Replayer tool. The time stamp of each stage is displayed under the corresponding image. Snapshots focus on a particular region on the whiteboard where the relevant drawing activity is taking place

stages of 137's drawing actions: 137 initiates his drawing actions with six lines that form the hexagon in stage 1. Then he adds three diagonal lines in step 2. The third snapshot shows the additional two lines drawn parallel to one of the diagonals. The fourth snapshot shows a similar set of two parallel lines added with respect to another diagonal. The fifth snapshot shows slight modifications performed on the new set of parallel lines to ensure intersections at certain places. The sixth snapshot shows the final stage of 137's drawing).

137's chat posting in line 1 that follows his drawing effort (which can be read as a self-critical, sarcastic "great") suggests that he considers his illustration inadequate in some way. He makes this explicit by soliciting help from other members to produce "a diagram of a bunch of triangles" on the whiteboard, and then removing the diagram he has just produced (the boxes following this posting in Fig. 12.5 correspond to deletion actions on the whiteboard). By removing his diagram, 137 makes that space available to other members for the projected drawing activity. Qwertyuiop responds to 137's query with a request for clarification regarding the projected organization of the drawing ("just a grid?"). After 137's acknowledgement, Qwertyuiop performs a series of drawing actions that resemble the latter stages of 137's drawing actions, namely, starting with the parallel lines tipped to the right first, then drawing a few parallel lines tipped to the left, and finally adding horizontal lines at the intersection points of earlier lines that are parallel to each other (see Figs. 12.4 and 12.5). Having witnessed 137's earlier actions, the similarity in the organizations of both drawing actions suggest that Qwertyuiop has appropriated some key aspects of 137's drawing strategy, but modified/reordered the steps (e.g., he did not start with the hexagon at the beginning) in a way that allowed him to produce a grid of triangles as a response to 137's request.

The key point we would like to highlight in this episode is that *the availability of the sequencing of the drawing actions that produces a diagram on the shared whiteboard can serve as a vital resource*

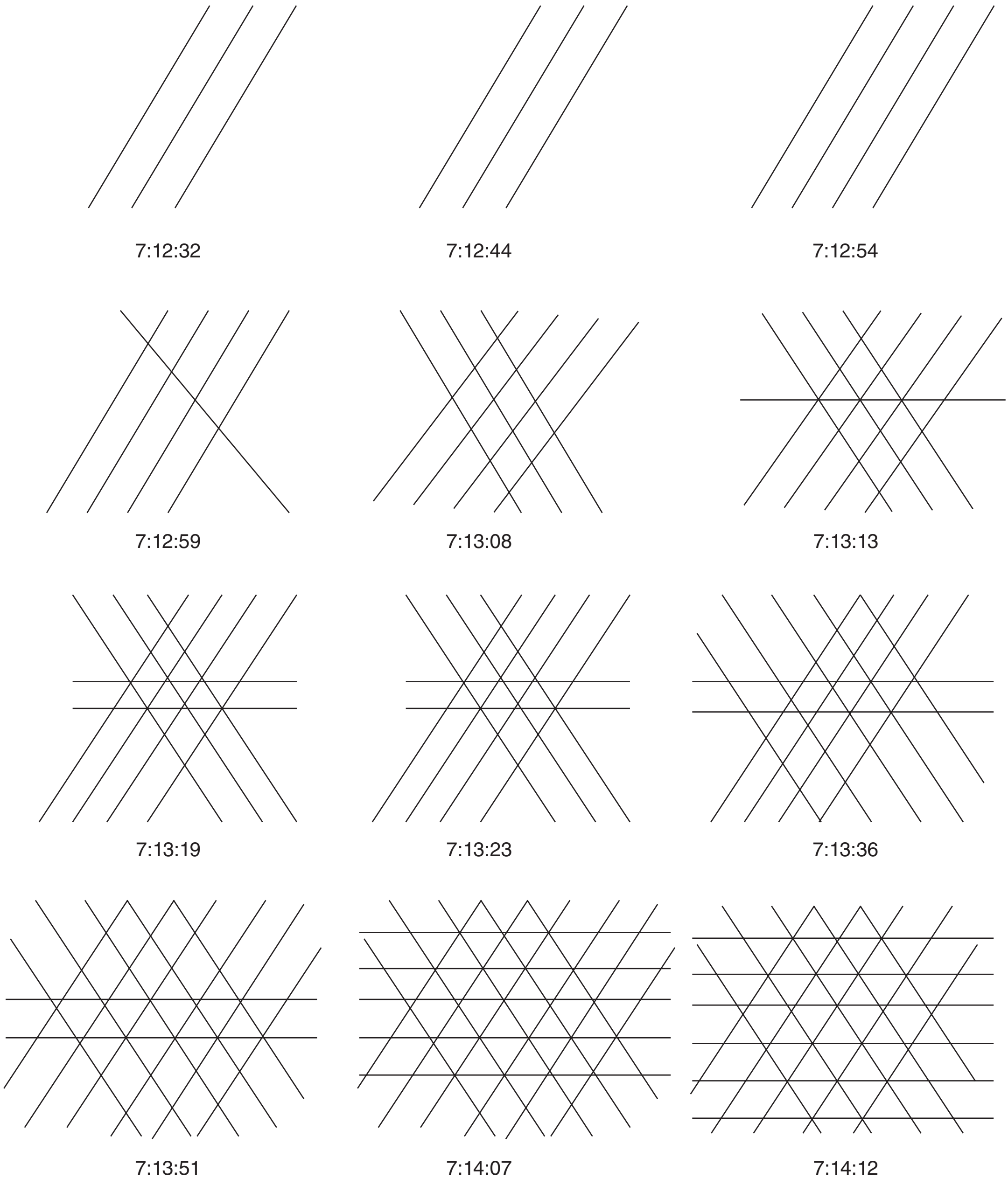


Fig. 12.4 The evolution of Qwertyuiop's drawing in response to 137's request

for collaborative sense-making. As seen in Log 12.1, 137 did not provide any explanation in chat about his drawing actions or about the shape he was trying to draw. Yet, as we have observed in the similarity of Figs. 12.3 and 4, the orderliness of 137's actions has informed Qwertyuiop's subsequent performance. The methodical use of intersecting parallel lines to produce triangular objects is common to both drawing performances. Moreover, Qwertyuiop does not repeat the same set of drawing actions, but selectively uses 137's steps to produce the relevant object (i.e., a grid of triangles) on the whiteboard. Qwertyuiop does not initially constrain his representational development by constructing

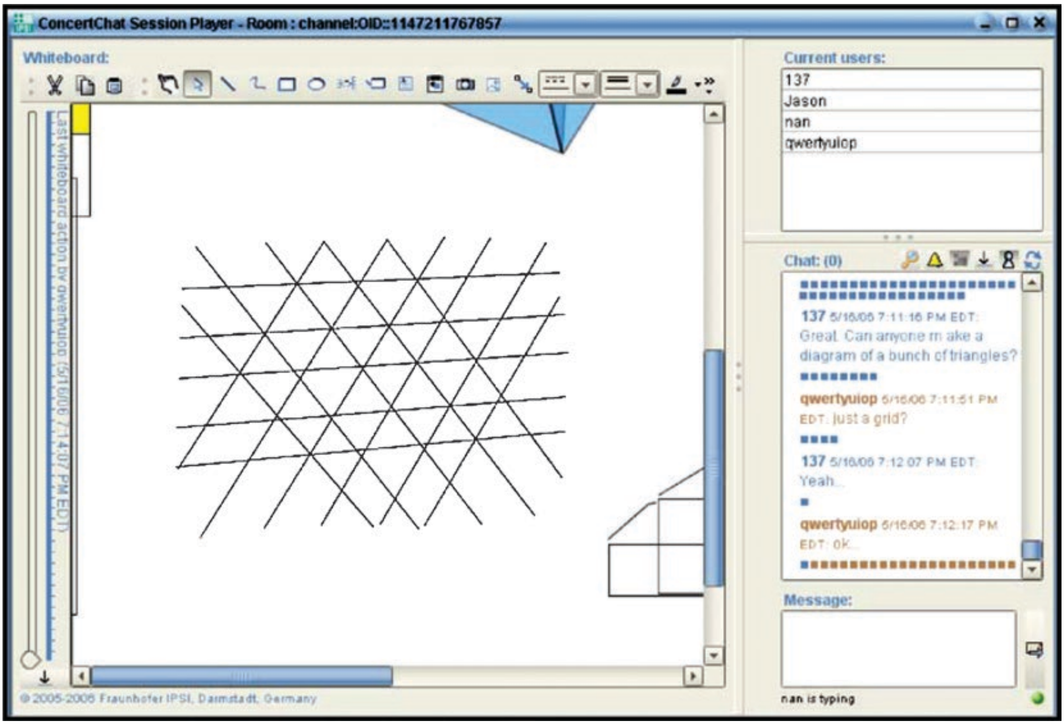


Fig. 12.5 The interface at the 12th stage of Fig. 12.4

a hexagon first, but allows a hexagon (or other shapes made with triangles) to emerge from the collection of shapes implied by the intersecting lines. Thus, Qwertyuiop's performance shows us that he is able to *notice a particular organization* in 137's drawing actions, and he has *selectively appropriated and built upon* some key aspects of 137's drawing practice. As we will see in the following logs,[1] the group's subsequent use of this drawing will provide us additional evidence that Qwertyuiop's diagram serves as an adequate response to 137's request.

This excerpt highlights a fundamental difference between the two interaction spaces: whiteboard and chat contributions differ in terms of the availability of their production process. As far as chat messages are concerned, participants can only see who is currently typing,[2] but not what is being typed until the author decides to send the message. A similar situation applies to *atomic* whiteboard actions such as drawing an individual line or a rectangle. Such actions make a single object appear in the shared drawing area when the user releases the left mouse button; in the case of editable objects such as textboxes, the object appears on the screens of the computers of all chat participants when the editor clicks outside the textbox. However, the construction of most shared diagrams includes the

[1]For instance, after Qwertyuiop declares the completion of the grid in line 11, 137 anchors Qwertyuiop's drawing to the background at 7:15:47 (see Log 12.3). Because such a move preserves the positions of the selected objects and the objects affected by the move include only the lines recently added by Qwertyuiop, 137's anchoring move seems to give a particular significance to Qwertyuiop's recent drawing. Hence, 137's anchoring move can be treated as an (implicit) endorsement of Qwertyuiop's drawing effort in response to his previous request.

[2]While a participant is typing, a social awareness message appears under the chat entry box on everyone else's screen stating that the person "is typing" (see Fig. 12.5). When the typist posts the message, the entire Message appears suddenly as an atomic action in everyone's chat window.

production of multiple atomic shapes (e.g., many lines), and hence the sequencing of actions that produce these diagrams is available to other members. As we have observed in this excerpt, the availability of the drawing process can have interactionally significant consequences for math problem-solving chats due to its instructionally informative nature. In short, the whiteboard affords an *animated evolution* of the shared space, which makes the *visual reasoning process* manifest in drawing actions *publicly available* for other members' inspection. For instance, in Fig. 12.4, transitions from stages 1 to 2 and 7 to 8 show modifications performed to achieve a peculiar geometric organization on the shared workspace.

Mutability of Chat and Whiteboard Contents

Another interactionally significant difference between the chat and the whiteboard interaction spaces, which is evidenced in the excerpt above, is the difference in terms of the mutability of their contents. Once a chat posting is contributed, it cannot be changed or edited. Moreover, the sequential position of a chat posting cannot be altered later on. If the content or the sequential placement of a chat posting turns out to be interactionally problematic, then a new posting needs to be composed to repair that. On the other hand, the object-oriented design of the whiteboard allows users to reorganize its content by adding new objects and by moving, annotating, deleting, and reproducing existing ones. For instance, the way 137 and Qwertyuiop repaired their drawings in the excerpt above by repositioning some of the lines they drew earlier to make sure that they intersect at certain points and/or that they are parallel to the edges of the hexagon illustrates this difference. Such demonstrable tweaks make the mathematical details of the construction work visible and relevant to observers and hence, serve as a vital resource for joint mathematical sense making. By seeing that Qwertyuiop successively and intentionally adjusts lines in his whiteboard drawing to appear more parallel or to intersect more precisely, the other group members take note of the significance of the arrangement of lines as parallel and intersecting in specific patterns.

While both chat and whiteboard in VMT support persistence, visibility, and mutability, they do so in different ways. A chat posting scrolls away only slowly and one can always scroll back to it, whereas a drawing may be erased by anyone at any time. Chat conventions allow one to replace (i.e., follow) a mistyped posting with a new one, and conversational conventions allow utterances to be retracted, repaired, or refined. The mechanisms of the two mediational technologies are different, and the characteristics of their persistence, visibility, and mutability differ accordingly. Collaborative interaction in the dual-space environment is sensitively attuned to these intricate and subtle differences.

Monitoring Joint Attention

The excerpt in Log 12.2 immediately follows the one in Log 12.1, where the team is oriented to the construction of a triangular grid after a failed attempt to embed a grid of triangles inside a hexagon. As Qwertyuiop is adding more lines to the grid, the facilitator (Nan) posts two questions addressed to the whole team in line 5. The question not only queries about what is happening now and whether everybody knows what others are currently doing but the placement of the question at this point in interaction also problematizes the relevance of what has been happening so far. 137's response in lines 6 and 8 treats the facilitator's question as a problematic intervention. Qwertyuiop's response indicates he is busy with making triangles, and hence may not know what others are doing. Jason acknowledges that he is following what has been going on in line 9. These responses indicate that the team members have been following (perhaps better than the facilitator) what has been happening on the whiteboard so far as something relevant to their task at hand.

Log 12.2

5	7:14:09	nan	so what's up now? does everyone know what other people are doing?
	7:14:12	Qwertyuiop	< *Qwertyuiop adds a line to the grid of triangles*>
6	7:14:25	137	Yes?
7	7:14:25	Qwertyuiop	no-just making triangles
	7:14:32	Qwertyuiop	< *Qwertyuiop adds a line to the grid of triangles*>
8	7:14:33	137	I think… [REF to line 6]
9	7:14:34	Jason	Yeah
	7:14:36	Qwertyuiop	< *Qwertyuiop adds a line to the grid of triangles*>
10	7:14:46	nan	good :-)
11	7:14:51	Qwertyuiop	Triangles are done
12	7:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?

In this excerpt, the facilitator calls on each participant to report on his/her understanding of the activities of other participants. There was an extended duration in which no chat postings were published while whiteboard actions were being performed by Qwertyuiop. Because it is not possible for any participant to observe other participants directly, it is not possible to monitor a class of actions others may perform that (1) are important for how we understand ongoing action but (2) do not involve explicit manipulation of the VMT environment, actions like watching the screen, reading text, inspecting whiteboard constructs, and so forth. The only way to determine if those kinds of actions are occurring is to explicitly inquire about them using a chat posting.

Past and Future Relevancies Implied by Shared Drawings

Following Qwertyuiop's announcement in line 11 of Log 12.2 that the drawing work is complete, 137 proposes that the team calculate "the number of triangles" in a "hexagonal array" as a possible question to be pursued next. Although a hexagon was previously produced as part of the failed drawing, this is the first time someone explicitly mentions the term "hexagonal array" in this session. What makes 137's proposal potentially intelligible to others is the availability of referable resources such as whiteboard objects, and the immediate history of the production of those objects such that the proposal can be seen to be embedded in a sequence of displayed actions. 137's use of "So" to introduce his proposal presents it as a consequence of, or a making explicit of, what preceded. His suggestion of it as a "first" (next) move implies that the drawings opened up multiple mathematical tasks that the group could pursue and that the proposed suggestion would be a candidate for a next move. In other words, the objects on the whiteboard and their visually shared production index a horizon of past and future activities. The indexical terms in 137's proposal (like "hexagonal array") not only rely on the availability of the whiteboard objects to propose a relevant activity to pursue next but also modify their sense by using linguistic and semantic resources in the production to label or gloss the whiteboard object and its production. This allows actors to orient in particular ways to the whiteboard object and the procedures of its co-construction—providing a basis for coordinated joint activity. The joint activity acquires a temporal structure that is defined by the details of chat wording, the animation of graphical construction, and the sequentiality of proposing.

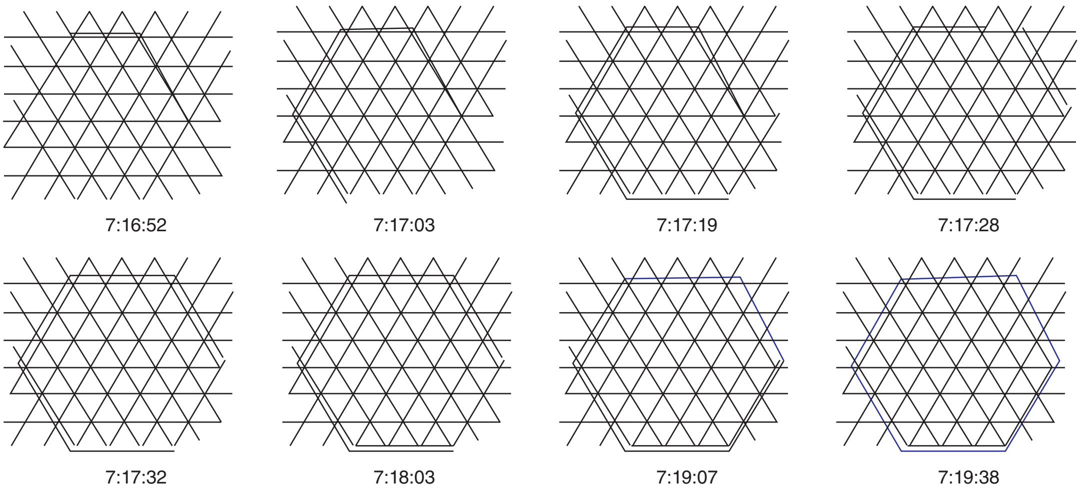


Fig. 12.6 Snapshots from the sequence of drawing actions performed by 137

Methods for Referencing Relevant Objects in the Shared Visual Field

Bringing relevant mathematical objects to other members' attention often requires a coordinated sequence of actions performed in both the chat and whiteboard interaction spaces. The episode following 137's proposal (Log 12.3) provides us with an appropriate setting to illustrate how participants achieve this in interaction. Following 137's proposal in line 12, both Qwertyuiop and Jason post queries for clarification in lines 13 and 16, respectively, which indicate that the available referential resources were insufficient for them to locate what 137 is referring to with the term "hexagonal array." Jason's query in the chat is particularly important here because it explicitly calls for a response to be performed on the shared diagram, that is, in a particular field of relevance in the other interaction space. Following Jason's query, 137 begins to perform a sequence of drawing actions on the shared diagram. He adds a few lines that gradually begin to enclose a region on the triangular grid[3] (see Fig. 12.6).

Log 12.3

11	7:14:51	Qwertyuiop	Triangles are done
12	7:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
13	7:15:45	Qwertyuiop	What's the shape of the array? a hexagon? <*REF to 12*>
	7:15:47	137	<137 *locks the triangular grid that Qwertyuiop has just drawn*>
14	7:16:02	137	Ya <*REF to line 13*>
15	7:16:15	Qwertyuiop	ok…
	7:16:18–7:16:35	137	<137 *performs a few drawing actions and then erases them*>
16	7:16:41	Jason	wait–can someone highlight the hexagonal array on the diagram? i don't really see what you mean…

[3] In the meantime, Qwertyuiop also performs a few drawing actions near the shared drawing, but his actions do not introduce anything noticeably different because he quickly erases what he draws each time.

	7:16:45–7:17:28	137	*<137 adds new lines to the grid on the whiteboard which gradually forms a contour on top of the grid. Figure 12.6 shows some of the steps performed by 137>*
17	7:17:30	Jason	Hmm… okay
18	7:17:43	Qwertyuiop	Oops *<REF to Whiteboard>*
19	7:17:44	Jason	so it has at least 6 triangles?
20	7:17:58	Jason	in this, for instance *<REF to Whiteboard>*
	7:18:03–7:18:17	137	*<137 completes the contour by adding more lines, which forms a hexagon>*
21	7:18:53	137	How do you color lines?
22	7:19:06	Jason	There's a little paintbrush icon up at the top
23	7:19:12	Jason	it's the fifth one from the right
	7:19:13–7:19:20	137	*<137 begins to change the color of the lines that form the contour to blue>*
24	7:19:20	137	Thanks
25	7:19:21	Jason	There ya go :-)
	7:19:25–7:19:48	137	*<137 finishes the coloring. Now the contour is highlighted in blue>*
26	7:19:48	137	Er… That hexagon
27	7:20:02	Jason	so… should we try to find a formula i guess

When the shared diagram reaches the stage illustrated by the fourth frame in Fig. 12.6, Jason posts the message "hmmm… okay" in line 17, which can be read as an acknowledgement of 137's performance on the whiteboard as a response to his recent chat query. Because no chat message was posted after Jason's request in line 16, and the only shared actions were 137's work on the whiteboard, Jason's chat posting can be read as a response to the ongoing drawing activity on the whiteboard. As it is made evident in his posting, Jason is treating the evolving drawing on the shared diagram as a response to his earlier query for highlighting the hexagonal array on the whiteboard: The question/answer adjacency pair is spread across the two interaction spaces in an unproblematic way.

Following provisional acknowledgement of 137's drawing actions on the whiteboard, Jason posts a claim in line 19. This posting is built as a declarative: "so it has at least 6 triangles," with a question mark appended to the end. The use of "so" in this posting invites readers to treat what follows in the posting as a consequence of the prior actions of 137. In this way, Jason is (a) proposing a defeasible extension of his understanding of the sense of 137's actions and (b) inviting others to endorse or correct this provisional claim about the hexagonal array by presenting this as a query using the question mark.

In line 20, Jason provides further specificity to what he is indexing with the term "it" in line 19 by highlighting a region on the grid with the referencing tool of the VMT system. The textual part of the posting makes it evident that the highlighted region is an instance of the object mentioned in line 19. Moreover, the six triangles highlighted by the explicit reference recognizably make up a hexagon shape altogether. Hence, Jason's explicit reference seems to be pointing to a particular stage (indexed by "at least") of the hexagonal array to which the team is oriented (see Fig. 12.7).

In other words, having witnessed the production of the hexagonal shape on the whiteboard as a response to his earlier query, Jason displays his competence by demonstrating his recognition of the hexagonal pattern implicated in 137's graphical illustration. 137's drawing actions highlight a particular stage of a growing pattern made of triangles, stage N=3, as we will see in Fig. 12.9. However, recognizing the stick pattern implicated in 137's highlighting actions requires other members to project how the displayed example can be grown and/or shrunk to produce other stages of the hexagonal array. Thus, Jason's description of the shape of the "hexagonal array" at a different stage—N=1—is a public display of his newly achieved comprehension of the significance of the math object in the whiteboard and the achievement of "indexical symmetry" among the parties involved with respect to this math object (see Stahl, 2009b, chap. 14).

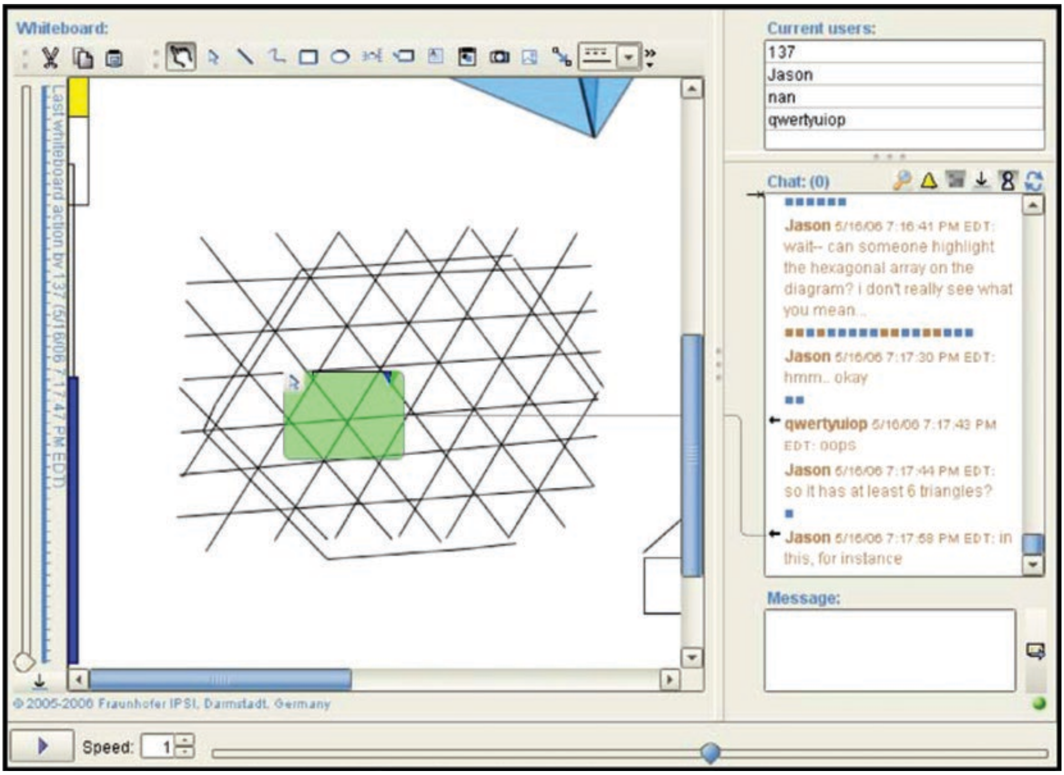


Fig. 12.7 The use of the referencing tool to point to a stage of the hexagonal array

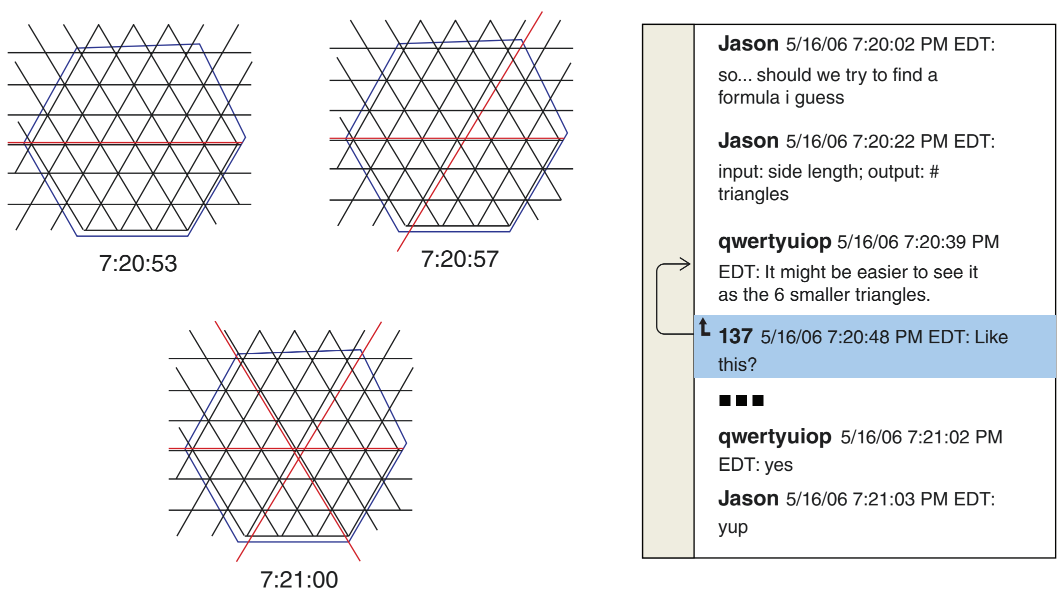


Fig. 12.8 137 splits the hexagon into six parts

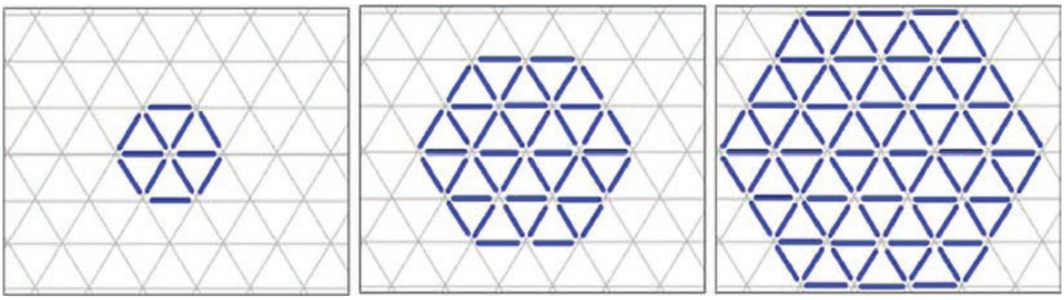


Fig. 12.9 A reconstruction of the first three iterations of the geometric pattern

Although Jason explicitly endorsed 137's drawing as an adequate illustration, the small boxes in the chat stream that appear after Jason's acknowledgement in line 17 show that 137 is still oriented to and operating on the whiteboard. In line 21, 137 solicits other members' help regarding how he can change the color of an object on the board, which opens a side sequence about a specific feature of the whiteboard system. Based on the description he got, 137 finishes marking the hexagon by coloring all its edges with blue, and he posts "that hexagon" in line 25. This can be read as a chat reference to the whiteboard shape enclosed by the blue contour and as a response to other members' earlier requests for clarification.

In this excerpt, we have observed two referential methods enacted by participants to bring relevant graphical objects on the whiteboard to other group members' attention. In the first case, 137 *marked the drawing* with a different color to identify the contour of a hexagonal shape. As evidenced in other members' responses, this was designed to make the hexagonal array embedded in a grid of triangles visible to others. Jason demonstrated another method by using the explicit referencing tool to support his *textual description* of the first stage of the pattern. Both mechanisms play a key role in directing other members' attention to features of the shared *visual field* in particular ways. This kind of deictic usage isolates components of the shared drawing and constitutes them as relevant objects to be attended to for the purposes at hand. As we shall see, these guided shifts in visual focus of the group have strategic importance for the group's mathematical work. Hence, such referential work establishes a fundamental *relationship between the narrative and mathematical terminology used in text chat and the animated graphical constructions produced on the whiteboard*. The shared sense of the textual terms and the inscriptions co-evolve through the referential linkages established as the interaction sequentially unfolds in both interaction spaces.

In Log 12.3, the group tentatively proposes a major mathematical insight that a hexagon can be viewed as six symmetric triangular areas. It is a visual achievement. It emerges from a visual inspection by Jason of 137's graphical diagram, based on Qwertyuiop's method of visually representing hexagons as patterns of triangularly intersecting lines. By literally focusing his eyes on a smallest hexagon in the larger array and counting the number of triangles visible within a hexagonal border, Jason discovers that there are at least six triangles at the initial stage of a hexagon with one unit on each side. We will see how the group visualizes the generalization of this picture to other stages. However, it is already interesting to note that Jason not only observes the composition of a small hexagon out of six triangles, but he conveys this to the rest of the group in both media. He posts chat line 19 and then references from chat line 20 to a visually highlighted view in the whiteboard, so that his *visual* understanding can be shared by the group as well as his *narrative* description in his claim. The next step for the group will be to formulate a *symbolic* mathematical expression of this claim.

Whiteboard Visualizations, Chat Narratives, and Wiki Symbolisms

The excerpt in Log 12.4 immediately follows Log 12.3. The way 137 uses both interaction spaces in this episode highlights another important aspect of collaborative problem-solving work in an environment like VMT. Because participants can contribute to only one of the interaction spaces at a time, they cannot narrate their whiteboard actions simultaneously with chat postings, as can be done with talking about a whiteboard in a face-to-face setting. However, as we will observe in 137's use of the whiteboard in the following excerpt, participants can achieve a similar interactional organization by coordinating their actions in such a way that whiteboard actions can be seen as part of an exposition performed in chat.

Log 12.4

27	7:20:02	Jason	so… should we try to find a formula i guess
28	7:20:22	Jason	input: side length; output: # triangles
29	7:20:39	Qwertyuiop	It might be easier to see it as the 6 smaller triangles
30	7:20:48	137	Like this? <REF *to line 29*> 7:20:53
		137	*<137 draws a red line>* 7:20:57
			137 *<137 draws a red line>* 7:21:00137 *<137 draws a red line>*
31	7:21:02	Qwertyuiop	Yes
32	7:21:03	Jason	Yup
	7:21:03	137	*<137 moves the second red line>*
	7:21:05	137	*<137 moves the second red line again. It is positioned on the grid now>*
33	7:21:29	Qwertyuiop	Side length is the same…
34	7:22:06	Jason	Yeah

Jason brings the prior activity of locating the hexagonal array on the shared drawing to a close with his so-prefaced posting in line 27, where he invokes the task of finding a formula that was mentioned by 137 earlier. Jason provides further specificity to the formula he is referring to in the next line (i.e., given the side length as input, the formula should return the number of triangles as output). In line 29, Qwertyuiop takes up Jason's proposal by suggesting the team considers the hexagonal array as six smaller triangles to potentially simplify the task at hand. In the next line, 137 posts a question phrased as "like this?" which is addressed to Qwertyuiop's prior posting, as indicated by the use of the referential arrow. Next, we observe the appearance of three red lines on the shared diagram, which are all added by 137. Here, 137 demonstrates a particular way of splitting the hexagon into six parts: The image on the left of Fig. 12.8 corresponds to the sequence of three whiteboard actions represented as three boxes in the chat excerpt. After 137 adds the third line whose intersection with the previously drawn red lines recognizably produces six triangular regions on the shared representation, Qwertyuiop and Jason both endorse 137's demonstration of a particular way of splitting up the hexagonal shape.

One important aspect of this organization is directing other members' attention to the projected whiteboard activity as a relevant step in the sequentially unfolding exposition in chat. For instance, the deictic term "this" in 137's chat line 30 refers to something yet to be produced, and thereby projects that there is more to follow the current posting, possibly in the other interaction space. Moreover, the use of the referential link and the term "like" together inform others that what is about to be done should be read in relation to the message to which 137 is responding. Finally, 137's use of a different color marks the newly added lines as recognizably distinct from what is already there as the background, and hence, noticeable as a demonstration of what is implicated in recent chat postings.

Again, the progress in understanding the mathematics of the problem is propelled through visual means. In response to Jason's proposal of finding a formula, Qwertyuiop suggests that "it might be easier to see it" in a certain way. Jason's proposed approach might be difficult to pursue because no one has suggested a concrete approach to constructing a formula that would meet the general criteria of producing an output result for any input variable value. By contrast, the group has been working successfully in the visual medium of the whiteboard drawing and has been literally able to "see" important characteristics of the math object that they have co-constructed out of intersecting lines. Jason has pointed out that at least six triangles are involved (in the smallest hexagon). So, Qwertyuiop proposes building on this in-sight. 137 asks if the way to see the general case in terms of the six small triangles as proposed by Qwertyuiop can be visualized by intersecting the hexagon array with three intersecting lines to distinguish the six regions of the array. He does this through a visual construction, simply referenced from the chat with his "Like this?" post.

By staring at the final version of the array (stage 3 in Fig. 12.8), all members of the group can see the hexagon divided into six equal parts at each stage of the hexagonal pattern. Near the intersection of the red lines, they can see a single small triangle nestled in each of the six regions. As will be evidenced in Log 12.5, within the larger hexagon delimited by the blue lines, they can see a set of 1+3+5=9 small triangles in each of the six larger triangular regions. Similarly, midway between stage N=1 and stage N=3, one can visually observe 1+3=4 small triangles in each region. The new view, scaffolded by 137's red lines, entails *visual reasoning* that leads to mathematical deductions.

As soon as Qwertyuiop and Jason see 137's construction, they both concur with it as the easier way to see the mathematical pattern of triangles in the hexagonal array. The visual reasoning supported by whiteboard and narrated textually in the chat will lead in the next episode to symbolic reasoning for posting in the wiki.

A first glance at the chat logs might suggest that the group is narrating their problem-solving process in the chat and illustrating what they mean by "napkin" drawings in the whiteboard, to use Dillenbourg and Traum's (2006) metaphor. However, a second look reveals that the most significant insight and sharing is occurring in the whiteboard, more along the lines of a visual "model" metaphor. Perhaps the best way to describe what is going on is to say that the group is very carefully coordinating their work in the dual space as a whole to achieve a shared progression of understanding of the pattern problem. This is accomplished with an efficiency and effectiveness that could not be achieved in either a purely textual chat system or a purely graphical whiteboard. Although in this view the chat and whiteboard both function as symmetric parts of a coordinated whole in which chat references drawing and drawing illustrates chat, it is important to differentiate their roles as well.

Using Representations of Specific Instances as a Resource for Generalization

Immediately following the previous excerpt, the team moves on to figuring out a general formula to compute the number of triangles in a hexagonal pattern. In line 34 of Log 12.5, Jason relates the particular partitioning of the hexagon illustrated on the whiteboard to the problem at hand by stating that the number ("#") of triangles in the hexagon will equal to six times ("x6") the number of triangles enclosed in each partition. In the next posting, 137 seems to be indexing one of the six partitions with the phrase "each one." Hence, this posting can be read as a proposal about the number of triangles included in a partition. The sequence of numbers in the expression "1+3+5" calls others to look at a partition in a particular way. While 137 could have simply said here that there are nine triangles in each partition, he instead organizes the numbers in summation form and offers more than an aggregated result. His expression also demonstrates a systematic method for counting the triangles. In other words, his construction is designed to highlight a particular orderliness in the organization of triangles that form a partition. Moreover, the sequence includes increasing consecutive odd numbers, which implicitly informs a certain progression for the growth of the shape under consideration.

Log 12.5

34	7:22:13	Jason	so it'll just be x6 for # triangles in the hexagon
35	7:22:19	137	Each one has 1+3+5 triangles
36	7:22:23	Jason	but then we're assuming just regular hexagons
37	7:22:29	Qwertyuiop	the "each polygon corrisponds to 2 sides" thing we did last time doesn't work for triangles
38	7:23:17	137	It equals 1+3+...+(n+n-1) because of the "rows"?
39	7:24:00	Qwertyuiop	yes- 1st row is 1, 2nd row is 3…
40	7:24:49	137	And there are n terms so…n(2n/2)
41	7:25:07	137	or n^2 *<REF to line 40>*
42	7:25:17	Jason	Yeah
43	7:25:21	Jason	then multiply by 6
44	7:25:31	137	To get 6n^2 *<REF to line 43>*

About a minute after his most recent posting, 137 offers an extended version of his sequence as a query in line 38. The relationship between the sequence for the special case and this one is made explicit through the repetition of the first two terms. In the new version, the "…" notation is used to substitute a series of numbers following the second term up to a generic value represented by "n+n-1," which can be recognized as a standard expression for the nth odd number. Hence, this representation is designed to stand for something more general than the one derived from the specific instance illustrated on the whiteboard. 137 attributes this generalization to the concept of "rows" and solicits other members' assessment regarding the validity of his version (by ending with a question mark). 137's use of the term "rows" seems to serve as a pedagogic device that attempts to locate the numbers in the sequence on the nth stage of the hexagonal pattern (see Fig. 12.9 for an analyst's illustration of the generalized hexagonal pattern). For stages 1, 2, and 3, the hexagonal shape has 6*(1) = 6, 6*(1+3) = 24, 6*(1+3+5) = 54 triangles, respectively.

Qwertyuiop's endorsement of 137's proposal comes in line 39. He also demonstrates a row-by-row iteration on a hexagon, where each number in the sequence corresponds to a row of triangles in a partition. In other words, Qwertyuiop elaborates on 137's statement in line 38 of the chat by displaying his understanding of the relationship between the rows and the sequence of odd numbers. Although he does not explicitly reference it here, Qwertyuiop may be viewing the figure in the whiteboard to see the successive rows. The figure is, of course, also available to 137 and Jason to help them follow Qwertyuiop's chat posting and check it.

Then 137 proposes an expression for the sum of the first n odd numbers in line 40.[4] Jason agrees with the proposed expression and suggests that it should be multiplied by six next. In the following line, 137 grammatically completes Jason's posting with the resulting expression. In short, by virtue of the agreements and the co-construction work of Jason and 137, the team demonstrates its endorsement of the conclusion that the number of triangles would equal $6n^2$ for a hexagonal array made of triangles. As the group collaboratively discovered, when n equals the stage number (as "input" to the formula), the number of triangles is given by the expression $6n^2$.

The way team members orient themselves to the shared drawing in this episode illustrates that the drawings on the whiteboard have a figurative role in addition to their concrete appearance as illustrations of specific cases. The particular cases captured by concrete, tangible marks on the whiteboard are often used as a resource to investigate and talk about general properties of the mathematical objects indexed by them.

[4] 137 makes use of Gauss's method for summing this kind of series, adding the first and last term and multiplying by half of the number of terms: $(1 + n + n - 1)*n/2 = n^2$. This method was used by the group and shared in previous sessions involving the stair pattern that is still visible in the whiteboard.

Another important aspect of the team's achievement of a general expression in this episode is the way they transformed a particular way of *counting* the triangles in one of the partitions (i.e., a geometric observation) into an algebraic mode of investigation. This shift from a visual method led the team members to recognize that a particular sequence of numbers can be associated with the way the partition grows in subsequent iterations. The shift to this symbolic mode of engagement, which heavily uses the shared drawing as a resource, allowed the team to go further in the task of generalizing the pattern of growth by invoking algebraic resources. In other words, the team made use of multiple realizations (graphical and linguistic) of the math object (the hexagonal array) distributed across the dual-interaction space to co-construct a general formula for the task at hand.

Chat Versus Whiteboard Contributions as Persistent Referential Resources

In all of the excerpts we have considered so far, the shared drawing has been used as a resource within a sequence of related but recognizably distinct activities. For instance, the group has oriented itself to the following activities: (1) drawing a grid of triangles, (2) formulating a problem that relates a hexagonal array to a grid of triangles, (3) highlighting a particular hexagon on the grid, (4) illustrating a particular way to split the shape into six smaller pieces, and (5) devising a systematic method to count the number of triangles within one of the six pieces. As the group oriented to different aspects of their shared task, the shared diagram was modified on the whiteboard and annotated in chat accordingly. Yet, although it had been modified and annotated along the way, the availability of this shared drawing on the screen and the way participants organize their discussion around it highlights its persistent characteristic as an ongoing referential resource. In contrast, none of the chat postings in prior excerpts were attributed a similar referential status by the participants. As we have seen, in each episode, the postings responded or referred either to recently posted chat messages or to the visual objects in the shared space.

The textual chat postings and the graphical objects produced on the whiteboard differ in terms of the way they are used as referential resources by the participants. The content of the whiteboard is persistently available for reference and manipulation, whereas the chat content is visually available for reference for a relatively shorter period. This is due to the linear growth of chat content, which replaces previous messages with the most recent contributions inserted at the bottom of the chat window. Although one can make explicit references to older postings by using the scroll bar feature, the limited size of the chat window affords a referential locality between postings that are visually (and hence temporally) close to each other.

By contrast, objects drawn in the whiteboard tend to remain there for a long time. They are often only erased or moved out of view when space is needed for drawings related to a new topic. While they may be modified, elaborated, or moved around, whiteboard objects may remain visible for an entire hour-long session or even across sessions. Like the chat, the whiteboard has a history scrollbar, so that any past state of the drawing can be made visible again—although in practice students rarely use this feature. Although both media technically offer a persistent record of their contents, the visual locality of the whiteboard—the fact that graphical objects tend to stay available for reference from the more fleeting chat—qualifies it as the more persistent medium as an interactional resource. This notion of persistence does not imply that the shared sense of whiteboard objects is fixed once they are registered to the shared visual field. As they continue to serve as referential resources during the course of the problem-solving effort, the sense of whiteboard objects may become increasingly evident and shared, or their role may be modified as participants make use of them for varying purposes.

Implications for CSCL Chat Interaction Analysis

In this case study, we investigated how a group of three upper-middle-school students put the features of an online environment with dual-interaction spaces into use as they collaboratively worked on a math problem they themselves came up with. Our analysis has revealed important insights regarding the affordances of systems with dual-interaction spaces. First, we observed that the whiteboard can make visible to everyone the animated evolution of a geometric construction, displaying the *visual reasoning* process manifested in drawing actions. Second, whiteboard and chat contents differ in terms of *mutability* of their contents, due to the object-oriented design of the whiteboard that allows modification and annotation of past contributions. Third, the media differ in terms of the *persistence* of their contents: Whiteboard objects remain in the shared visual field until they are removed, whereas chat content gradually scrolls off as new postings are produced. Although contents of both spaces are persistently available for reference, due to linear progression of the chat window, chat postings are likely to refer to visually (and hence temporally) close chat messages and to graphical whiteboard objects. Finally, the whiteboard objects *index* a horizon of past and future activities as they serve as an interactional resource through the course of recognizably distinct but related episodes of chat discussion.

Our analysis of this team's joint work has also revealed methods for the organization of collaborative work, through which group members co-construct mathematical meaning sedimented in semiotic objects distributed across the dual-interaction spaces of the VMT environment. We observed that bringing relevant math artifacts referenced by indexical terms such as "hexagonal array" to other members' attention often requires a coordinated sequence of actions across the two interaction spaces. Participants use explicit and verbal references to guide each other about how a new contribution should be read in relation to prior contents. Indexical terms stated in chat referring to the visible production of shared objects are instrumental in the reification of those terms as meaningful mathematical objects for the participants. Verbal references to co-constructed objects are often used as a resource to index complicated and abstract mathematical concepts in the process of co-constructing new ones. Finally, different representational affordances of the dual-interaction spaces allow groups to develop multiple realizations of the math artifacts to which they are oriented. Shared graphical inscriptions and chat postings are used together as semiotic resources in mutually elaborating ways. Methods of coordinating group interaction across the media spaces also interrelate the mathematical significances of the multiple realizations.

Overall, we observed that actions performed in both interaction spaces constitute an evolving historical context for the joint work of the group. What gets done now informs the relevant actions to be performed next, and the significance of what was done previously can be modified depending on the circumstances of the ongoing activity. As the interaction unfolds sequentially, the sense of previously posted whiteboard objects and chat statements may become evident and/or refined. In this way, the group's joint problem space is maintained.

Through the sequential coordination of chat postings and whiteboard inscriptions, the group successfully solved their mathematical challenge, to find a formula for the number of small triangles in a hexagonal array of any given side length. Their interaction was guided by a sequence of proposals and responses carried out textually in the chat medium. However, the sense of the terms and relationships narrated in the chat were largely instantiated, shared, and investigated through observation of visible features of graphical inscriptions in the whiteboard medium. The mathematical object that was visually co-constructed in the whiteboard was named and described in words within the chat. Finally, a symbolic expression was developed by the group, grounded in the graphic that evolved in the whiteboard, and discussed in the terminology that emerged in the chat. The symbolic mathematical result was then posted to the wiki, a third medium within the VMT environment. The wiki is intended for sharing group findings with other groups as part of a permanent archive of work by virtual math teams.

Our case study in this paper demonstrates that it is possible to analyze how math problem-solving—and presumably other cognitive achievements—can be carried out by small groups of students. The students can define and refine their own problems to pursue; they can invent their own methods of working; they can use unrestricted vocabulary; they can coordinate work in multiple media, taking advantage of different affordances. Careful attention to the sequentiality of references and responses is necessary to reveal *how* the group coordinated its work and how that work was driven by the reactions of the group members' actions to each other. Only by focusing on the sequentiality of the actions can one see how the visual, narrative, and symbolic build on each other as well as how the actions of the individual students respond to each other. Through these actions, the students co-construct math objects, personal understanding, group agreement, and mathematical results that cannot be attributed to any one individual but that emerge from the interaction as complexly sequenced.

This analysis illustrates a promising approach for CSCL research to investigate aspects of group cognition that are beyond the reach of alternative methods that systematically ignore the full sequentiality of their data.

The Group as the Unit of Analysis

For methodological reasons, quantitative approaches—such as those reviewed in the next section—generally (a) constrain (scaffold) subject behaviors, (b) filter (code) the data in terms of operationalized variables, and (c) aggregate (count) the coded data. These acts of standardization and reduction of the data eliminate the possibility of observing the details and enacted processes of unique, situated, indexical, and sequential group interaction (Stahl, 2006, Chap. 10). An alternative form of interaction analysis is needed to explore the organization of interaction that can take place in CSCL settings.

In this paper, we focused on small-group interactions mediated by a multimodal interaction space. Our study differs from similar work in CSCL by our focus on groups larger than dyads whose members are situated outside a controlled lab environment and by our use of open-ended math tasks where students are encouraged to come up with their own problems. Moreover, we do not impose any deliberate restrictions on the ways students access the features of our online environment or on what they can say. Our main goal is to investigate how small groups of students construe and make use of the "available features" of the VMT online environment to discuss mathematics with peers from different schools outside their classroom setting. In other words, we are interested in studying interactional achievements of small groups in complex computer mediations "in the wild" (Hutchins 1996).

Our interest in studying the use of an online environment with multiple interaction spaces in a more naturalistic use scenario raises serious methodological challenges. In an early VMT study where we conducted a content analysis of collaborative problem-solving activities mediated by a standard text-chat tool in a similar scenario of use, we observed that groups larger than dyads exhibit complex interactional patterns that are difficult to categorize based on a theory-informed coding scheme with a fixed/predetermined unit of analysis (Stahl, 2009b, Chap. 20). In particular, we observed numerous cases where participants post their messages in multiple chat turns, deal with contributions seemingly out of sequence, and sustain conversations across multiple threads that made it problematic to segment the data into fixed analytic units for categorization. Moreover, coming to agreement on a code assignment for a unit that is defined a priori (e.g., a chat line) turned out to be heavily dependent upon how the unit can be read in relation to resources available to participants (e.g., the problem description) and to prior units (Stahl, 2009b, chap. 22). In other words, the sense of a unit not only depends on the semantic import of its constituent elements but also on the occasion in which it is situated

(Heritage 1984). This often makes it possible to apply multiple categories to a given unit and threatens the comparability of cases that are labeled with the same category. More importantly, once the data is reduced to codes and the assignments are aggregated, the complex sequential relationships among the units are largely lost. Hence, the coding approach's attempt to enforce a category to each fixed unit without any consideration to how users sequentially organize their actions in the environment proved to be too restrictive to adequately capture the interactional complexity of chat (Stahl, 2009b, chap. 23). Moreover, the inclusion of a shared drawing area in our online environment made the use of a standard coding schema even harder due to increased possibilities for interaction. The open-ended nature of the tasks we use in our study makes it especially challenging to model certain types of actions and to compare them against ideal solutions.

The issue of unit of analysis has theoretical implications. In text chat, it is tempting to take a single posting as the unit to be analyzed and coded, because a participant defined this as a unit by posting it as a message and because the chat software displays it as a visual unit. However, this tends to lead the analyst to treat the posting as a message from the posting individual—that is, as an expression of a thought in the poster's mind, which must then be interpreted in the minds of the post readers. Conversation analysis has argued for the importance of *interactions* among participants as forming more meaningful units for analysis. These consist of sequences of multiple utterances by different speakers; the individual utterances take each other into account. For instance, in a question/answer "adjacency pair," the question elicits an answer and the answer responds to the question. To take a pair of postings such as a question/answer pair as the analytic unit is to treat the interaction within the group as primary. It focuses the analysis at the level of the group rather than the individual. As mentioned, in online text chat, responses are often separated from their referents, so the analysis is more complicated. In general, we find that the important thing is to trace as many references as possible between chat postings or whiteboard actions in order to analyze the interaction of the group as it unfolds (Stahl, 2009b, chap. 26). As seen in our case study, it is through the co-construction of a rich nexus of such references that the group weaves its joint problem space.

Analysis at the group unit focuses on the co-construction, maintenance, and progressive refinement of the joint problem space. This is a distinctive analytic task that takes as its data only what is shared by the group. Whatever may go on in the physical, mental, or cultural backgrounds of the individual participants is irrelevant unless it is brought into the group discourse. Because the students know nothing about the gender, age, ethnicity, accent, appearance, location, personality, opinions, grades, or skills of the other participants other than what is mentioned or displayed in the chat interaction, these "factors" from the individual and societal levels can be bracketed out of the group analysis. Survey and interview data are unnecessary; individual learning trajectories are not plotted. The VMT Project has been designed to make available to the analyst precisely what was shared by the student group, and nothing else.

Relatedly, the notion of common ground (see section on grounding) as an abstract placeholder for registered cumulative facts or pre-established meanings has been critiqued in the CSCL literature for treating meaning as a fixed/denotative entity transcendental to the meaning-making activities of inquirers (Koschmann, 2002). The common ground that supports mutual understanding in group cognition or group problem-solving is a matter of semantic references that unfold sequentially in the momentary situation of dialog, not a matter of comparing mental contents (Stahl, 2006, pp. 353–356). Committing to a reference-repair model (Clark & Marshall, 1981) for meaning making falls short of taking into account the dynamic, constitutive nature of meaning-making interactions that foster the process of inquiry (Koschmann, LeBaron, Goodwin, & Feltovich, 2001).

As we saw in the preceding case study, the understanding of the mathematical structure of the hexagon area did not occur as a mental model of one of the students that was subsequently externalized in the chat and whiteboard and communicated to the other students. It emerged in the discourse media in a way that we could witness as analysts. It consisted of the layering of inscriptions (textual and graphical) that referenced one another. The referential network of group meaning can be observed in the way that deictic and indexical expressions are resolved. The three students each contribute to the progressive development of the shared meaning by responding appropriately to the ongoing state of the discourse. This is a matter of linguistic skill—including the ability in discussing mathematical matters—not of articulating mental representations. It is surprising from a rationalist perspective how poor students are at explaining (Stahl, 2009b, chap. 26), reproducing (Koschmann & LeBaron, 2003), or even recalling (Stahl, 2009b, chap. 6) what they did in the group when they are no longer situated in the moment.

Given these analytical and theoretical issues, we opted for an alternative to the approaches reviewed below that involve modeling of actions and correct solution paths or treating shared understanding as alignment of preexisting individual representations and opinions. In this paper, we built on our previous work on referencing math objects in a system with chat and a whiteboard (Stahl, 2009b, chap. 17); we presented a "micro-ethnographic" (Streeck & Mehus, 2003) case study using interaction analysis (Jordan & Henderson, 1995). We focused on the *sequence of actions* in which the group co-constructs and makes use of *semiotic resources* (Goodwin 2000) distributed across dual-interaction spaces to *do* collaborative problem-solving work. In particular, we focused on the joint organization of activities that produce graphical drawings on the shared whiteboard and the ways those drawings are used as resources by actors as they collaboratively work on an open-ended math task. Through detailed analysis at the group unit of analysis, we investigated how actions performed in one workspace inform the actions performed in the other and how the group coordinates its actions across both interaction spaces.

Other Approaches in CSCL to Analyzing Multimodal Interaction

Multimodal interaction spaces—which typically bring together two or more synchronous online communication technologies such as text chat and a shared graphical workspace—have been widely used to support collaborative learning activities of small groups (Dillenbourg and Traum 2006; Jermann 2002; Mühlpfordt and Wessner 2005; Soller & Lesgold, 2003; Suthers et al., 2001). The way such systems are designed as a juxtaposition of several technologically independent online communication tools carries important interactional consequences for the users. Engaging in forms of joint activity in such online environments requires group members to use the technological features available to them in methodical ways to make their actions across multiple spaces intelligible to each other and to sustain their joint problem-solving work.

In this section we summarize our review (Çakir, 2009) of previous studies in the CSCL research literature that focus on the interactions mediated by systems with multimodal interaction spaces to support collaborative work online. Our review is not meant to be exhaustive, but representative of the more advanced analytical approaches employed. We have selected sophisticated analyses, which go well beyond the standard coding-and-counting genre of CSCL quantitative reports, in which utterances are sorted according to a fixed coding scheme and then statistics are derived from the count of utterances in each category. Unlike the simple coding-and-counting studies, the approaches we review attempt to analyze some of the structure of the semantic and temporal relationships among chat utterances and workspace inscriptions in an effort to get at the fabric of common ground in dual-interaction online environments.

The communicative processes mediated by multimodal interaction spaces have attracted increasing analytical interest in the CSCL community. A workshop held at CSCL 2005 specifically highlighted the need for more systematic ways to investigate the unique affordances of such online environments (Dillenbourg, 2005). Previous CSCL studies that focus on the interactions mediated by systems with two or more interaction spaces can be broadly categorized under (1) prescriptive approaches based on models of interaction and (2) descriptive approaches based on content analysis of user actions.

1. The *modeling approach* builds on the content-coding approach by devising models of categorized user actions performed across multimodal interaction spaces, for example:
   (a) Soller and Lesgold's (2003) use of hidden Markov models (HMM)
   (b) Avouris, Dimitracopoulou, and Komis's (2003) object-oriented collaboration analysis framework (OCAF)

   In these studies, the online environment is tailored to a specific problem-solving situation so that researchers can partially automate the coding process by narrowing the possibilities for user actions to a well-defined set of categories. The specificity of the problem-solving situation also allows researchers to produce models of idealized solution cases. Such ideal cases are then used as a baseline to make automated assessments of group work and learning outcomes.
2. The *descriptive approach* informed by content analysis also involves categorization of user actions mediated by multimodal interaction spaces, applying a theoretically informed coding scheme. Categorized interaction logs are then subjected to statistical analysis to investigate various aspects of collaborative work such as:
   (c) The correlation between planning moves performed in chat and the success of subsequent manipulations performed in a shared workspace (Jermann 2002; Jermann and Dillenbourg 2005)
   (d) The relationship between grounding and problem-solving processes across multiple interaction spaces (Dillenbourg and Traum 2006)
   (e) A similar approach based on cultural-historical activity theory (Baker et al., 1999)
   (f) The referential uses of graphical representations in a shared workspace in the absence of explicit gestural deixis (Suthers, Girardeau, & Hundhausen, 2003)

These studies all focus on the group processes of collaboration, rather than treating it as a mere experimental condition for comparing the individuals in the groups. Also, they employ a content-coding approach to categorize actions occurring in multiple interaction spaces. In most cases, representational features like sentence openers or nodes corresponding to specific ontological entities are implemented in the interface to guide/constrain the possibilities for interaction. Such features are also used to aid the categorization of user actions. The categorization schemes are applied to recorded logs and subjected to statistical analysis to elicit interaction patterns.

The analytic thrust of these studies is to arrive at quantitative results through statistical comparisons of aggregated data. To accomplish this, they generally have to restrict student actions in order to control variables in their studies and to facilitate the coding of student utterances within a fixed ontology. We fear that this unduly restricts the interaction, which must be flexible enough to allow students to invent unanticipated behaviors. The restrictions of laboratory settings make problematic experimental validity and generalization of results to real-world contexts. Even more seriously, the aggregation of data—grouping utterances by types or codes rather than maintaining their sequentiality—ignores the complexity of the relations among the utterances and actions. According to our analysis, the temporal and semiotic relations are essential to understanding, sharing, and coordinating meaning, problem-solving, and cognition. While quantitative approaches can be effective in testing model-based hypotheses, they seem less appropriate both for exploring the problem of interactional organization and for investigating interactional methods, which we feel are central to CSCL theory.

Despite the accomplishments of these studies, we find that their approaches introduce systematic limitations. Interactional analysis is impossible because coherent excerpts from recorded interactions are excluded from the analysis itself. (Excerpts are only used anecdotally, outside of the analysis, to introduce the features of the system to the reader, to illustrate the categorization schemes employed, or to motivate speculative discussion). Moreover, most studies like these involve dyads working on specific problem-solving contexts through highly structured interfaces in controlled lab studies in an effort to manage the complexity of collaboration. The meanings attributed by the researchers to such features of the interface need to be discovered/unpacked by the participants as they put them into use in interaction—and this critical process is necessarily ignored by the methodology. Finally, most of these papers are informed by the psycholinguistic theory of common ground and are unable to critique it systematically. By contrast—as we shall see in the following section—our analysis of the joint organization of interaction in the case study positions us to understand how the group grounds its shared understanding in interactional terms at the group level.

Grounding Through Interactional Organization

The coordination of visual and linguistic methods (across the whiteboard and chat workspaces) plays an important role in the establishment of common ground through the co-construction of references between items in the different media within the VMT environment. Particularly in mathematics—with its geometric/algebraic dual nature—symbolic terms are often grounded in visual presence and associated visual practices, such as counting or collecting multiple units into a single referent (Goodwin 1994; Healy and Hoyles 1999; Livingston, 2006; Sfard, 2008; Wittgenstein, 1944/1956). The visually present can be replaced by linguistic references to objects that are no longer in the visual field but that can be understood based on prior experience supported by some mediating object such as a name—see the discussion of mediated memory and of the power of names in thought by Vygotsky (1930/1978, 1934/1986). A more extended analysis of the co-construction of mathematical artifacts by virtual math teams, the complementarity of their visual, semantic, and symbolic aspects, their reliance on pre-mathematical practices and processes of reification into concepts are beyond the scope of this paper and require comparison of multiple case studies (see Çakir, 2009). However, for this paper it is important to understand something of how the interactional organization that we have observed here functions to ground the group's understanding of their math object (the hexagonal array) as a shared group achievement.

As implied in the OCAF study (Avouris et al., 2003) mentioned in the previous section, investigating grounding and problem-solving processes in online dual-interaction environments like VMT requires close attention to the relationships among actions performed in multiple interaction spaces. Our case study illustrates some of the practical challenges involved with producing mathematical models that aim to exhaustively capture such relationships. For instance, the hexagonal array that was co-constructed by the team draws upon a triangular grid that is formed by three sets of parallel lines that intersect with each other in a particular way. In other words, these objects are layered on top of each other by the participants to produce a shape recognizable as a hexagon. Despite this combinatoric challenge, a modeling approach can still attempt to capture all possible geometric relationships among these graphical objects in a bottom-up fashion. However, when all chat messages referring to the whiteboard objects are added to the mix, the resulting model may obscure rather than reveal the details of the interactional organization through which group members discuss more complicated mathematical objects by treating a collection of atomic actions as a single entity. Terminology co-constructed in the chat-and-whiteboard environment—like "hexagonal array"—can refer to complexly defined math objects. What is interesting about the student knowledge building is how they aggregate elements and reify them into higher-order, more powerful units (Sfard, 2008). A model should mirror this rather than to simply represent the elements as isolated.

The challenges involved with the modeling approach are not limited to finding efficient ways to capture all relationships among actions and identifying meaningful clusters of objects. The figurative uses of the graphical objects present the most daunting challenge for such an undertaking. For instance, the team members in our case study used the term "hexagonal array" to refer to a mathematical object implicated in the witnessed production of prior drawing actions. As we have seen in the way the team used this term during their session, "hexagonal array" does not simply refer to a readily available whiteboard illustration. Instead it is used as a *gloss* (Garfinkel and Sacks 1970) to talk about an imagined pattern that grows infinitely and takes the shape illustrated on the whiteboard only at a particular stage. In the absence of a fixed set of ontological elements and constraints on the types of actions a user can perform, modeling approaches that aim to capture emergent relationships among semiotic objects distributed across multiple interaction spaces need to adequately deal with the retrospective and prospective uses of language in interaction. Rather than relying upon a generic approach to modeling imposed by the researchers, our ethnographic approach aims to discover the unique "model"—or, better, the specific meaning—that was constructed *by the group* in its particular situation.

In another study discussed earlier, Dillenbourg and Traum (2006) offer the napkin and mockup models in their effort to characterize the relationship between whiteboard and chat spaces. In short, these models seem to describe two use scenarios where one interaction space is subordinated to the other during an entire problem-solving session. The complex relationships between the actions performed across both interaction spaces in our case made it difficult for us to describe the interactions we have observed by committing to only one of these models, as Dillenbourg and Traum did in their study. Instead, we have observed that in the context of an open-ended math task, groups may invoke either type of organization, depending upon the contingencies of their ongoing problem-solving work. For instance, during long episodes of drawing actions where a model of some aspect of the shared task is being co-constructed on the whiteboard (as in our first excerpt), the chat area often serves as an auxiliary medium to coordinate the drawing actions, which seems to conform to the mockup model. In contrast, when a strategy to address the shared task is being discussed in chat (as in the excerpt where the group considered splitting the hexagon into six regions), the whiteboard may be mainly used to quickly illustrate the textual descriptions with annotations or rough sketches, in accordance with the napkin model. Depending on the circumstances of ongoing interaction, participants may switch from one type of organization to another from moment to moment. Therefore, instead of ascribing mockup and napkin models to the entire problem-solving sessions, we argue that it would be more fruitful to use these terms as glosses or descriptive categories for types of interactional organizations that group members may invoke during specific episodes of their interaction.

Another provocative observation made by Dillenbourg and Traum is that the whiteboard serves as a kind of shared external memory where group members keep a record of agreed-upon facts. In their study, the dyads were reported to post text notes on the whiteboard to keep track of the information they had discovered about a murder-mystery task. This seems to have led the authors to characterize the whiteboard as a placeholder and/or a shared working memory for the group, where agreed-upon facts or "contributions" in Clark's sense are persistently stored and spatially organized. As Dillenbourg and Traum observed, the scale of what is shared in the course of collaborative problem-solving becomes an important issue when a theory operating at the utterance level like contribution theory (Clark & Marshall, 1981) is used as an analytic resource to study grounding processes that span a longer period of time. Dillenbourg and Traum seem to have used the notion of persistence to extend common ground across time to address this limitation. In particular, they argued that the whiteboard grounds the solution to the problem itself rather than the contributions made by each utterance. In other words, the whiteboard is metaphorically treated as a physical manifestation of the common ground. We certainly agree with this broadening of the conceptualization of common ground, although we do not see the whiteboard as just a metaphor or externalization of a mental phenomenon. Rather, *common ground is established in the discourse spaces* of text chat and graphical whiteboard. Their differential forms of persistence provide a continuing resource for sharing, modifying, and remembering the group meaning of joint artifacts and products of group cognition.

In our case study, we have observed that the whiteboard does not simply serve as a kind of shared external memory where the group keeps a record of agreed-upon facts, opinions, hypotheses, or conclusions. The shared visible communication media are places where the group does its work, where it cognizes. Ideas, concepts, meanings, and so forth can *subsequently* be taken up by individuals into their personal memories as resources for future social or mental interactions. There is no need to reduce group meaning to identical individual mental contents or to hypothesize a mysterious "group mind" as the location of common ground—the location is the discourse medium, with all its particular affordances and modes of access.

In our sessions, the whiteboard was primarily used to draw and annotate graphical illustrations of geometric shapes, although users occasionally posted textboxes on the whiteboard to note formulas they had found (see Fig. 12.2). While the whiteboard mainly supported visual reasoning—and textual discussion or symbolic manipulation occurred chiefly in the chat stream—actions were carefully, systematically coordinated across the media and integrated within an interactionally organized group cognitive process. As we have illustrated in our analysis, the fact that there were inscriptions posted on the whiteboard did not necessarily mean that all members immediately shared the same sense of those graphical objects. The group members did considerable interactional work to achieve a shared sense of those objects that was adequate for the purposes at hand. For instance, the crosshatched lines that Qwertyuiop originally drew became increasingly meaningful for the group as it was visually outlined and segmented and as it was discussed in the chat and expressed symbolically.

Hence, the whiteboard objects have a different epistemic status in our case study than in Dillenbourg and Traum's experiment. Moreover, the participants did not deem all the contents of the whiteboard relevant to the ongoing discussion. For instance, Fig. 12.2 shows a snapshot of the entire whiteboard as the team was discussing the hexagonal pattern problem. The figure shows that there are additional objects in the shared scene like a blue hypercube and a 3D staircase, which are remnants of the group's prior problem-solving work. Finally, the sense of previously posted whiteboard objects may be modified or become evident as a result of current actions (Suchman, 1990).

In other words, group members can not only reuse or reproduce drawings but they can also make subsequent sense of those drawings or discard the ones that are not deemed relevant anymore. Therefore, the technologically extended notion of common ground as a placeholder for a worked-out solution suffers from the same issues stated in Koschmann and LeBaron's (2003) critique of Clark's theory. As an abstract construct transcendental to the meaning-making practices of participants, the notion of common ground obscures rather than explains the ways the whiteboard is used as a resource for collaborative problem-solving.

Instead of using an extended version of common ground as an analytical resource, we frame our analysis using the notion of "indexical ground of deictic reference," which is a notion we appropriated from linguistic anthropology (Hanks 1992). In face-to-face interaction, human action is built through the sequential organization of not only talk but also coordinated use of the features of the local scene that are made relevant via bodily orientations, gesture, eye gaze, and so forth. In other words, "human action is built through simultaneous deployment of a range of quite different kinds of semiotic resources" (Goodwin 2000, p. 1489). Indexical terms and referential deixis play a fundamental role in the way these semiotic resources are interwoven in interaction into a coherent whole.

Indexical terms are generally defined as expressions whose interpretation requires identification of some element of the context in which it was uttered, such as who made the utterance, to whom it was addressed, and when and where the utterance was made (Levinson, 1983). Because the sense of indexical terms depends on the context in which they are uttered, indexicality is necessarily a relational phenomenon. Indexical references facilitate the mutually constitutive relationship between language and context (Hanks 1996). The basic communicative function of indexical referentials is "to individuate or single out objects of reference or address in terms of their relation to the current interactive context in which the utterance occurs" (Hanks 1992, p. 47).

The specific sense of referential terms such as *this*, *that*, *now*, and *here* is defined locally by interlocutors against a shared indexical ground. Conversely, the linguistic labels assigned to highlighted features of the local scene shapes the indexical ground. Hence, the indexical ground is not an abstract placeholder for a fixed set of registered contributions. Rather, it signifies an emergently coherent field of action that encodes an interactionally achieved set of background understandings, orientations, and perspectives that make references intelligible to interlocutors (Zemel, Koschmann, LeBaron, & Feltovich, 2008).

Despite the limitations of online environments for supporting multimodality of embodied interaction, participants make substantial use of their everyday interactional competencies as they appropriate the features of such environments to engage with other users. For instance, Suthers et al.'s (2003) study reports that deictic uses of representational proxies play an important role in the interactional organization of online problem-solving sessions mediated by the Belvedere system. The authors report that participants in the online case devised mechanisms that compensate for the lack of gestural deixis with alternative means, such as using verbal deixis to refer to the most recently added text nodes and visual manipulation of nodes to direct their partner's attention to a particular node in the shared argument map.

In contrast to the Belvedere system, VMT offers participants additional resources such as an explicit referencing mechanism, a more generic workspace that allows producing and annotating drawings, and an awareness feature that produces a sense of sequentiality by embedding indicators for drawing actions in the sequence of chat postings. Our case study shows that despite the online situation's lack of the familiar resources of embodied interaction, team members can still achieve a sense of shared access to the meaningful objects displayed in the dual-interaction spaces of the VMT environment. Our analysis indicates that coherence among multiple modalities of an online environment like VMT is achieved through group members' development and application of shared methods for using the features of the system to coordinate their actions in the interface.

Through coordinated use of indexical-referential terms and highlighting actions, team members help each other to literally "see" the objects implicated in the shared visual field (Goodwin 1994) and to encode them with locally specified terminology for subsequent use. They demonstrate how to "read" graphical as well as textual objects through the way the objects are built up sequentially and are spatially arranged in relation to each other through sequences of actions. The deictic references that link chat messages to features of graphical inscriptions and to prior chat content are instrumental in the sequential achievement of indexical symmetry, intersubjectivity, or common ground.

Sequential Analysis of the Joint Organization of Interaction

To sum up, the focus of our ethnomethodological inquiry is directed toward documenting how a virtual team achieved intersubjectivity and coherence among their actions in an online CSCL environment with multiple interaction spaces. We looked at the moment-to-moment details of the practices through which participants organize their chat utterances and whiteboard actions as a coherent whole in interaction—a process that is central to CSCL. We observed that referential practices enacted by the users are essential, particularly in the coordinated use of multimodalities afforded by environments like VMT. The referential uses of available features are instrumental not only in allocating other members' attention to specific parts of the interface where relevant actions are being performed but also in the achievement of reciprocity (intersubjectivity, common ground, shared understanding, group cognition) among actions in the multiple interaction spaces, and hence, a sense of sequential organization across the spaces.

In our case study, we have seen the establishment of an indexical ground of deictic references co-constructed by the group members as an underlying support for the creation and maintenance of their joint problem space. We have seen that nexus of references created interactionally as group members propose, question, repair, respond, illustrate, make visible, supply symbols, name, and so forth. In the VMT dual-media environment, the differential persistence, visibility, and mutability of the media are consequential for the interaction. Group members develop methods of coordinating chat and drawing activities to combine visual and conceptual reasoning by the group and to co-construct and maintain an evolving shared indexical ground of their discourse.

In this paper, we have reconceptualized the problem of common ground from an issue of sharing mental representations to a practical matter of being able to jointly relate semiotic objects to their indexed referents. The references do not reside in the minds of particular actors, but have been crafted into the presentation of the chat postings and drawing inscriptions through the details of wording and sequential presentation. The references are present in the data as affordances for *understanding* by group participants as well as by analysts (Stahl, 2006, chap. 17). The *meaning* is there in the visual presentation of the communication objects and in the network of interrelated references (Stahl, 2007), rather than in mental representations of them. The understanding of the references is a matter of normally tacit social practice, rather than of rationalist explicit deduction. The references can be explicated by analysis, but only if the structure of sequentiality and indexicality is preserved in the data analysis and only if the skill of situated human understanding is applied.

In our case study of an 18-min excerpt taken from a four hour group chat, three students construct a diagram of lines, triangles, and hexagons; propose a math pattern problem; analyze the structure of their diagram; and derive an algebraic formula to solve their problem. They propose their own creative problem about mathematical properties; gradually construct a complex mathematical object; explore related patterns with visual, narrative, and symbolic means; express wonder; gain mathematical insight; and appreciate their achievement. They do this by coordinating their whiteboard and chat activities in a synchronous online environment. Their accomplishment is precisely the kind of educational math experience recommended by mathematicians (Livingston, 2006; Lockhart, 2008; Moss & Beatty, 2006). It was not a mental achievement of an individual, but a group accomplishment carried out in computer-supported discourse. By analyzing the sequentiality and indexicality of their interactions, we explicated several mechanisms of the group cognition by which the students coordinated the group meaning of their discourse and maintained an effective joint problem space.

The coordination of visual and textual realizations of the mathematical objects that the students co-construct provides a grounding of the algebraic formulas the students jointly derive using the line drawings that they inspect visually together. As the students individualize this experience of group cognition, they can develop the deep understanding of mathematical phenomena that comes from seeing the connections among multiple realizations (Sfard, 2008; Stahl, 2008). Our case study does not by any means predict that all students can accomplish similar results under specific conditions, but merely demonstrates that such group cognition is possible within a synchronous CSCL setting and that a fine-grained sequential analysis of interaction can study how it is collaboratively accomplished.

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Investigation 13. The Singapore Experience: Synergy of National Policy, Classroom Practice, and Design Research

Chee-Kit Looi, Hyo-Jeong So, Yancy Toh, and Wenli Chen

Abstract

In recent years, there has been a proliferation of research findings on CSCL at the micro- and macro-levels, but few compelling examples of how CSCL research has impacted actual classroom practices at the meso-level have emerged. This paper critically examines the impact of adopting a systemic approach to innovative education reforms at the macro-, meso-, and micro-levels in Singapore. It presents the case for adopting design research as a methodology for CSCL integration that meets the needs of schools and discusses a specific CSCL innovation that holds the potential for sustaining transformation in classroom practices. Our driving question is: In what ways can the routine use of CSCL practices in the classroom be supported by exploring systemic factors in the school setting through design research? We will explore the synergistic conditions that led to meaningful impact (at the micro-level), mediated by systemic approaches to working with teachers in the schools (at the meso-level), guided by Singapore's strategic planning for scalability (at the macro-level).

Keywords

CSCL practices · CSCL impact · Sustainability and scaling · School-based CSCL · Design-based research

> Decades of funded study that have resulted in many exciting programs and advances have not resulted in pervasive, accepted, sustainable, large-scale improvements in actual classroom practice, in a critical mass of effective models for educational improvement, or in supportive interplay among researchers, schools, families, employers, and communities. (Sabelli & Dede, 2001)

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C.-K. Looi (✉) · H.-J. So · Y. Toh · W. Chen
Chen National Institute of Education,
Singapore, Singapore
e-mail: cheekit.looi@nie.edu.sg

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Introduction

With the realization of the immense challenges of putting real transformations of educational paradigms into practice, this quote made almost a decade ago still seems pertinent. Research supported by individual grants to researchers has produced interesting ideas and small-scale proofs of concept. However, when one thinks about transforming school systems, one sees that the practical tools are fragmentary and scattered. Putting together a coherent classroom program requires work that has not yet been done. This work includes surveying what is available and adapting it to local conditions; setting up infrastructure, carrying out the missing research, adopting long-term approaches to training, and supporting teachers; and effecting a cultural change of public expectations, understandings, and attitudes. These require massive funding for resources such as coordinated research, infrastructure, administrative support, training, teacher time for mentoring, and textbook materials (G. Stahl, personal communication 2009). The growing concern about the disconnect between education research—in particular educational technology research and classroom practice (Lagemann, 2000; National Research Council, 2002)—is still a looming challenge.

To surmount the above challenges, policymakers, researchers, and practitioners need to make coordinated efforts when implementing reforms to impact real practices. In Singapore, there exists a combination of strong, explicit top-down directives and bottom-up desire for transforming and improving the educational system. Educational reforms can be actualized through a coherent program that spans the spectrum of many critical dimensions: from exacting top-down policy imperatives to encouraging school ground-up efforts, from translating research to impacting practice, from implementing one classroom project to scaling for more successes, from mere usage to effecting cultural and epistemological shifts of the stakeholders, and from experimenting with technology to providing robust national or district technology infrastructures.

This paper will focus within the spectrum of educational innovations in Singapore with specific examples of CSCL practices in four Singapore schools. While the field of CSCL has matured as a distinctive field of research over the past two decades, much of the published research on CSCL focuses on micro-level interactions. There is little reported research on the examination of classroom implementation issues and impacts of CSCL, especially those that consider multiple dimensions of educational reform. Through elucidating an account of design research, this paper discusses the impact and challenges of implementing a specific CSCL innovation in school contexts. In so doing, we argue for design research as the methodological framework for designing and enacting school-based research which can impact school practices as well as for refining theoretical understandings on how beliefs about the premises of CSCL are shaped and changed in the course of research implementation.

To make our point about the complexity and interplay of multiple dimensions of education reforms more lucid, the research innovations in this paper are discussed from a systemic change perspective that includes the micro-, meso-, and macro-levels of educational systems. This paper briefly reviews the policy imperatives governing Singapore's educational landscape as macro-level factors and the contextualized classroom-based interactions as micro-level factors. By meso-levels, we support the view put forth by Jones, Dirckinck-Holmfeld, and Lindstrom (2006) where they define: "meso is an element of a relational perspective in which the levels are not abstract universal properties but descriptive of the relationships between separable elements of a social setting" (p. 37). In other words, meso-level forces are situated within the encompassing sociocultural environment where learning takes place. Meso-level agencies can be perceived as the "recontextualizers" or "constructors" of pedagogic discourse who de-locate and re-locate discourse, moving it from its original site to a pedagogic site" (Jephcote & Davies, 2004, p 549).

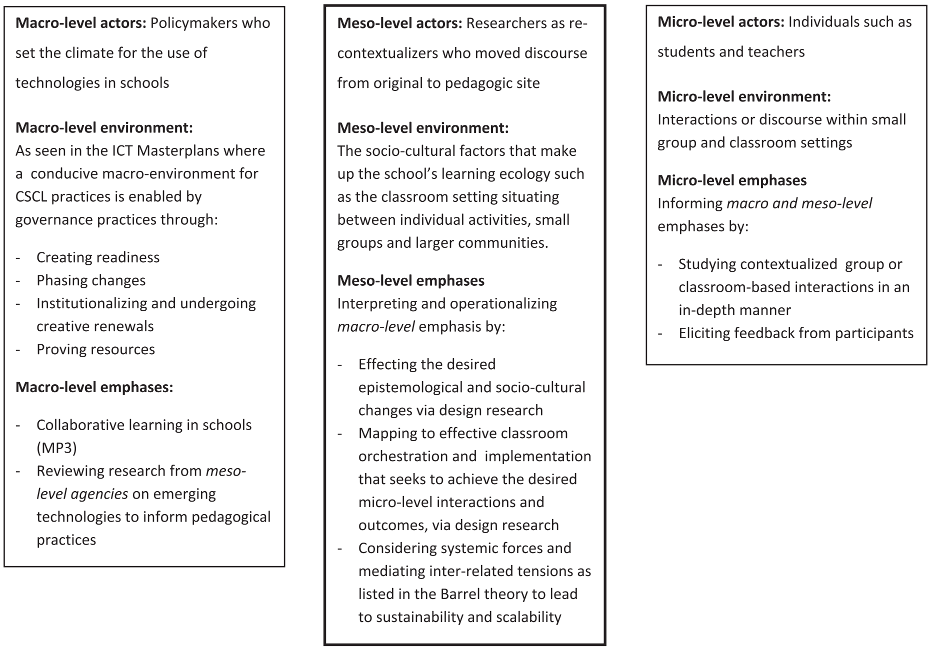

Fig. 13.1 A systemic framework for enabling CSCL practices via the alignment of macro-, meso-, and micro-levels in the Singapore context

We argue that the sociocultural factors of the school's learning ecology constitute the meso-level environment and researchers from university research centers can be interpreted as an example of meso-level actors who work in that environment to re-contextualize pedagogic discourse. This re-contextualization process will be referred to as a "meso-level" mechanism. The seamless orchestration of efforts from all actors will contribute explanatory power to the sustainability of an intervention. Figure 13.1 shows our conceptualization of a systemic framework for enabling CSCL practices via the alignment of macro-, meso- and micro-levels in the Singapore context. By analyzing this pedagogy-driven reform at the macro-, meso- and micro-levels, it is contended that the alignment of systemic forces at work will provide a buttress for sustainability.

The Policy Imperatives in Singapore

Singapore's Systemic Reform Initiatives for ICT Integration

Policymakers worldwide have to perpetually grapple with the "wicked problem" (Rittel & Webber, 1973, p. 161) of understanding the affordances of emerging technologies in order to formulate meaningful directions for pedagogy-driven reforms. In Singapore, there is growing emphasis on student-centered learning in order to prepare citizens for twenty-first-century skills, competencies, and dispositions. These issues are especially important in many Asian school systems, which operate within a more centralized education system and a focus on standardized examinations compared to their Western counterparts. Well known for its academic rigor, Singapore students are constantly ranked by the Trends in International Mathematics and Science (TIMMS) as top performers in mathematics and science (TIMSS, 2007) . The challenge for Singapore now is to continue to excel in traditional assessments while preparing students for twenty-first-century skills with learner-centered approaches. This shift calls for systemic changes to ensure that all components of information and communication technologies (ICT) policies are in line with the cornerstones of the nation's educational philosophy.

As analyzed from a macro perspective, the use of ICT in Singapore schools is pervasive due to the co-evolution of top-down and bottom-up approaches. The top-down approaches accelerated the adoption rate of technology in classrooms. With all stakeholders accepting accountability for implementing constant checks and balances, polices become dynamic in nature so as to reflect the changing needs of the global landscape in a timely fashion. In other words, the interaction among all levels of actors shapes and is shaped by the macro-level governance. Singapore's quest for infusing technology into schools started more than a decade ago, and the current knowledge is a culmination of critical and recursive reviews gathered from different phases of implementation.

The Ministry of Education (MOE) has worked with the schools since the inception of the first ICT Masterplan (MP1) in 1997. This Masterplan provided for the establishment of basic infrastructure and attainment of core competencies by teachers and students alike. A satisfactory outcome of MP1 was that teachers began to accept ICT as an integral tool and resource in their repertoire of teaching practices, which was not the case before MP1. Their willingness to tinker with technology for teaching is reflected in the results of the Second Information Technology in Education Study (SITES 2) conducted by the International Association for the Evaluation of Educational Achievement in 1999, in which Singapore school principals achieved an overwhelmingly positive attitudinal score of 90 on a scale of 100 (Koh & Lee, 2008).

The second Masterplan (MP2) from 2003 to 2008, moved from a teacher-centric pedagogy to a learner-centric pedagogy, and allowed schools to have greater autonomy in utilizing their ICT funds to customize their ICT implementation (Koh & Lee, 2008) . The government recognized the differential pace of the implementation of ICT in the schools and therefore set realistic baseline ICT competencies, which all schools had to achieve while encouraging technology-ready schools to be trailblazers. This resulted in some schools forging ahead in adopting technology-enabled teaching and learning, while some schools still used ICT minimally as part of their repertoire of teaching practices.

Being cognizant of the goals, achievements and gaps of MP1 and MP2, the third IT Masterplan's (MP3, 2009–2014) focal point is to facilitate a greater level of technological integration in curriculum, assessment, and pedagogy so as to equip students with critical competencies, such as self-directed learning and collaboration skills (Ministry of Education Singapore, 2008). Thus, MP3 explicitly foregrounds a specific outcome for technology-enabled learning: to develop students to be collaborative learners. MP3 also recognizes the need to address the curriculum and assessment conundrum in order for technology-enabled pedagogical practices to really take off in schools.

It is the intention of MP3 to create a pervasive culture of innovative ICT practices across all schools and a corps of specialist teachers in every cluster of schools who demonstrate a deep understanding of how ICT can transform teaching and learning both within and outside the classroom. While it is recognized that the use of ICT needs to move in tandem with changes in curriculum, assessment, and pedagogy, the challenge of reconsidering deeply ingrained institutional curriculum and assessment practices at the systemic policy level looms large.

Implications of Systemic Change Perspectives

The preceding sections delineated Singapore's ICT-enabling journey from a macro perspective. One may ask, "What is the strength of Singapore's ecology?" and "What are the critical success factors?" These could be answered by closely examining how the three phases of the ICT Masterplans were planned and enacted from systemic change perspectives. Lessons reported in the literature have attested to looking at technology adoption and integration in the classroom and in schools as part of complex systems of change involving administrative procedures, curriculum, pedagogical practices, teacher knowledge, technical infrastructure, and other logistical and social factors (Chang et al., 1998; Fisher, Dwyer, & Yocam, 1996; Fishman, Pinkard, & Bruce, 1998; Means, 1994; Sandholtz, Ringstaff, & Dwyer, 1997).

In this section, we analyze the policy imperatives in Singapore by focusing on the four major phases of systemic change processes for sustainability at the macro-level. They are (1) creation of readiness, (2) phasing of changes, (3) institutionalization, and (4) ongoing evolution and creative renewal of the policies (Adelman & Taylor, 2003, p 5).

Creating Readiness

In order to establish a climate for transformation, the Singapore government works with meso-level actors such as researchers from the National Institute of Education to identify barriers of integrating ICT into education. Understanding the nature of barriers and identifying strategies to overcome them are important as they provide insights into how to create readiness and change mindsets for successful enculturation. As an example, researchers Lim and Khine (2006) identify barriers that four schools in Singapore faced for ICT integration and discuss strategies employed by schools to overcome such barriers. One of the barriers cited by the teachers in their study is the critical lack of time for preparing and delivering ICT-enhanced lessons as well as some technical problems. Other barriers include teachers' tendency to precipitate traditional modes of teacher-centered teaching. This is due to the coupling effect of time and resource constraints. Teachers also have reservations about sharing their successes and failures of planning and delivering ICT-integrated lessons.

In view of the complexity of the problem, the MOE has taken multi-pronged steps such as re-culturing and building capacity to tackle the challenges. For re-culturing, there are attempts to inculcate the value of student-centered learning during professional development sessions as well as in-service teacher-training programs. Fostering local capacity building will help to enhance the sustainability of innovations. Local capacity-building strategies could include (a) supportive context such as incentives, professional development and information systems, (b) consultation and coaching, and (c) sufficient material and technical resources (Duttweiler, 1995). To ensure that progress is not wrought by technical difficulties, schools are also allowed to hire in-house technical specialists to train teachers on ICT-related issues and to troubleshoot technical problems in the classrooms. MOE also espouses action research in schools to "social market" (Adelman & Taylor, 2003, p21) data for appraising what is worth sustaining and how best to avoid costly mistakes.

Phasing Changes

Adelman and Taylor (2003) argue that the diffusion of innovative projects is often crippled because "the nation's research agenda does not include major initiatives to delineate and test models for widespread replication of school-based innovations" (p21). In Singapore, this is addressed by the government's approach to phase changes and to elicit feedback from all stakeholders. For example, in the MP3 Implementation, 15 schools are slated to be FutureSchools based on their technological and pedagogical readiness. However, the government selected the first five schools and studied them closely before calling for subsequent rounds of application for FutureSchool status. For the island-wide Standard Operating Environment (SOE) project where every school will be endowed with campus-wide wireless connectivity in 2012, the government—together with meso-level actors like system integrators—will implement the program in early 2011 in pilot schools before scaling up to other schools by the end of 2012. This circumspect approach allows for flexibility by policymakers to evaluate and fine-tune policies before jumping onto the bandwagon of innovation.

Institutionalization and Creative Renewal

With a proliferation of ICT related projects, there is a need for the institutionalization of sustainable development, where the concept will be embedded in government operations in the long term. The call for Singapore schools to conduct action research can be perceived as making such an attempt. Schools documented and critically evaluated their projects to make their tacit knowledge explicit. This serves to shorten the learning curves for other schools. In addition, the staggered approach of the three Masterplans is based on the iterative feedback from the previous attempts. The invaluable lessons learnt thus became an institutional memory. We can expect changes of the global landscape to be fast and furious, and it is an imperative for the local system to undergo renewals as well. This can be manifested in areas such as bringing in new stakeholders, revamping professional development programs, upgrading infrastructures, reorganizing structures, as well as creating wholesome environments for social and emotional support.

In sum, the policy imperatives, coupled with efficiency in their implementation at the ground level, serve as a key strength in Singapore's ecology, providing the commitment, funding, resources, and vision to plan for reforms in schools to successfully harness ICT to enable students to learn better. A key strategy in MOE's policy imperative is to support funding for school-based research. To support the IT Masterplan in Education, Singapore's MOE established the Learning Sciences Lab (LSL) in 2005 to advance research on the efficacy of emerging technologies to improve teaching practices (Looi, Hung, Bopry, & Koh, 2004).

Research Supporting the Policy Imperative: The Learning Sciences Lab

One characteristic of technology-enabled learning research in Asian countries is the close partnerships between researchers and practitioner communities like schools. In the praxis of research honed and informed by practice, the research community in Singapore has much to share on the design, development, and evaluation of technology-enabled learning approaches and practices. Researchers in Singapore schools have capitalized on the nexus between research and practice. The Singapore Ministry of Education (MOE) funded the setting up of a Learning Sciences Lab (LSL) at the National Institute of Education (NIE) within Nanyang Technological University (NTU) in 2005 to do research to inform the planning and implementation of the MOE's Masterplan 2 and to conduct research that would help develop technology-enabled pedagogical models and practices. It was MOE's intention that new concepts and methods of ICT-infused pedagogy need to be prototyped, tested, and transferred to classrooms and schools. LSL plays a role as the meso-level conduit that "provide(s) a means to re-interpret macro-level changes and to access the range of new choices that they present to subject factions and associations" (Jephcote & Davies, 2004, p. 549). The LSL is positioned to strengthen MOE's capacity to undertake active research programs on the use of ICT in education as well as to expose school leaders and teachers to workable models and prototypes in order to transform their mindsets toward learning.

Realizing the enormous challenges of changing traditional pedagogical mindsets in schools, LSL has the long-term view of deriving design principles that are scalable and sustainable. In the more immediate term, it aims to develop point-at-able examples through working with partner schools on practical school-based problems. By point-at-able examples, we mean demonstrable models of educational practice that policymakers, school leaders, and teachers can look toward as models of what is desired. The models also point to possible outcomes arising from the research, and the implementation trajectories and challenges that might be faced when adopting these practices. The addressing of the school-based problems needs to be translated into research goals and questions. Within each of these questions, key learning theories are to be improved upon based on the research. If the research project is interventionist in orientation, design principles and factors or conditions needed for the innovation have to be documented and explained.

Remaining Issues: How to Impact CSCL Practices in School

Meso-Level Issues

With background information about synergizing policy and research initiatives in Singapore, now we turn our focus specifically to the CSCL community. For the past two decades, CSCL has emerged as a distinctive field of research grounded on multiple theoretical perspectives of unpacking processes of collaborative meaning-making practices supported by computer technologies. In addressing the need to impact school practices, the CSCL research community has made a great advancement for theoretical understanding of the micro-level of collaborative-learning aspects in small-group settings under specific local conditions. The idea of combining computer and collaboration to enhance learning experiences, however, is often viewed as a challenge in school contexts (Stahl, Koschmann, & Suthers, 2006). We argue that one of the core challenges in the CSCL community currently is how to influence practices beyond small-group cognition under highly contextualized conditions, and this issue necessarily requires more CSCL research looking closely into the complex interplay and enactment of multiple dimensions at the meso-level of collaborative learning. By focusing on the interaction within small groups and larger cultural practices as separate entities, it is easy to miss the very mechanisms happening at the intermediate level, that is, the classroom setting situated between individual activities, small groups, and larger communities.

Here, the emphasis on meso-level interaction involves viewing a class and school as an ecological system with the potential to change. Within this view, classroom structure and culture for social interaction are no longer fixed but can be designed and adapted with careful consideration of multiple dimensions such as cultural beliefs, practices, socio-techno-spatial relations, and interaction with the outside world (Bielaczyc, 2006). Recently, Dillenbourg (2009) further substantiates this meso-level view by arguing the need for conducting more CSCL research on "design for orchestration," especially in terms of gaining a better understanding of the supporting and constraining conditions for the effective use of CSCL tools and practices. What underlies this notion of design for orchestration is the need to "empower teachers," and this starts from enabling deeper understanding of the fundamental challenges and issues that teachers are facing with CSCL ideas, tools, and practices. The effective adoption and enactment of CSCL approaches and tools in a classroom require the teacher to be an "orchestrator." Teachers innovate in the classroom by orchestrating activities in an environment plagued by multiple constraints such as the need to attend to classroom management problems, adhere to curriculum requirements, consider appropriate assessment modes, work within tight schedules, design lessons that are compatible with students' learning spaces, and ensure that safety standards are met (Dillenbourg, 2009).

Indeed, CSCL researchers who attempt to impact collaborative-learning practices in school often face cultural and epistemological challenges to transform classroom cultures. Dominant cultures in classrooms are still teacher-centric and individual-performance based, and collaborative-learning practices are not naturally cultivated with the mediation of CSCL technologies alone. This issue is even more prevalent and important in Asian countries than in Western countries, since much of the Asian school-assessment culture is based on individual performance, competitive assessment, and ability-based grouping.

A culture of social practices for collaborative meaning making has to be enculturated, and teachers play critical roles in orchestrating such endeavors during this enculturation process. Our interaction and conversation with Singapore teachers, however, shows that they tend to hold deep concerns and doubts about pedagogical approaches promoting greater student agency and social interaction and about whether such pedagogical approaches would work for academically lower-achieving students.

Scaling Up CSCL Practices and Empowering Teachers

In Singapore, the term "collaborative learning" has appeared more frequently in the discourse of teachers, school leaders, and stakeholders due to the explicit emphasis listed on the government's reform agenda. Formal and informal structures are in place to support teachers to translate their pedagogical beliefs and knowledge of CSCL into actual practices. We have seen more cases of students participating and engaging in various CSCL activities in class and online. In sum, we believe that conditions for impacting schools with scalable CSCL practices are more conducive than ever.

By impacting schools with scalable practices, we are talking about the complex interrelationship among teachers, school culture, leadership, and educational policies. Coburn (2003) defined scale as encompassing four interrelated dimensions: *depth, sustainability, spread* and *shift in reform ownership*. Depth refers to deep and consequential change in classroom practice, altering teachers' beliefs, norms of social interaction, and pedagogical principles as enacted in the curriculum. Sustainability involves maintaining these consequential changes over substantial periods of time, while spread is based on the diffusion of the innovation to large numbers of classrooms and schools. Shift requires districts, schools, and teachers to assume ownership of the innovation, deepening, sustaining, and spreading its impact. Building on this work, Clarke and Dede (2009) added a fifth dimension, namely, evolution, in which the innovation, as revised by its adapters, is influential in reshaping the thinking of its designers and creating a community of practice that evolves the innovation.

Embracing the ideas of meso-level interaction and design for orchestration aforementioned, we revisit the issue of empowering teachers in terms of the two inter-related dimensions of scale by Coburn (2003), which are *depth of change* and *sustainability*. Lessons learned from prior technology-based educational improvement research clearly indicate the importance of empowering teachers and building capacity to effect deeper changes in teachers' beliefs, knowledge, and practices (Fishman, 2005). Deep changes go beyond the superficial piecemeal changes in structures and procedures but work toward integrated changes in beliefs, norms of social interaction, and pedagogical approaches enacted in teaching and learning practices (Coburn, 2003). Teachers are more likely to embrace and

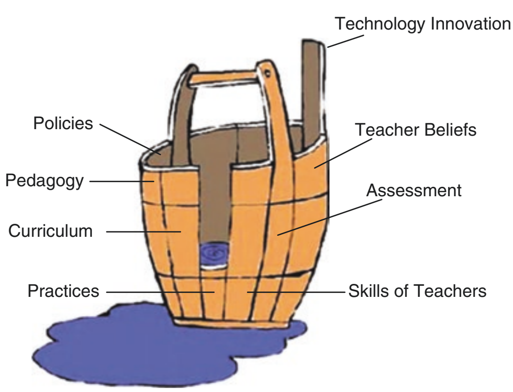

Fig. 13.2 The barrel theory

practice CSCL when they can see the connection between the use of technology, the learning needs of their students, and the content of the mandated curriculum.

Another central element of scale is sustainability where changes are sequential and sustained *over time.* So far, we have seen some successful stories of CSCL research, but little is known about whether such successful practices have been sustained over time after an initial influx of resources and other forms of external support. We believe that more research documenting "implementation paths" (Bielaczyc, 2006) and "essential tensions" (Barab, Barnett, & Squire, 2002) in the trajectory of adopting CSCL practices in classrooms are necessary. For sustained changes, we would reemphasize the importance of meso-level mechanisms that support teacher capacity building and reinforce school leadership and culture.

In re-conceptualizing scalable and sustainable CSCL practices, we argue that we need to take a design-based research approach in school-based work to address complex problems in real classroom contexts in collaboration with practitioners and to integrate design principles with technological affordances to render plausible solutions. We use a Chinese proverb of the barrel metaphor (木桶原理) to represent why we need to adopt a comprehensive systemic perspective when a school adopts an innovation. The wooden-barrel theory states that the capacity of a barrel is determined not by the longest wooden bar or plank but by the shortest (Fig. 13.2). As researchers, we tend to focus on just one or a couple of planks, but that creates a challenge for impacting practice. We extend the barrel theory to say that the capacity of a barrel is also determined by the seams or the lack of seams between planks, meaning that we need alignment of neighboring planks. Taking an intervention that is developed in the laboratory and supplanting it in school is least likely to work. Therefore, we need design research that entails working with stakeholders to help address their problems and not just focus on the planks that are of research interest. We also need to adopt design research on a systemic scale to align the planks (e.g., between curriculum, practices, and assessment as in Fig. 13.2), to look after the edges of the barrel, so to speak.

The goal of design research is to conduct rigorous and reflective inquiry to test and refine innovative learning environments as well as to refine new learning design principles (Brown, 1992; Collins, 1992). Design-based research is iterative as researchers relentlessly strive to engage in design, work with teachers to enact the design in classroom settings, research on the contextualized learning processes, develop or refine theories of learning, engage in re-design, and continue the cycle of design and implementation. Design research is also characterized as being interventionist, iterative, process-oriented, utility-oriented, and theory-oriented (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006).

Example of School-Based CSCL Research from a Design-Research Perspective

In this and the next few sections, we would like to describe an example of a LSL project that has the potential to be part of a sustainable transformation of classrooms into an environment that is conducive for collaborative learning. We will contextualize the design-based approach of the 3-year GroupScribbles (GS) project in Singapore and present its uniqueness in an Asian school context.

Interventionist Strategies

The Singapore GS project is about bringing technology into classrooms to serve as a catalyst for introducing collaborative group work. As in most traditional classrooms reported in the literature

(Mehan, 1979; Nassaji & Wells, 2000; Wells, 1999), the typical discourse interaction in the Singapore classroom is the IRE (initiation-response-evaluation) pattern (Lossman & So, 2010). In the IRE, a teacher initiation (I) is followed by a student reply (R) and then by the teacher's evaluation of this reply (E). IRE has been criticized for leading to unrewarding and boring classroom discussions. Most of the epistemic agency rests on the teacher: a student's primary, active, role is to respond. Changing such deep-seated traditional patterns of classroom discourse poses a considerable degree of challenge for educators. One of the objectives of the intervention is "empowering teachers" to be innovative in changing the traditional teacher-centered discourse patterns with CSCL ideas, tools, and practices.

Context of Intervention

In recent years, interactive technologies have been designed to support active classroom participation by harnessing the collective intelligence inherent in the classroom. One of the technologies is GroupScribbles (GS) 2.0 co-developed by SRI International and the National Institute of Education, Singapore. GS enables collaborative generation, collection, and aggregation of ideas through a shared space based upon individual effort and social sharing of notes in graphical and textual form (SRI International 2006; please refer also to http://gs.lsl.nie.edu.sg). The GS interface consists of a multi-pane window. The default configuration consists of two panes, a lower pane and an upper pane, but the user can slide in more panes as desired. The lower pane is usually the private board, or the user's personal work area, with a virtual pad of fresh "Scribble Sheets" or notes on which the user can draw or type. The upper pane is usually a public board or group board, into which users can post their Scribble Sheets, position them relative to other Scribble Sheets, and take items back to the private

Fig. 13.3 A Morae screenshot of the GS public and private boards

board for amendments or elaboration. When any Scribble Sheet is posted, moved, or updated by a student, other students can see the effect almost immediately. On each pane, there is a drop-down menu to allow users to switch to other boards. Students post anonymously so as to freely express their ideas.

GroupScribbles is designed to be lightweight, flexible, customizable, and content independent so that activity design can be easily improvised by teachers for collaboration. It attempts to maximize the power of digital scribbling and interactive engagement, so that teachers can improvise different patterns of collaborative activities for students without the need for additional software programming (Chaudhury et al., 2006; Roschelle et al., 2007). GS enables students to get acquainted with an important twenty-first-century skill—Rapid Collaborative Knowledge Improvement (RCKI). RCKI seeks to harness the collective intelligence of groups to learn faster, envision new possibilities, and reveal latent knowledge. Its techniques include problem identification, brainstorming, prioritizing, concept mapping, and action planning (diGiano, Tatar, & Kireyev, 2006; Looi, Chen, & Patton, 2010). Figure 13.3 shows a screenshot of the GS technology.

Creating Readiness

We designed an intervention framework that articulates the RCKI principles for designing lessons (which will be discussed in next section) and activities that tap the affordances of GS. We postulated a logic model that links these principles and other contextual factors to the processes and outcomes of RCKI (Looi, Chen, & Patton, 2010). Our research explores the participation and discourse patterns in a GS class that seeks to harness collective intelligence. The enactment of RCKI principles in classroom discourse can support students in the GS class to generate more diverse ideas and to build on and refine each others' ideas. In early cycles of the intervention as enacted in classroom implementation, we have focused on understanding the classroom and school culture, co-designing of the GS lesson activities, integrating the tool into holistic lesson plans, conducting teacher profes-

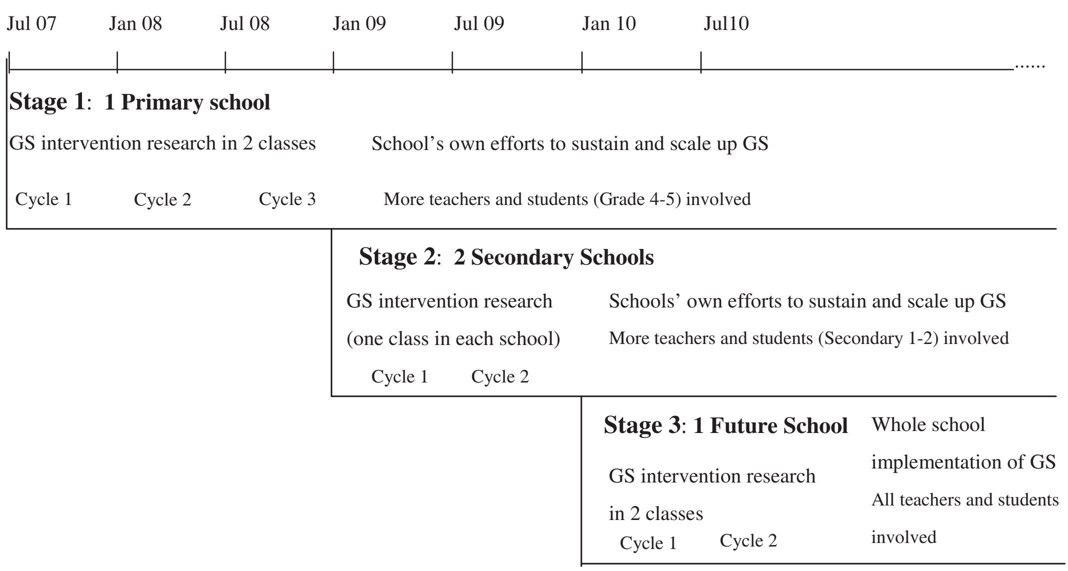

Fig. 13.4 Progress of school-based research

Fig. 13.5 Small group work using GS in the classroom

Fig. 13.6 Different collaboration patterns in the classroom: a student presenting to others in the group

Fig. 13.7 Different collaboration patterns in the classroom: a group of students presenting their group work to the whole class

Fig. 13.8 Small group work with GS interleaved with actual science experimentation

sional development, fixing technical problems that impede the smooth running of the technology, as well as informing the design of the new version of GS.

Our school-based research with GS interventions consisted of three stages which are implemented across different scales based on school conditions: (1) GS in two classes at one primary school (School M), (2) GS in two classes at two secondary schools (School F and W), respectively, and (3) GS in a secondary School (School S) which uses ICT intensively and plans to have a whole-school GS adoption in a two-year time frame. Figure 13.4 shows the progress of our school-based research with GS interventions.

Within each stage of research in each of the schools, there was more than one cycle of GS implementation. Basically the intervention approaches are similar across the three stages. Next, we will describe the details of the primary school intervention to illustrate our design-based research. The first stage of our intervention work involved a primary (elementary) school (School M). Participants included students and science teachers from two Primary 4 classes, one of which is a high ability class led by a senior female teacher called Jeanette who had good pedagogical knowledge but limited ICT expertise and the other a mixed ability class led by a young female teacher called Janet who had less experience in teaching but was confident in the use of ICT. Each class has 40 students. We followed this cohort of students for 2 years as they progressed from Primary 4 to Primary 6, by working with the teachers to design and enact science lessons using GS routinely. Figures 13.5, 13.6, 13.7, and 8 show the different configurations of collaboration patterns that were enabled by GS in these two classes. We will next describe the process of our design-based research.

Before the first cycle of the intervention work, the researchers observed the classes for a few sessions and interviewed the school leaders and teachers to understand the students better. We found that the school leaders and teachers realized the importance of integrating ICT to support students' collaborative learning, but they lacked the pedagogical knowledge and technological skills to make it happen. The teachers believed that examination scores were the most important indicator of students' learning, and they hoped to see the students achieve higher examination scores after the integration of CSCL technologies in classroom learning. Some of the teachers had some misunderstanding of collaborative learning—they considered all group work as "collaborative learning" though some group work was not collaborative at all. In most of the classes we observed, there was a jarring lack of a collaborative learning culture. Sometimes students did group work by dividing the work and completing their individual part, and there was no interdependence among students. We found that the use of ICT in the classroom was still teacher-directed rather than student-centered. In most lessons, teachers used PowerPoint presentations to teach the students. The researchers decided to unpack the problems

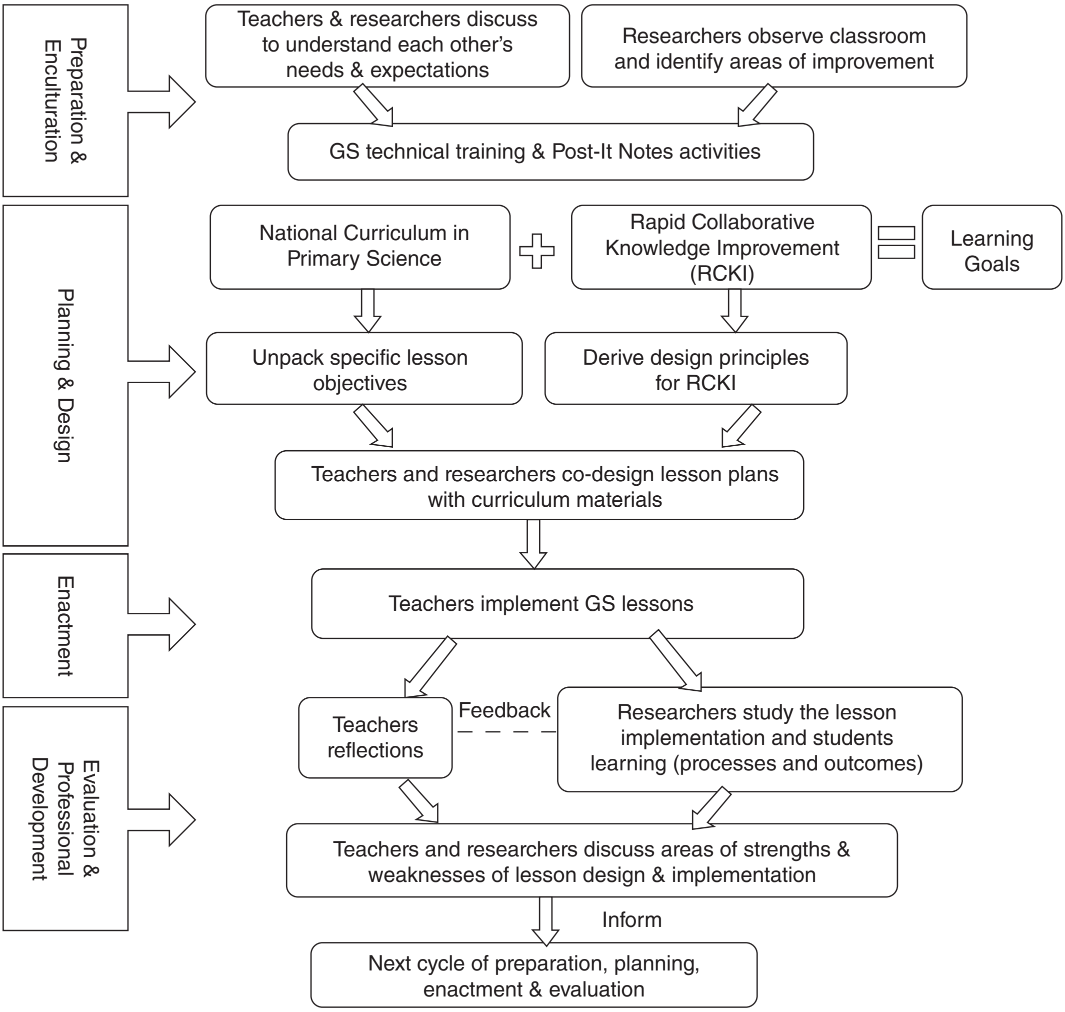

Fig. 13.9 Research intervention framework (one cycle)

Fig. 13.10 A enculturation activity in the classroom

and to address them step by step. This marks the start of the first cycle of intervention. Figure 13.9 shows the process of our first cycle of intervention:

Cycle 1

Before introducing GS to the class, the researchers and teachers had a few rounds of discussions to understand each other's needs and expectations. The researchers provided teachers with technical training on GS technologies and pedagogical training on RCKI theory and principles. The teachers shared with the researchers the context of the classroom culture, the students' + background, their learning performance, and the schools' previous curriculum design and specific lesson objectives. With the realization that both teachers and students lacked the expertise to facilitate collaborative learning, the researchers and teachers co-designed 6 weeks (1.5 h each week) of collaborative learning activities by using Post-it notes (we called it Paper Scribbles) to enculturate the teachers and the students to use rapid collaborative brain-storming and critiquing with the relevant protocols and social etiquettes. We felt that the classroom culture that engenders group collaboration, mutual engagement, problem-solving, and knowledge sharing should remain the same regardless of the technology used. In Paper Scribbles, easy-to-use sticky notes were adopted so that students could contribute their ideas and participate in the activities facilitated by the teacher. For example, they used a set of 3 × 5 inch Post-It® notes to guess animals based on characteristics given by each student, to post the names of organs in the human digestive system, to post different living organisms in a particular habitat, and to classify fruits according to different characteristics. They used sticky notes to comment on each other's postings as well. Students worked in groups of four, in a face-to-face manner. They first posted sticky notes on A4 size magnetic boards ("group boards") and put them on the class whiteboard for other groups to see (Fig. 13.10). Sometimes the teachers projected the group boards onto a large screen for whole class viewing. At the end of the enculturation activities, the teachers and students were more conformable and confident with collaborative learning activities. Through this process, the students set the ground rules for themselves when doing collaborative learning activities, such as "do not post for the sake of posting," "respect each other's ideas", and "critique others' ideas in a polite way."

Subsequently, the classes were provided GS software and user training for two 1-hour sessions followed by the routine use of GS technology for 10 weeks. Each week they had a 1-hour GS science lesson in the computer laboratory and a 1-hour traditional science lesson (non-GS) in the classroom. In the GS lessons, each student was equipped with a Tablet-PC (TPC) with GS client software installed. The GS lesson was implemented in learning situations where students used it to learn science topics in the standardized syllabus for the Primary grade 4 curriculum—the circulatory system, energy, light, and heat. The GS activities were co-designed by the researchers and the teachers to achieve specific objectives according to the curriculum syllabus. The lessons were designed not for the convenience of research but were integrated tightly with the science-curriculum topics. Thus, the focus of Cycle 1 is enculturation of the students and teachers. To enhance accountability, the teachers and stakeholders co-designed the lessons, and students were given autonomy to set their own protocols for GS activities.

Cycle 2

Scaling Up by Achieving "Spread"

After the first half-year of our intervention on science lessons (Cycle 1), we sought greater depth of the innovation by continuing GS lessons for the science subject and expanding the subject areas to mathematics (taught by the same two science teachers) and Chinese language (CL, taught by two Chinese language teachers) and working with the same classes (Cycle 2). By intensifying the usage of the GS technologies and the pedagogical practices enabled thereof, the students were given more time to develop into a community of collaborators well seeped in rapid knowledge-improvement practices across the curricula. At the end of the first year (two cycles) of school-based research with this primary school, we have developed a set of design principles for RCKI (e.g., distributed cognition, volunteerism, spontaneous participation, etc.) and curricular products for three subjects.

Cycle 3

Scaling Up by Achieving "Depth"

By the end of the second cycle of GS intervention, the students were going to be grade 6 students, who would be taking the national Primary School Leaving Examination (PSLE). The researcher felt that students had made great progress in RCKI—they were able to think actively, articulate ideas within groups better, and critique other groups' work constructively. However, the class had yet to evolve into a mature community that did RCKI in a sustained manner. So after getting approval from the school leader, we implemented another cycle of GS intervention when the students were at Primary 6. In this cycle, we took a more holistic view to design the GS lessons. Rather than designing a separate lesson based on individual lesson objectives and a particular collaborative pattern, we designed a series of GS lessons that allow students to engage in RCKI continuously with different collaborative patterns such as the jigsaw cooperative pattern. Thus our longitudinal work with this same class of students has allowed us to try variations in collaborative pattern design that should make the GS innovation adoptable and adaptable. At the end of the third cycle, the students had been doing more than 60 GS-based RCKI lessons and were able to form a knowledge-creation community that helped each other learn better collectively.

Scaling Up by Achieving Sustainability, Spread, and "Shift" in Ownership

After the end of the research cycle, the school (School M) started to sustain and scale up the GS work on its own accord by identifying key GS teachers to be the pioneers to conduct professional development for other teachers. It installed GS in one more computer laboratory so that more than one class can have GS lessons concurrently. The school adopted GS as the ICT tool in a 2-year school initiative code-named MAPLE (Mayflower Primary Literacy Excellence Program), which aimed to help students' literacy during their English lessons. In this way, GS was spread to five classes of Primary 3 students, with Jeanette appointed as the advisor for the use of GS as a tool in this project. For the Primary 4 and 5 levels, GS was adopted in one of the ICT modules in their science lessons (i.e., one module would use a few lessons using GS in their science curriculum for every class).

In terms of the shift in ownership, the school helped other schools adopt the GS innovation. The teachers shared their GS experiences with other school leaders of the same school zone. They demonstrated how they used GS for student collaborative learning in various educational events organized by MOE. Some teachers did action research on GS and shared the findings in different education conferences held in Singapore. This school also helped other schools that were interested in GS to set up the necessary GS infrastructure and to conduct teacher training. In January 2010, the research team and the school conducted a GS workshop for 30 teachers from more than 10 Singapore schools. The teachers shared their experiences and challenges of using GS for teaching and learning. Subsequently, six other schools decided to use GS for teaching and learning with the help of the Educational Technology Division of MOE.

Iteration of Design Principles

Ongoing Evaluation and Creative Renewals

In our initial efforts to co-design instructional activities with the teachers, we sought to incorporate the following ten principles of Rapid Collaborative-Knowledge Improvement (Looi, Chen, & Ng, 2010), of which the latter five were adapted from Scardamalia (2002):

1. Distributed cognition—designing for thinking to be distributed across people, tools and artifacts
2. Volunteerism—letting learners choose what piece of the activity they want to participate in
3. Spontaneous participation—designing for quick, lightweight interaction driven by students themselves
4. Multimodal expression—accommodating different modes of expression for different students
5. Higher-order thinking—encouraging skills like analysis, synthesis, evaluation, sorting, and categorizing
6. Improvable ideas—providing a conducive environment where ideas can be critiqued and improved
7. Idea diversity—exploring ideas and related/contrasting ideas, encouraging different ideas
8. Epistemic agency—encouraging students to take responsibility for their own and one another's learning
9. Democratizing knowledge—everybody participates and is a legitimate contributor to knowledge
10. Symmetric knowledge advancement—expertise is distributed and advanced via mutual exchanges

Through the process of incorporating these principles into the real classroom lessons, we sought feedback and reflections from the practitioners and learnt the challenges that they faced in the classroom in enacting these principles. One challenge concerned the overlapping of concepts in some of the principles. Another was that the teachers had difficulty in understanding the real meaning and application of these principles. Therefore, we condensed these principles into six simpler guidelines, which teachers can more readily understand and enact:

1. Make everybody think, as individuals and in teams.
2. The class accepts new ideas and constantly improves ideas.
3. Explore many ideas and from different angles.
4. Students take initiative for their own learning.
5. Everybody participates actively and contributes knowledge.
6. Students organize their ideas and are self-reflective.

The researcher and teachers discussed these principles together and "prioritized" the principles based on students' experiences, skills, and ability. For example, the teachers felt that principles such as "everybody participates actively and contributes knowledge" (principle 5) and "make everybody think" (principle 1) were easier to achieve, so we designed and implemented the subsequent GS lessons using these principles. Once students were able to think and participate class discussions actively, we designed and implemented GS activities that required students to organize ideas (principle 6) to explore and critique different ideas (principle 3) and to constantly improve ideas (principle 2), in this order. At the end of doing all these collaborative activities, students can take the initiative for their own learning (principle 4). With that, we were able to help teachers derive a better understanding of the gist of these guidelines. They were better enabled to design collaborative learning activities by drawing on the connections between these guidelines and the key affordances of GS.

Designing Curricular Products

Shared Accountability with Meso-Level Actors

Our curricular products consist of the lesson plans co-developed by the teachers and the research team. After the prior technical training and briefing on the use of GS, the teachers had a general idea of the affordances of GS. With some understanding of teachers' need to cover the syllabus content, we asked the teachers to draft the lesson plans with the lesson objectives they wanted to achieve, together with their ideas of using GS. The teachers drafted their lesson plans a week ahead of time and shared them with the research team through email or a shared portal. Some teachers would share their teaching presentation slides and images/templates of the public GS boards (these templates were used as platforms to facilitate the students in collaborating with one another). After analyzing the lesson plans and their respective teaching resources from the perspective of the GS principles, the researchers provided feedback to the teachers on how to re-design the lesson plans.

Immediately after the GS lessons, post-lesson feedback sessions were held. Many teachers provided feedback that they found the support from the researchers in guiding them to reflect on effective ways of carrying out collaborative work using GS to be very valuable. Through these dialogue sessions held on a regular weekly basis, the teachers were able to adapt and be open about adopting a student-centered learning culture. The following key changes were observed in the curricular products when the teachers participated in their co-design and subsequent improvement:

1. They were able to facilitate collaborative work with their designs of scaffolds (e.g., tables and mind maps) in the GS public boards.
2. They were able to give guidelines for students to provide constructive peer comments to each other's work.
3. They were more open and even able to design activities for inter-group interaction or collaboration such as patterns involving competition and jigsaw.

Professional Development of the Teachers

Capacity Building

A key aspect of our design-based research work is the close working relationships we have had with the teachers of the participating schools. Weekly meetings were held before the lesson implementations to discuss the design of the lesson plans. Researchers would observe the enactment of the lesson in class. They would also provide technical support to facilitate the smooth running of the technology as well as to fix technical problems, if any. After the lessons, the teachers and researchers met to share reflections on the lesson, focusing on the efficacy of the lesson implementation.

We studied developmental trajectories of teachers as they integrated GS technology in their classroom lessons over the period of about one academic semester (half a year) for some teachers and two or three academic semesters for other teachers. From the perspective of coherence diagrams for analyzing teachers' developmental trajectories in integrating GS technology (Chen, Looi, & Tan, 2010), the coherence between a teacher's beliefs, goals, and knowledge and the affordances of the technology is the main key in leveraging the technology successfully. Coherence diagrams capture the com-

Table 13.1 Stages of design research on GS

	Design principles	Curricular products	Technology development	Professional development	Spread of innovation
July-Oct 2007	Derived 10 RCKI principles; Organized class into groups of four and designed group boards accordingly to manage complexity	GS lessons for P4 science	Limitations of GS 1.0 were encountered; these informed the design of GS 2.0	Two P4 science teachers were trained; their lessons were observed; post-lesson PD sessions were held	Two classes from school M used GS for one subject
Jan-May 2008'	Use of 10 principles to design lessons; Uptake analysis used as framework for community-based individual knowledge building Looi and Chen (2010); Better understanding of affordances of F2F vs online collaboration Chen et al. (2010)	GS lessons for P5 science, mathematics and Chinese language (CL); a wider repertoire of pedagogical patterns used	GS 2.0 (beta) deployed but several performance issues were encountered; these informed the next design of GS	The same teachers were supported to design and enact GS activities in mathematics. Additionally, 2 CL teachers were trained	Same classes and teachers from school M continued their use of GS for the three subjects
		GS lessons for P5 science and CL	A more robust GS 2.0 version was deployed; the analysis of large amounts of classroom interaction data motivated the design of the analytical tool in GS	Continuous PD for the participating teachers	Same classes and teachers from school M continued their use of GS for two subjects
July-Oct 2008	10 principles were too challenging for teachers to apply, so they were rationalized into six principles				
	Logic models were developed to explain how each principle works Looi, Chen, and Patton (2010)				
Jan-Mar 2009	Designed principles for sustaining classroom community	More pedagogical patterns experimented such as the cooperative jigsaw pattern	GS 2.0 with activity management is deployed	School M identified key GS teachers to be the pioneers to conduct PD for other teachers; Researchers conducted PD for teachers in two secondary schools (W & F)	Same classes from school M continued the use of GS School M helped other schools adopt the GS innovation; their teachers did action research on GS GS research scale up to two secondary schools W & F) in three subjects

(continued)

Table 13.1 (continued)

	Design principles	Curricular products	Technology development	Professional development	Spread of innovation
April-Oct 2009	Use of classroom data to study the RCKI principles helped sharpen understanding of the principles and conditions for their use	More diverse pedagogical patterns for secondary science, math and CL were designed	Wireless connectivity worked in one of the secondary schools; analytical tool used to view interaction data; technical challenges for schools to install GS 2.0; this motivates the design of GS live and GS Mobile	Continued PD sessions for teachers	Same classes and teachers from three schools continued the use of GS Primary school M scaled to more classes and continued their sharing and helped other schools Secondary school F used GS for Chinese language learning and math (two classes) Secondary school W used GS for Chinese language learning and science (two classes).
Jan-Dec 2010	Explored GS collaborative patterns further for language learning, sharpening RCKI principles and conditions for language learning	More pedagogical patterns for language learning designed and deployed	GS in 1:1 Macbook with wireless network environment, refine GS2.0, analytic tool and activity management, developing GS live	Researchers and the teachers from three schools conducted two workshops for teachers from 20 schools in Singapore; researchers conducted PD for English and Chinese language teachers in school S	Same classes from 3 schools continued The 2 secondary schools started their own scalability journey on GS A team from MOE's educational technology division worked with six other schools in Singapore on using GS for collaborative learning

plex interplay of a teacher's knowledge (K), goals (G), and beliefs (B) in leveraging technology effectively in the classroom. The transition between each state of the coherence diagrams is nonlinear, implying the importance of ensuring high coherence right at the initiation stage. Support for the teacher, either from other teachers or researchers, remains an important factor in developing the teacher's competency to leverage the technology successfully. The stability of the KGB region further ensures smooth progress in the teacher's effective integration of technology in the classroom.

Achieving Sustainability by Ensuring Coherence

The degree of coherence between the teacher's knowledge, goals, and beliefs and the affordances of the technology provide an indication of the teacher's developmental progression through the initiation, implementation, and maturation phases of using technology in the classroom. Our analysis of three teachers' trajectories suggests that initial high coherence in a teacher's KGB region and having students who have already been enculturated with the technology-enabled pedagogies accelerate upward developmental trajectories in integrating technology in the classroom. Support from researchers, albeit an important factor, is secondary when compared with a teacher's KGB region.

Table 13.1 summarizes the stages of our design research process and the outcomes of each stage that concerns design principles, curricular products, professional development, and theory refinement.

Innovation Is Utility-Oriented

Our narrative of the design research with the three schools demonstrates to some extent acceptance of the intervention by most of the teachers and by the schools. Phillips (2006) characterizes these main purposes of a piece of design research:

1. To contribute to an understanding of the design process itself
2. To throw light on some educationally relevant phenomenon associated with the intervention being designed
3. To actually design a technically impressive program, intervention, or artifact
4. Or to do two or all of these things

The GS project prioritizes the third purpose, as at the outset, we want to design an innovation that can be sustained in the school as well as potentially scale up to more schools. This purpose would meet our stakeholders' need, namely, MOE, the schools we worked with, and the teachers. As researchers working at the meso-level mediating between the ministry and the schools, while we foreground 3, we also identify contributions to 1 and 2. Indeed, this paper provides a contribution of a design-research process that has some impact on real-world school practices.

As early as the first year of intervention, we started to collect encouraging results from our intervention. We did a comparison of the GS classes versus the non-GS classes by looking at the school's science summative assessments. The results show that the GS classes performed better than non-GS classes as measured by traditional assessments (Looi, Chen, & Ng, 2010). With GS, students were found to have more opportunities to participate in class discussions through both GS postings and verbal interactions and were exposed to diverse ideas (Chen et al., 2010; Chen & Looi, 2010). Analysis of data collected in the classroom as well as data on students' attitudes and perceptions indicate that GS facilitated students' collaborative learning and improved students' epistemology and attitudes toward science learning (Looi, Chen, & Ng, 2010).

Critical Reflections of the GS Innovation

In summary, our GS intervention project has supported the routine use of CSCL in the classroom for 2 years in one primary school and for a year in two secondary schools. Through our research, we have been able to explore systemic factors through design research, derive design principles for rapid collaborative learning, and build up some local capacity in the teachers we worked with, achieving some re-culturing of mindsets. We practiced shared accountability with the stakeholders, namely, the school leaders and the teachers we worked with, emphasizing their empowerment rather than just being a researcher-dominated innovation.

Toward the goal of doing CSCL research that impacts practices in school, we had argued for more research on the meso-level analysis. Our GS research is an example of this meso-level interaction. We view the class as an ecosystem and examine multiple interactions (social practices, culture transformation, accountability with various stake-holders, etc.) occurring at this level. Playing the role of meso-level actors, as researchers, we contextualized the application of RCKI principles to support collaborative learning in the schools we worked with. We moved the discourse of RCKI from research labs to pedagogic sites in the schools through a process of design research and thereby built up the capacity of teachers designing their own collaborative activities based on RCKI principles.

Taking a sociocultural perspective helped us to understand transformation at the meso-level. It helps address our concern with how to design for collaborative learning at the institutional level by considering the meso-level interactions at the school level. It allows us to see the tensions:

- Between a teacher's individual capacity and desire to change and the imperative of school leaders for teachers to innovate
- Between the researcher's desire to innovate and the teacher's desire to solve operational problems in the classroom
- Between the macro-level perspectives of very broad policy directions and the challenges of operationalizing them at the school and ultimately at the teacher's level
- Between the micro-level perspectives of promising literature reports of interactions at the micro-level and providing the institutional context for these interactions to take place

As meso-level actors, researchers like us can play a role to mediate between these tensions and for the school to progressively adopt innovations through the iterative design research approach. The artifacts created by design research, namely, the curricular products, the professional development of the teachers, the teacher sharing workshops, the articulation of GS design principles, and the various presentations of GS to school practitioners, provide a historical record and trail for the innovation to proliferate in the education community in Singapore.

In reflecting why this GS intervention works, we further postulated these supporting conditions for the success of GS intervention at the systemic level:

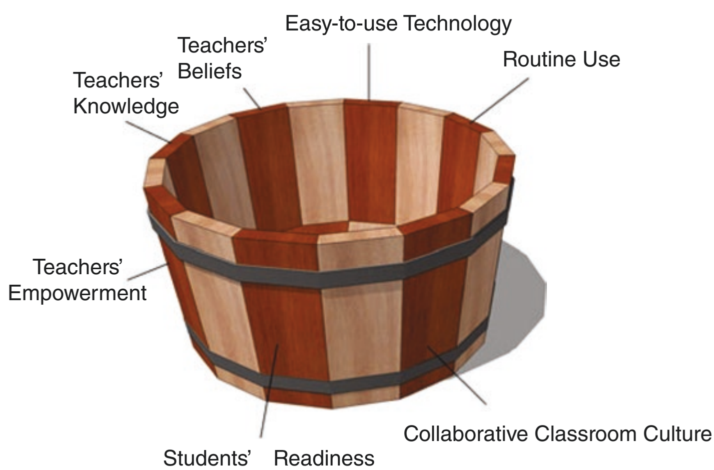

Fig. 13.11 How the Barrel for GS innovation holds water

- We emphasized routine use in the classroom at the outset. In the first school that we collaborated with, we worked with the teachers for a period of 2 years, supporting them in the routine use of GS in weekly lessons. The routine practices help alleviate the novelty effect of experiencing a new technology and the associated pedagogy.
- The technology was simple and easy to use. However, we did not start with a technology focus at the outset. Instead, we provided enculturation opportunities for the teachers and students to enact collaborative practices first before using the technology (Fig. 13.10).
- We focused on face-to-face CSCL in the classroom. The technology was used in class to mediate student-student and student-teacher conversations, increasing the bandwidth of communication.
- We iterated and derived GS design principles that empowered the teachers to design collaborative activities. Our objectives were for the teachers to be ingrained with these sound design principles for designing pedagogy, so that even without the use of the GS technology, the teachers would incorporate such notions of rapid collaborative idea improvement in their teaching (Looi, Chen, & Patton, 2010).
- Our lessons tapped existing curriculum and thus were integral to the learning of the curriculum. The RCKI principles fit well into the existing structure of the school curriculum. In the existing curriculum, each lesson has a topic to cover and specific learning objectives to achieve. Having RCKI activities that last for too long (e.g., more than one lesson) may affect the existing school class schedule.
- The lessons were co-designed by the teachers and researchers, providing ownership by the teachers of the lesson plans and resources. Toward the later part of the intervention, teachers were able to devise their own CSCL activities that tap RCKI principles using GS. At the end of the intervention, we arranged seminars for teachers to share their GS experiences and lesson plans with teachers at other schools.
- We provided extensive professional development for the teachers. We did sociocultural design to help teachers orchestrate collaborative learning activities in the classroom (Dillenbourg & Jermann, 2010).

Our design research is interventionistic and iterative in nature while driven by rigorous theories, providing a methodological approach to better unpack the enactment, adaptation, and diffusion of practices under local conditions. Through design research, we were able to cater to the needs of building up the planks of the metaphorical barrel and sealing the seams between the edges of planks nicely (Fig. 13.11).

The GS interventions were not always successful in every lesson. When doing school-based design research, we faced a lot of constraints and challenges. These are the short planks of the barrel.

- The researchers and the school are two different ecological systems. The two communities may not always see eye to eye with each other. The schools have a lot of different initiatives and many other priorities which are important for them. When there is a conflict between GS intervention and school's other initiatives in terms of teachers' time, lesson topic, and other resources, GS may have to give way to the schools' other initiatives. One lesson we learned is that it is important to have deep understanding of the school's ethos and culture. The GS intervention does not stand alone, and it should be aligned with the school's strategic plans. Otherwise the intervention effort will not be sustainable and scalable.
- Traditional assessment is always a concern for schools. It is not easy for researchers to establish causal relationships between the CSCL practices and traditional assessment. Many school teachers

want to be assured that the intervention will help improve their students' examination scores before going to the next step for sustainability and scaling up.

- There is an inherent tension between efficiency and innovation for school teachers. Many teachers we have worked with are good at delivering lesson content and helping students obtain good scores in the examinations. However they may not be good at "thinking outside the box" and adopting/adapting innovations in classrooms. Part of the reason could be that the time allocated for each topic is somewhat fixed. Teachers believe that they have to cover all the content and get students to finish the worksheet within the allocated time. If they have extra time, they will try innovation. If not, they prefer to stick to what they have been doing efficiently.
- Some of the school curriculum is not flexible enough for us to design meaningful collaborative learning activities. When identifying suitable topics for collaborative-learning activities with teachers, we found that much content is fact-based. They do not require students to use higher-order thinking and collaboration skills.
- Professional development of the teachers is very challenging for design-research in real classrooms. When introducing GS to classrooms, the teachers need to have a lot of adjustment to the new collaborative-learning pedagogy, the ICT environment, and students' new learning behaviors. Some teachers shared with us that they feel they need to be a "well-rounded" teacher to teach well in a GS class. The common issues they face when doing GS work are technology breakdowns, classroom management of students when they collaborate with each other (e.g., off-task, negative comment, inefficient group work, free loader), monitoring 40 students posting GS scribbles at the same time, and consolidating students' ideas at the end of the lesson.

To create changes in school practices, we need to understand the different planks of the barrel and to identify the shorter ones. All planks need to be long enough and to link seamlessly with each other to make the barrel work. In design research, we need dedicated and skillful researchers who understand and respect the school ecology, who can balance researchers' goals and schools' needs, and who can maintain good relationships with the teachers and provide sufficient professional-development support. In our journey with the schools, we realized that impacting practice is not easy, and the design research approach is more likely to be evolutionary than revolutionary.

Conclusion

We started by lamenting that the pace of education reform seems sluggish in the light of the cumulative amount of research grants that fund educational research that purports to transform teaching and learning. Many CSCL research projects report detailed findings at the interactional levels. Others present findings of experimental tests done in the lab. Still others look at CSCL practices at the macro-level of communities, using a specific technology like wikis, World of Warcraft, or Knowledge Forum. When one starts to ask how these findings are relevant to actual classroom practice, there is inevitably a gap in the research literature on the strategies and proven ways of taking some of these findings and applying them within a real-world context. The work reported in this paper hopes to make an initial contribution to addressing the chasm between CSCL research and CSCL practices.

We approached this multi-faceted problem from the perspective of a meso-level view on orchestrating change in schools, including systemic change and the dimensions of scaling. We explored the conditions that favor the nurturing of innovations in a sustainable way using the barrel theory metaphor. We anchored our discussion through a description of how the GS technologies and the associated pedagogies were integrated into Singapore schools by virtue of the CSCL approach. The macro context of the school environment includes the IT Masterplans initiated by the government to support the use of technology in transforming teaching and learning in the schools. Our approach to working with schools is design research that allows us to work with the teachers to first co-design CSCL activities in classroom lessons and eventually to enable teachers to design their own CSCL activities. Methodologically, design research enables us to systemically research the enactment, adaptation, and diffusion of practices under local conditions while being anchored with a set of design principles, namely, the RCKI principles. The focus of design-based research is to study learning environments not only for the advancement of theoretical understanding but also for the refinement of teaching and learning practices in practical contexts (Barab & Squire, 2004). Hence, these RCKI principles are subsequently refined based on teachers' and researchers' in-depth understanding of the collaborative process at the micro-level.

We started this journey in integrating CSCL into schools by working at the meso-level. Our GS research is integrated with a systemic effort that seeks to align the interests and goals of various stakeholders as well as the policies, the pedagogies, the assessment modes, and the classroom practices. We describe the conditions that enable GS to have an impact— routine use, where the curriculum leverages the affordances of technologies or where it is easy for teachers or students to add to the repertoire of technology-enabled activities.

There are many interrelationships between research in CSCL and practices in CSCL. We have presented an example of a research innovation that has shown impact and exhibits potential for sustainability. While this case study is situated in the sociocultural context of research and practice in Singapore, the principles of research and planning for sustainability are tenets that can be adopted for other countries and school districts as well.

Being able to determine the current state of affairs and the people's mindset toward alternative pedagogies and technologies is crucial. Understanding what CSCL research is and how it can be applied to improve the educational process in schools is the contribution we hope to make to the CSCL community. Our research experiences in the GS project led us to reflect on the nature of sustainable and scalable CSCL practices in relation to the multiple levels of the education system. In considering scale, it is easy to define it as a quantifiable measure, such as the number of students, teachers, and districts involved in research. As illustrated in the GS project, we wanted to highlight that scale involves expansion on both the vertical and horizontal dimensions, ultimately leading to deeper pedagogical changes in teaching and learning practices.

Although we foreground the meso-level interactions in this paper, we would also want to highlight that the success of school-based interventions is very often the result of systemic tinkering with all factors: macro, meso, and micro. The micro-level interactions provide insights about group dynamics, which are also inter-meshed with meso-level forces such as the sociocultural context of the school or class. Researchers who are meso-level actors strive to re-contextualize pedagogic discourse by studying micro-level factors and aligning school practices with macro-level policies. In the process of doing so, meso-level actors can potentially shape macro-level policies as well. By adopting the ecological perspective, we maintain the stand that the three different layers are interlocked. They are all planks of the proverbial barrel. Since the binding constraints determine the outcome of intervention, all actors in the ecology should strive to remove the short-board effect. This can be achieved by maintaining ongoing dialogues so that schools can ultimately benefit from the enduring and synergistic alignment of policy, practice, and research.

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Investigation 14. Bridging Research and Practice: Implementing and Sustaining Knowledge Building in Hong Kong Classrooms

Carol K. K. Chan

Abstract

Despite major theoretical progress in computer-supported collaborative learning (CSCL), relatively less attention has been paid to the problem of how research advances may impact schools and classrooms. Given the global changes and educational policies for twenty-first-century education, issues of how research in CSCL can be integrated with classroom practice for innovation pose important challenges. This paper draws on experiences in Hong Kong and examines research-based CSCL classroom innovations in the context of scaling up and sustaining a knowledge-building model in Hong Kong classrooms. It begins with an examination of the rationale for CSCL research in classrooms and then considers a range of problems and constraints for school implementation. Classroom innovations involve complex and emergent changes occurring at different levels of the educational system. The experience of CSCL knowledge-building classroom innovations in Hong Kong schools is reported, including the macro-context of educational policies and educational reform, the meso-context of a knowledge-building teacher network, and the micro-context of knowledge-building design in classrooms. Three interacting themes—context and systemic change, capacity and community building, and innovation as inquiry—are proposed for examining collaboration and knowledge creation for classroom innovation.

Keywords

Knowledge building · Educational practice · CSCL pedagogy · Teacher communities · Learning technology · Knowledge forum

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C. K. K. Chan (✉)
Faculty of Education, The University of Hong Kong, Pok Fu Lam, Hong Kong
e-mail: ckkchan@hku.hk

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Introduction

With the advent of knowledge-based societies, global educational reform movements now emphasize the need for twenty-first-century skills. How people collaborate for knowledge creation has become an important educational goal for productive citizenship. Computer-supported collaborative learning (CSCL) is a maturing field with increasing breadth and depth in examining theory, method, pedagogy, and technology related to how collaboration and learning emerge when people work together (Stahl & Hesse, 2010)· While major theoretical progress has been made, the complex problem of how CSCL research can impact educational practice has received limited attention—success in CSCL research is not easily translated into classroom practice. CSCL research that examines collaboration among individuals, groups, communities, and organizations is well positioned to examine how CSCL approaches can be drivers for classroom innovations for knowledge advances and impacts on schoolings.

Broadly speaking, the failure of educational research and technologies to alter the core practices of schools has been observed to be pervasive in educational reforms throughout the twentieth century, from the use of radio and television to the Internet (Cuban, 1986; Cuban, Kirkpatrick, & Peck, 2001)·More recently, the IEA SITES 2006 study reveals that despite much investment and infrastructure growth, pedagogical orientations had not altered substantially when information and communication technologies (ICT) were introduced (Law et al., 2008)· Researchers have noted that decades of funded research on exciting programs in technology-enhanced learning have not resulted in sustained or effective improvements to classroom practice (Sabelli and Dede, 2000). The problem of how researcher-designed innovation can have sustained practice in classrooms has perplexed researchers in science and math education (Barab and Luehmann, 2003; Roschelle et al., 2008). This paper proposes that it is time to examine more directly questions of impacts of CSCL research, pedagogy, and tools on educational practice.

Over the past two decades, a wealth of theoretical perspectives has emerged in the fields of learning sciences and CSCL that posit learning as distributed, social, collective, and mediated by the use of tools (Bereiter, 2002; Salomon, 1997; Sfard, 1998; Stahl, 2006)· There are a spectrum of theories and systems of analyses that examine how collaboration takes place with multivocal paradigms and approaches (Stahl, Koschmann, & Suthers, 2006)· Various collaborative-inquiry-based approaches examine how students engage with complex problems, interact with others, and co-construct understanding supported by CSCL technology. Web-based learning has become more engaging and provides increased opportunities for interaction, while collaborative practice has increasingly characterized both formal and informal learning (Koschman, Hall, & Miyake, 2002)· In the 1990s, there were focused efforts to bring insights of cognitive science research to classroom practice (Le. the Schools for Thought project; Goldman, 2005); some researchers have examined the problem of scaling up (Dede & Honan, 2005)· Advances in design-based research are taking place that aim to bridge the gap between research and practice (Collins, Joseph, & Bielaczyc, 2004)· With these developments, the gap between research and practice is still wide; it would be fruitful to build upon these advances to investigate how CSCL research can impact classroom practice for educational change.

Educational reform is a global phenomenon that is particularly active in the Asia-Pacific region Since the education school systems in Asian countries tend to be more centralized than their Western counterparts, their changing educational policy may be more aligned with research, and educational reforms may provide exciting opportunities for CSCL research to impact classroom practice. As such, some researchers in the Asia-Pacific region have initiated research projects using models of CSCL and learning sciences in close collaboration with schools and teachers, in some cases focusing on research for classroom innovation (Looi et al., 2011)·.

This paper explores issues and questions of CSCL research in classrooms through examining the experience of how knowledge building—a research model of CSCL—is implemented and scaled up in Hong Kong classrooms. Since 2000, the Hong Kong Government has launched major initiatives to implement educational reforms that reflect twenty-first-century education and to support classroom innovations in schools. The experience of the knowledge-building innovation may highlight issues and questions for examining how CSCL can be integrated into classroom systems. This paper does not employ methods of detailed reporting of data collection and analyses; rather, it adopts a specific scientific genre that combines descriptive and narrative accounts with conceptual analyses supplemented with data to examine issues and questions related to the problems.

The paper begins by considering the need to examine CSCL research in classrooms and follows with analyses of problems and constrains. Educational change and classroom innovation are both complex, and it is useful to examine changes at different levels of the education ecological system (Resnick, 2010). At the *macro-level*, the case study begins with educational reforms and the policies of the Hong Kong Government that provided a favorable context for CSCL classroom innovation. At the *meso-level*, its focus is on how a knowledge-building teacher network supported teacher change toward classroom innovation. The study also addresses the *micro-level* classroom design to illustrate how principles, pedagogy, and technology are integrated, considering the sociocultural context, for example, the strong emphasis on examinations in Hong Kong schools. This paper proposes three interacting themes—context and systemic change, capacity and community building, and innovation as a process of inquiry—with which to examine issues and questions of how CSCL research may create innovation in classrooms. Specifically, this paper discusses efforts to create research-practice links and considers organizational challenges, capacity building, and pedagogical transformation with research implications for CSCL.

Examining Impacts of CSCL Research in Classrooms

Changing global, technological, socioeconomic, and educational contexts emphasize the importance of collaboration in a knowledge-based economy In Asian countries and internationally, education reform movements have emphasized the need to develop citizens' capacities for knowledge creation, inquiry, and collaboration, all of which are central to CSCL research. These needs are stated in educational research and policy documents produced by diverse bodies, such as the National Council of Teachers of Mathematics in the USA, the Organization for Economic Cooperation and Development, and various governments in Asian countries. Collaboration is pivotal to the advancement of knowledge, and CSCL community can help to provide the knowledge needed to meet the demands of globalization and education in the twenty-first century.

An analysis of current work in CSCL, for example, indicates its interdisciplinary focus with diverse approaches, paradigms, and multivocality of analyses. CSCL research examines dialectics of both individual and collective cognition and modes of participation; it addresses various research themes including, to name a few, intersubjectivity, group cognition, scripting, argumentation, and knowledge building. CSCL practice ranges from dyads, small groups, classes in laboratories, classrooms, and communities of practice to multi-institutional research. The interdisciplinary nature of the CSCL field makes it a rich ground for examining diverse approaches and theory-research-practice synergy.

As a key element of CSCL research is to examine how learning and collaboration emerge mediated by technology, discourse naturally becomes a key object of analysis. While advances are being made, currently, the bulk of CSCL research focuses on investigating micro-level analyses of discourse, mostly in small groups, rather than examining how complex emergent social structures may constrain or facilitate CSCL participation. Concerns have also been raised that the unit of analysis usually focuses on short durations (minutes) rather than on sustained periods of collaboration for knowledge production. Generally, CSCL research has given relatively less attention to conducting research in classroom settings.

These concerns suggest the need to examine the complex interplay and alignment of cognition, discourse, design, and context (or internal and external processes) in which CSCL pedagogy and tools are introduced. For CSCL tools to be effective, changes are needed in institutional practices, norms, and culture; reciprocally, changing those practices also requires a detailed understanding of student thinking. Dillenbourg, Jarvela, & Fischer, (2009) discuss the challenge of orchestrating and integrating CSCL activities into larger pedagogical scenarios and classroom practice. Hakkarainen (2009) critiques knowledge-building theory for focusing too much on the progress of ideas. He argues that it is difficult to implement knowledge building in schools because the dimension of knowledge-building *practice* is often neglected. From a sociocultural perspective, Krange and Ludvigsen (2009) argue that interventions are not fixed entities and must be examined in relation to how students interpret schooling situated within historical, sociocultural, and situated perspectives. A dialectical approach is needed to analyze how institutional settings and environments can affect the way CSCL tools are practiced and how meaning is constituted (Arnseth & Ludvigsen, 2006). Analyses need to go beyond separate components to examining system-level properties, such as the use of activity theory to examine the dynamics of networked communities for school reforms (Rasmussen & Ludvigsen, 2009).

Specifically, researchers have proposed supplementing micro-level analysis of group interactions to meso-level analysis of collaboration in classrooms, school settings, institutions, and networked communities (Jones, Dirckinck-Holmfeld, & Lindström, 2006). Meso-level forces and processes are not just organizational structure; they refer to relational properties with interaction dynamics situated in social settings for relating different properties and dynamics and can be examined to see how they mediate between macro-level influences such as policy context and micro-level group interaction processes. In the broader realms of theories of learning, researchers have discussed changing metaphors of learning in terms of knowledge acquisition, acculturation, and knowledge creation (Paavola, Lipponen, & Hakkarainen, 2004). Questions exist as to how CSCL research may be extended from dyads and small groups to classrooms and knowledge-creating communities and to examine design and conditions facilitating collaboration in complex educational settings. Researching CSCL practice in classrooms and schools in productive ways requires inquiry into more powerful theories and analytic approaches.

It is a common belief that theoretical knowledge is created in lab-based studies before being applied in the real world, a view that perpetuates the theory-practice gap (Sabelli & Dede, 2000). Much interest has been given to the notion of Pasteur's quadrant (Stokes, 1997), which includes basic, applied, classification, and user-inspired approaches. Stokes argues that user-inspired approaches are fruitful because they demand research into fundamental scientific problems that can address practice. In a similar vein, design research in education is important for understanding real-world problems (Collins et al., 2004). Through implementing innovative designs and through iterations of formative evaluation to shape those designs, theories of learning and collaboration can be refined in classrooms. Similarly, Bereiter and Scardamalia (2008) argue against the separation of basic research and applied research—they propose the idea of research-based innovation as a third type of research that aims to create innovation to advance research and design.

Accordingly, classrooms are not merely sites for implementing research results; they may become sites for knowledge creation. How CSCL research works in broader social and policy contexts for policy-research-practice synergy is an important question to address.

Problems and Challenges of Implementing CSCL Research in Classrooms

One can easily recognize the many challenges limiting the impact of CSCL research on practice. Researchers often work on identifying some phenomena, assuming them to be general and leaving it to practitioners to apply their findings in classrooms (Sabelli & Dede, 2000). Schoenfeld (2006) notes that there are no mechanisms to take lab-based ideas into practice. There have been advances made through research, but there are few infrastructures in which scholars can apply them; the need to develop a stable research base for classroom application is *lacking*. In fact, there are few rewards in universities for such research innovation.

It is also recognized that the wider implementation of CSCL and technology-enhanced experiments has been constrained at different levels involving organizational, pedagogical, and epistemological factors. Engeström, Engeström, & Suntio, (2002) point out that there are various factors that make transforming schools very difficult, including the broader social, spatial, and temporal structures. Furthermore, there are problems with capacity gaps, and teachers need to buy into the innovation. Epistemological and cultural factors, such as student beliefs and the tradition of teachers working as individual professionals, are generally not congruent with research in learning sciences, and CSCL organizational and school-level constraints make it very difficult for teachers to reflect collectively on their practices and engage in sustained expansive learning in CSCL environments.

Scalability, adapting a successful local innovation to other contexts while retaining its principles and effectiveness, is a significant barrier to research impacting school practice (Dede & Honan, 2005). It is very difficult to scale up success from one education setting to another, particularly when the innovations involve the application of technology. For educational innovations to scale up, various dimensions need to be considered, including the breadth of use across classrooms, the depth of understanding, the sustainability of innovation, and the ability of teachers to shift, change, and refine the innovation (Dede & Honan, 2005).

The above problems and challenges exist at different levels and are compounded by barriers to coordinate changes among these levels. From the macro-level, governmental ministry decisions for implementing a given pedagogy or innovation are often not based on research findings, let alone on the quality of the research. At the meso-level, there are few enabling frameworks or structures for productive collaboration among researchers and teachers. At the micro-level of day-to-day classroom operations, teachers tend to work alone; they are busy and have little time to try out new approaches. Moreover, students generally hold epistemological views that are not congruent with what is advocated in CSCL research. Specifically, the practical tools are limited and require surveying what is available, adapting it to the local conditions, setting up infrastructure, carrying out the missing research, adopting long-term approaches to training and supporting teachers, and affecting a cultural change of public expectations, understanding, and attitudes (Stahl, personal communication, 2009). The different cultures of research and practice, and the lack of conceptual and practical tools to coordinate changes, result in theory-practice gaps that are wide and enduring.

Conceptual Themes for Examining Research-Practice Gaps

Given the complexity of organizational, social, pedagogical, epistemological, and practical constraints, it may be useful to consider innovations as interacting changes occurring at different levels and nested systems of an ecological system. As individuals and groups influence the people, communities, and institutions of ecology, they are, in turn, influenced by them. Various theoretical analyses have been made; for example, Dede (2006) depicts educational innovation as evolving ecological systems, similar to the adaptation of biological organisms; Lemke and Sabelli (2008) discuss how educational change can be examined as processes of a complex system, in which emergent properties and changes at one level lead to changes in other levels due to feedback loops inherent to the system.

In the area of educational research, curriculum theorists have examined different levels of interacting changes. For example, Doyle (1992) discusses three levels of change: institutional, referring to the intersection of society and culture; programmatic, referring to program-level changes in schools; and classroom-level changes, referring to how teachers and students interpret the curriculum. Cognitive science researchers working on school implementation have discussed the importance of designing for and examining changes at different levels and of making coordinated changes in classrooms, schools, and school districts (Resnick, 2010).

Research on scaling up for success also provides insights into possible conceptual analytic tools. Fishman et al. (2004) discuss scaling up efforts for learning technology in urban schools and postulate a framework on bridging cultural, capacity, and management gaps. Goldman (2005) describes designing for educational improvement based on a decade of work on the Schools for Thought project and highlights three sets of principles pertaining to educational change, organization change, and individual change. Dede and Honan (2005), drawing from successful examples of scaling up, discuss four themes: coping with change, promoting ownership, building capacity, and effective decision-making. For capacity building, a community of practice is an important strategy; for example, the Wide-scale Interactive Development for Educators facilitates teachers' professional development through constructivist pedagogies supported by Internet technology (Wiske & Perkins, 2005). Means and Penuel (2005) focus on inquiring into large-scale innovation and using evaluation data at multiple levels to inform and improve the process of innovation. Roschelle et al. (2008) demonstrate that it is possible to conduct experiments into scaling up for robustness when examining the overall effects of intervention, including similar or dissimilar effects and variability across different sites.

These theoretical analyses all suggest that designing for collaboration and educational innovation involves changes at different levels of the system that need to be coordinated. As such, the case of knowledge-building innovation in Hong Kong will be examined at various levels: macro-level systems and processes including educational policies and reforms, evolving and enabling meso-level system of a teacher network, and micro-level dynamics of how individuals and groups in classrooms engage, interpret, and create new knowledge. The study's emphasis is on the meso- and micro-levels and the macro-level will provide an important context.

The Macro-Context: Educational Reforms and Sociocultural Context in Hong Kong

Educational change in the knowledge era is a global phenomenon, and it takes different forms in different countries around the world. While competitive examinations remain a defining feature of Asian school systems, there have been major educational policy shifts toward new education goals that are quite compatible with the visions of learning sciences and CSCL. Paradoxically, despite cutting-edge research advances, the educational policies in Western countries seem more inclined toward standardized testing and the monitoring of students' basic skills (i.e., no child left behind). The SITES study shows that with the exception of Finland, countries with more centralized curricula reported more increases in student-centered pedagogy in ICT integration compared to their counterparts (Law et al., 2008). The case of Asian schools engaging in CSCL classroom innovation is of particular interest because while changes are necessary to meet twenty-first-century education goals, teachers are still pressured to help students face competition and meet examination standards.

The Hong Kong Government has undertaken major initiatives to support the development of twenty-first-century education. In September 2000, the Education Commission of Hong Kong published the document *Learning to Learn—Learning for Life*, formally launching a comprehensive reform of education in Hong Kong to ensure that students are prepared for the twenty-first century. The document specifies four key learning tasks or pillars—project learning, information technology, reading to learn, and moral and civics education. Educational policies and curriculum reforms over the last decade include such major initiatives as structural change to the years of schooling (New Secondary Senior Curriculum), a shift from highly specialized curricula to diverse subject choices, introduction of a new interdisciplinary Liberal Studies curriculum, and assessment reforms incorporating more formative elements and school-based assessments.

In the area of computer-supported learning, the Education Bureau (Ministry of Education) has developed three 5-year plans as strategies for the development of ICT in education since the 1990s. The first strategy, "Information Technology for Learning in a New Era: Five-Year Strategy" (1998–2003), focused on four key components to transform school education from a teacher-centered approach to a learner-centered one: (a) access and connectivity, (b) teacher enablement, (c) curriculum and resource support, and (d) community-wide culture. This first 5-year plan laid the foundation of establishing IT infrastructure in schools and training teachers in its use. However, it focused mainly on technology and paid limited attention to pedagogical practices in technology-enhanced learning.

The second strategy, "Empowering Learning and Teaching with Information Technology," launched in 2004, envisioned "turning schools into dynamic and interactive learning institutions, and fostering collaboration among schools, parents and the community." The notion of collaboration was mentioned more explicitly in this strategy. This 5-year plan consisted of several strategic goals, including the intent to "enable students to engage in empowering modes of learning which include collaboration, inquiry and production of knowledge" and plans to empower teachers by developing communities of practice.

Although there are admirable goals in the documents, the ongoing evaluation showed that schools were still dominated primarily by traditional pedagogical practices, so a third strategy was launched, "Right Technology at the Right Time for the Right Task," stating more explicitly that IT was to be integrated through pedagogical practices rather than simply through technology implementation. This strategy highlights the importance of using ICT *at the right time* and *in the right place* and of changing mindsets and practices in collaboration through technology. It also warns against techno-centric thinking, likening this to "jumping on the bandwagon without critically examining whether adopting a particular technology will genuinely improve learning outcomes" (The Third Strategy on IT in Education, 2007, 4). There is more realization that the critical barrier is how teachers may be able to integrate technology into their curriculum and pedagogy.

Although these ICT reform plans are not focused on CSCL per se, they provide the readiness for the development of CSCL by encouraging schools to engage in pedagogical and technological innovation. At a macro-level, the institutional context includes issues, discourses, and decisions on the interactions between society, culture, and schooling. While educational reforms are occurring worldwide, Hong Kong's education system may be one of the few that engages in major system revamping. The government has focused on new educational goals such as learning how to learn, collaboration, and technology skills to meet emergent societal needs. At the heart of Hong Kong Government's educational vision for the twenty-first century is a desire to address pressing economic, social, cultural, and technological challenges through institutional changes.

As new education policy sets the stage, various factors facilitate changes for innovation, including top-down and bottom-up initiatives. Many Asian educational systems, including that of Hong Kong, have centralized curricula, and schools are required to follow changes outlined in reform documents. Teachers are expected to meet the requirements for technology competence, and schools must engage in school-based reforms. To phase in these changes, school-based development initiatives are encouraged, and a variety of seed projects have been developed within clusters of schools to encourage innovation. Funding opportunities exist for teacher buyout time for new pedagogy and technology, and various schemes enable schools to collaborate with universities and the Education Bureau for teacher development. In addition, schools are encouraged to seek support for reform initiatives from the public, including various stakeholders and parental support. Strong political leadership during the time of educational policy reforms made these major changes possible.

The macro-context includes societal and institutional forces, as well as historical and cultural values and norms. It is a perplexing phenomenon that Asian students consistently score higher on international tests than do their Western counterparts; the most recent example of this are the PISA results. While these tests may not be addressing the kinds of deep collaborative thinking advocated in CSCL research, they nonetheless point to interesting questions. Various explanations have been proposed, including historical-philosophical traditions and family norms that emphasize academic achievement. While embracing and initiating new notions of educational goals, government policies continue to stress public examinations and standards common among Asian societies. Although emphasizing both deep inquiry and standardized examination seems almost paradoxical, such reform efforts are designed so as not to contradict deeply ingrained cultural beliefs (macro- and micro-level processes interact). These underlying sociocultural and historical beliefs will influence how new pedagogy and technology are interpreted when CSCL research is introduced into school practice.

Educational reforms are fraught with challenges. Despite efforts in policy documents, many initiatives in Hong Kong merely focus on sharing educational information and materials on Web portals. It is widely acknowledged that teachers seldom read curriculum guides, believing them to consist merely of clichés. Government policies and reforms may provide the facilitating macro-contexts and conditions, but the actual implementation of initiatives must come from schools and teacher communities; coordination across levels is needed. Schools are key venues in which teachers gather together to negotiate and interpret reform documents. Through technological advances and CSCL research, a new kind of structure, teacher network, may emerge as a type of meso-level structure to bridge government policy with capacity building and classroom implementation. Various teacher communities have emerged in Hong Kong, some spontaneously and some supported by the government and universities.

The Meso-Context: The Knowledge-Building Teacher Network

The Knowledge-Building Teacher Network (KBTN), which consists of more than 50 teachers funded by the Education Bureau since 2006, is an attempt to address new educational reform goals. Knowledge building, sometimes called knowledge creation, is one of the early models of CSCL that predates the advent of the World Wide Web (Scardamalia & Bereiter, 1994). While knowledge building is a common theme in small group-based research, Scardamalia and Bereiter focus on collective cognitive responsibility for knowledge creation in communities, arguing that children need to develop knowledge-creation capacity similar to that of members advancing new knowledge in scientific and scholarly communities (Bereiter, 2002; Scardamalia & Bereiter, 2006).

This model is particularly relevant when examining education reforms as it seeks to address prevalent school problems that usually focus on task completion, even with new pedagogy such as project learning. These researchers argue that even young children can improve, refine, and produce community knowledge needed for twenty-first-century education. In their model, knowledge-building discourse is mediated by Knowledge Forum®, a computer-supported learning environment in which students collaboratively formulate problems, construct and improve ideas, and refine theories in pursuit of collective progress.

Since the 1990s, various research studies have been conducted in North America, Europe, and Asia examining knowledge-building theories, methods, pedagogy, and technology (e.g., Hakkarainen (2002), van Aalst and Chan (2007); see Special Issue (Scardamalia, 2010; Zhang et al., 2009)). With regard to developing research-practice synergy and impacts for educational innovation, the Knowledge Society Network, based at the University of Toronto, consists of researchers and practitioners from different countries working toward creating knowledge communities and networks (Hong, Scardamalia, & Zhang, 2010). The Knowledge-Building Teacher Network in Hong Kong, which is linked to the international knowledge-building network, examines how the model of knowledge-building research can be implemented and scaled up in the Asian classroom context. The network has been funded in phase one (2006–2008) and phase two (2008–2011); this division also reflects the formative evaluation of and ongoing inquiry into improved design for implementing and scaling up knowledge-building innovation.

Phase One (2006–2008): Context and Participants

The Knowledge-Building Teacher Network began in Hong Kong in 2006 with a teacher "secondment" scheme funded by the Education Bureau (Ministry of Education). Since 2001, knowledge-building research projects have been conducted in Hong Kong classrooms (Lai & Law, 2006; Lee, Chan, & van Aalst, 2006; van Aalst & Chan, 2007). As is the case with most research, these projects investigated knowledge building in individual classrooms for short durations. In collaboration with the Centre for Information in Education, which provided strong technology and infrastructure support, the author developed a knowledge-building teacher network to examine teacher learning and to extend the knowledge-building model to a range of classrooms in Hong Kong.

Table 14.1 shows the overall picture of the teacher network over the 4 years. The initial network consisted of seven experienced teachers "seconded" from the Education Bureau. Within that year, there were more than 20 new teachers recruited from different subject areas (including science, humanities, languages) and different school levels (Grades 5–12, ages 10–17). The seconded teachers' salary was supported by the Education Bureau, with 50% release time, so they have time to work on the project. All of the first batch of seconded teachers had experience with knowledge building in their own classrooms—they were joined together as a group with release time to work with the university researchers to implement knowledge building in schools. The new teachers were recruited to join projects funded by the Education Bureau. With education reforms, schools are required to participate in pedagogical and technological innovation projects. School principals would choose from different projects supported by the Education Bureau, and they recommend their teachers to participate; KBTN is one among other projects. While the government support provides access to research sites, other sources of research funds make it possible for undertaking policy-research-practice integration.

Table 14.1 Basic information of the Knowledge-Building Teacher Network (2006–2010)

	Phase one: teacher secondment scheme			Phase two: university-school partnership scheme
	Year 1 (2006–2007)	Year 2 (2007–2008)	Year 3 (2008–2009)	Year 4 (2009–2010)
Number of participating schools	18	26	25	29
Primary schools	5	7	11	12
Secondary schools	13	19	14	17
Participating teachers	25–30	40–50	50–60	50–60
Seconded teachers	7	6	6	6
Teacher associates			6	9
Curriculum areas	Primary science, integrated science, chemistry, physics, biology, geography, history, Chinese, English, liberal studies, mathematics, design, and technology			

Multiple sets of data were collected, including student discourse on forums, domain tests and questionnaires, teacher discourse in meetings and workshops, teacher interviews, teacher artifacts, and classroom observation. As the focus of the paper is on the conceptual analysis of classroom practice of CSCL, data analyses will not be exhaustive, but highlights are included for illustrative purposes.

Phase One (2006–2008): Design and Reflection on Teacher Collaboration

The first batch of seconded teachers worked closely with the researchers setting up the initial structure of the network. Setting up the infrastructure to bridge different levels and contexts turned out to be a highly complex task. In the initial phase, much time was spent on building basic infrastructures, teacher scheduling, need identification, resource allocation, setting up technology, and intergroup liaisons. Early teacher discussions mainly focused on administration, task allocation, resource needs, scheduling, and division of labor and role assignment. There was also much negotiation as researchers and teachers sought to define their new roles as co-inquirers and to work with different cultural norms and expectations.

Another challenge was to support multiple classes using Knowledge Forum. Typically, Knowledge Forum databases are designed for individual classes or for several classes within a single school; now, however, the program needs to accommodate a network of 30 to 40 classes in a variety of schools. Teachers and researchers decided to allow cross-fertilization among network teachers while maintaining technical feasibility and pedagogical goals. Using the affordance of multiple views and links, the platform was designed to allow teachers in different schools to work together and to have access to other classroom communities. The database in year 1 with many classes turned out to create many technology problems that were gradually improved over the next few years. In later years, teachers from different schools sharing similar curriculum areas and grade levels and inquiry topics were joined together and that facilitated the growth of subcommunities.

Teacher development activities included the following: The seconded teachers and researchers met weekly to act as a design team to design and improve knowledge-building practices in their own classrooms, share their understanding with their colleagues in their own schools, and provide peer coaching to other new teachers in the teacher network. Halftime release enabled the seconded teachers to stay in classrooms to extend their work and work collaboratively with their colleagues; they also needed to support new teachers through regular school and classroom visits and sharing their work on Knowledge Forum.

At the weekly meetings, the seconded teachers planned workshops, designed curriculum materials, and outlined instructional tasks. A teacher database was set up, which was used mostly as a clearinghouse for teacher materials. Although there were strong teachers in the group, it was quite challenging for them to work together: there were different viewpoints, and some participants were resistant to new ideas. Furthermore, the initial underlying belief—that good knowledge-building teachers would be able to share their experience and help new teachers to learn—was found to be simplistic. While these experienced teachers advocated deep inquiry in the classroom, they often resorted to telling their peer teachers what to do in their classroom or making the Knowledge Forum views for them rather than engaging newcomers in reflection or scaffolding their understanding.

There were many failed attempts and false starts with iterative efforts while interesting lessons were learned. Although Knowledge Forum is usually included at the start of knowledge building in Canadian classrooms, it was not quite possible for the KBTN teachers. The new teachers who were first introduced to Knowledge Forum tended to focus on the tool itself and used the forum as a technology-based venue merely for teacher-directed instruction (e.g., posting questions as assignments).

This observation showed us that teachers needed to change their mindsets and understand that their students can work together to build knowledge. These unsuccessful starts led to emergent changes with the teacher-researcher design of the knowledge-building pedagogy model (described in a later section), which includes an initial phase of acculturating students to a collaborative culture before introducing Knowledge Forum.

Phase One (2006–2008): Analysis and Ongoing Evaluation

Analysis was undertaken as feedback to the innovation in classroom and the teacher network. As discussed before, the project started with seven seconded teachers; these experienced teachers played a key role in recruiting new teachers to join the network through ministry-university-school joint everts. By the end of year 2, there were more than 40 participating teachers. There were other teachers who had attended the network activities; but only those who were active enough to have conducted Knowledge Forum work were counted. There were many teachers attending the network activities with many fluctuations in sustained involvement.

Student Participation in Knowledge Forum

While there was growth in the number of teachers, the participation patterns and quality of discourse in Knowledge Forum varied greatly. Analyses of forum notes indicated that some new teachers were setting up questions on the forum for students to respond mainly as answers to teacher questions (assignments). This phenomenon seems similar to what Brown and Campione (1996) characterize as a “lethal mutation” in classroom innovation; they coined the term to describe the problem of teachers superficially copying surface procedures but neglecting and thereby contradicting the principles. It seems that these KBTN teachers were assimilating the new knowledge-building model and fitting it into something with which they were familiar. Furthermore, many students were engaged in sharing opinions or information or what has been called the knowledge-sharing discourse rather than collaborating for knowledge construction (van Aalst, 2009).

Examining Student and Teacher Beliefs

Analyses were conducted to examine what might contribute to different levels of participation, and a brief summary is reported here. Interviews with 23 network teachers were conducted to gain insights into their beliefs about knowledge-building practice. When asked about their goals, analyses suggest that some teachers focused on the technical aspects, as if classroom innovation were just about using a new piece of software. One teacher said:

> What do I think I can do to improve my knowledge-building practice next year? If your project provided me a CD or guides on how these Knowledge Forum functions work, I will learn them this summer and I think I can be much better next year. (Interview with a teacher, TCA)

Other teachers focused on the pedagogy and activity structures used in knowledge building. Here is an example:

> When planning for knowledge building in my classroom, my goal is to know more about pedagogy and curriculum designs of knowledge building I do have concerns about the worksheets used currently in my school…· I hope we can develop better materials for class activities. (Interview with a teacher, TYC)

Some of the teachers, however, reflected on how knowledge-building principles influenced the ways they view their classroom work. One teacher said:

> Unlike my mentor who can articulate the set of principles and I can't, [my goal] is that. *I will try to use these principles to remind myself.* Sometimes when I asked my students to do certain work, I may doubt if that would work [out] Then I think about some of these principles and remind myself that if community growth is possible. students may indeed be able to develop new knowledge when they work together. (Interview with a teacher, TTH) (italics for emphasis)

Further ongoing analyses show that the students of teachers with more principle-based views change more toward the view of collaboration that aligns with idea improvement and collective growth (Chan et al., 2008). Other analyses were also conducted. Student beliefs were examined using a questionnaire designed to tap into their views of collaboration as aligned with the knowledge-building perspective, the results of which showed that those students whose beliefs were more aligned with knowledge building had more productive participation patterns on Knowledge Forum (Chan & Chan, 2011). The ongoing analysis and inquiry into student participation patterns on Knowledge Forum and teacher understanding provide some background for designing the teacher network—primarily, it points to the importance of focusing on principles and more efforts to understand students' collaborative discourse. With the emphasis on continual inquiry for innovation, the teacher network underwent continual change.

Phase Two (2008–2010): Context and Participants

Over time, the network's infrastructure has become more established, with better links across multiple levels, including ongoing liaison with the Education Bureau. As the number of teachers involved increased, the network received further government funding. After 2 years, in addition to seconded teachers (50% release time), the project now includes "teacher associates," a group that includes seconded teachers who finished their term but sustained their practice and new teachers who have become active participants to spread the innovation. In year 4, the number grew to six seconded teachers and nine teacher associates. The number of teachers has fluctuated; but there were more than 50 teachers participating.

Phase Two (2008–2010): Designing for Teacher Collaboration and Knowledge Building

The goal of the design is to help network teachers develop some integral understanding of principles, pedagogy, and technology as they experience knowledge building. Table 14.2 shows the overall design including network activities and three key themes on community building, principle-based understanding, and technology-enhanced inquiry.

Primarily, the network activities include (a) design meetings among researchers and seconded teachers/teacher associates, (b) subject area and school-based meetings led by seconded teachers/teacher associates for new teachers, (c) classroom visits for implementing knowledge building and open classrooms, (d) network-wide university-based workshops, (e) summer institutes and collaboration with international communities, (f) technology-based meetings for tool development with network teachers, and (g) dissemination seminars for the public. Among these activities, the weekly design meetings were developed as key sites of inquiry, collaboration, and knowledge creation—the strategy was to develop seconded teachers and teacher associates as teacher leaders who would then spread the innovation to other teachers. Furthermore, the university-based teacher workshops provide the venue for network teachers to experience knowledge building and writing on Knowledge Forum. As an example, network teachers put forth their ideas and questions, adapting the notion of the knowl-

Table 14.2 Designing for teachers' knowledge building in the teacher network

Network activities	Teacher-researcher collaboration and community building	Principle-based design and understanding	Technology-enhanced inquiry
	Researchers work with seconded teachers (ST) and teacher associates (TA) in addressing common problems of understanding	ST and TA present classroom events and artifacts examined with principles	Multiple and connected knowledge forum databases for all participating classroom communities
Design meetings on classroom work and teacher professional development	Hybrid culture of teacher-researcher co-inquiry and teachers empowering teachers	Explicit focus on student discourse and analyses informed with principles	A knowledge forum teacher database to support teacher collective inquiry as a knowledge-creation space
		Collective effort to understand knowledge-building principles in light of student work	
Subject area and school-based teacher workshops	ST and TA as leaders in school-based workshops for network teachers, multiple zones of proximal development	ST and TA adapt selected principles making them accessible to new teachers	Multiple databases for cross-fertilization and joint classroom work
		ST and TA co-design curriculum with new teachers and model knowledge-building practices	
Classroom visits and open classrooms	ST and TA co-teach with new teachers based on curriculum designed in school-based workshops	Teachers reflect on classroom practice (e.g., KB talk) using principles	Video recording and analyses to scaffold classroom practice
	Multiple and emerging groupings, shared goals and social practice	Classroom support—Debriefing and scaffolding using principles	Suite of assessment tools including ATK and applets for formative assessment
		Experienced ST and TA open their classrooms for visits, develop artifacts informed with principles	
Network-wide university-based teacher workshops	Network teachers, ST, TA, researchers, and occasional visitors of students and ministry personnel working toward symmetrical advances	Workshops designed based on classroom problems informed with principles (e.g., student agency)	Resource web with teachers co-designing collective artifacts
Network activities	Teacher-researcher collaboration and community building	Principle-based design and understanding	Technology-enhanced inquiry
Collaboration with international communities	Network teachers working with knowledge-building teachers in other countries, connection with international communities at universities, networks of networks	Knowledge-building principles put forth as objects of inquiry in teacher online and offline discourse, emulate the process of knowledge building	A knowledge forum teacher database and assessment tools
		Teachers work on joint student databases using principles to design the curriculum	Knowledge forum joint databases across communities
		Attend Summer Institute at the University of Toronto to enrich their understanding of principles	Virtual conferences among international communities
Technology-based meetings for tool development	Researchers, engineers, graduate students, ST, and TA working toward a tool design research community	Technology design linked to principles and classroom needs; tools to be employed by teachers and students for agency teachers, researchers, and technical team work collectively; researchers design tools for teacher needs; teachers provide contextual information to enhance tool design	Technology-based assessment tools and ongoing development for research-practice synergy
Dissemination seminars	Education bureau, schools, parents, and public, connection with stakeholders and school community for sustained innovation	KBTN sharing advances in knowledge-building practices with possible feedback to ministry policy for future direction	KBTN web resource portal open to school communities

Teacher B: I am wondering how their discussion can be related to our problem of assessment. (#1).
Teacher H: Um… I wonder… as students' ideas are continually improving, is it possible for students to reflect on what they thought at the beginning… what they… thought later and um maybe they can even think about how they have deepened their ideas? (#2).

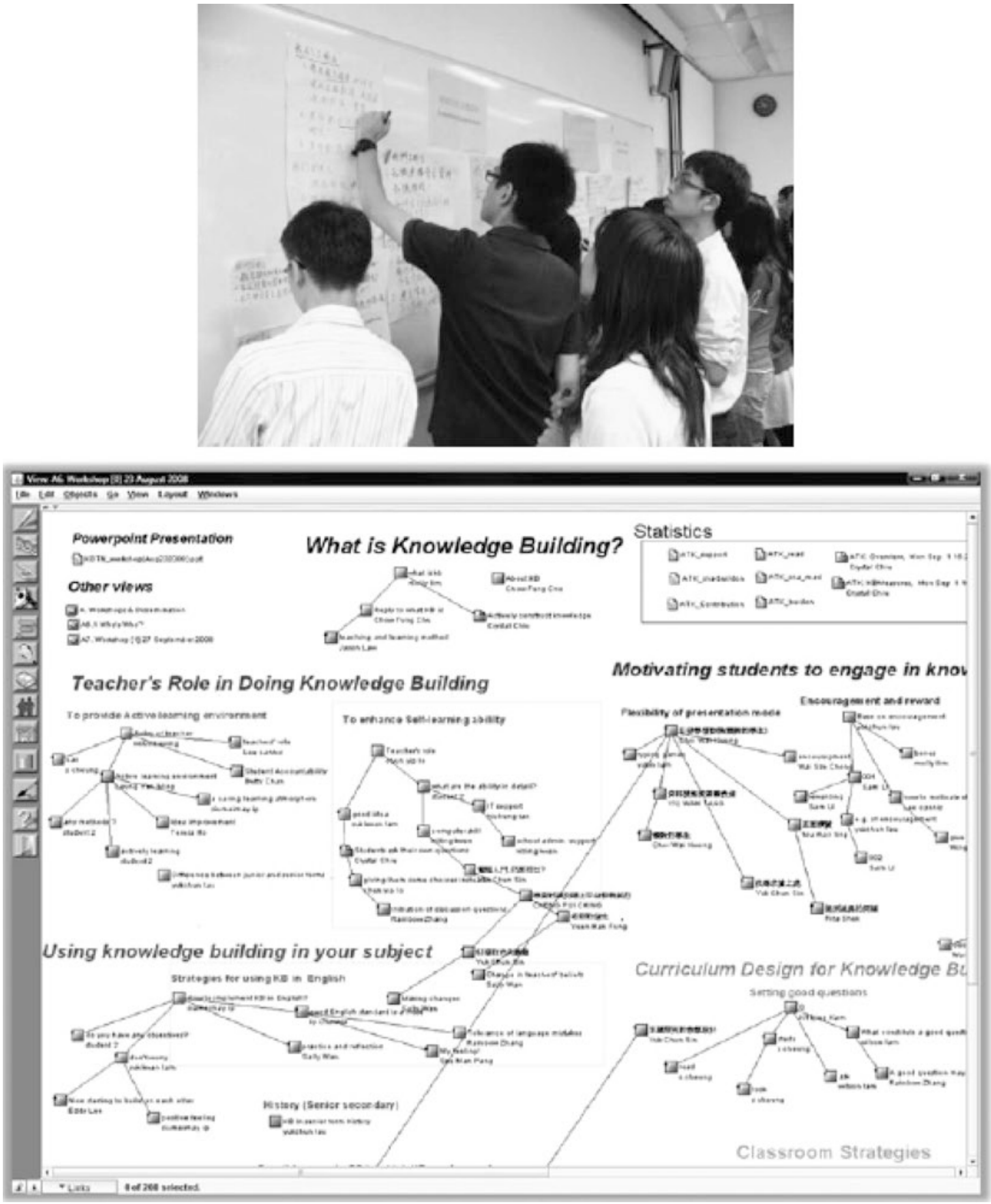

Fig. 14.1 Teachers working with ideas and engaging in collective inquiry on Knowledge Forum

edge-building wall, and these ideas are further inquired and elaborated on a teacher database (Fig. 14.1). In the following subsections, the three key themes are described.

Principle-Based Design and Understanding

Evaluations of phase one show that some network teachers merely worked on surface procedures, but those who focused on principles showed a deeper understanding. Various approaches were employed to help teachers move toward principles in their classroom implementation, for example, discussion of classroom and computer-supported discourse were conducted from the lens of principles, teachers interpreting principles with other peer teachers, and teachers working with their students in developing their sets of principles.

Typically, during the design meetings, one or two seconded teachers would present an artifact from their teaching—e.g., a video clip, a selection of computer notes, or some artifacts. A knowledge-building group discourse would ensue, generating questions and explanations, much as their students experience in their knowledge-building discourses. For example, this discussion followed the viewing of a video clip of a classroom discourse presented by a seconded teacher.

Teacher F: Um. I think it is difficult for students to find out their ideas [themselves] …. Maybe the teacher can write down important points that have been raised on the blackboard to make their idea clearer. (#3)

Teacher B: It may depend on the ability of the students. If the students in some classes are very bright, maybe they can reflect on what they have discussed? (#4)

Teacher E: I wonder if it is a good idea that the teacher points out the important ideas. It may be better if the students themselves can find out what is important, and then ask more questions in their [subsequent] problem-solving process? (#5)

Teacher H: Maybe the teachers can work with students together to find out the important questions and ideas they have raised. (#6)

Teacher B: We talked about idea change and improvement. If students can identify these changes, it would be important. ... I [didn't think about that before] but need to focus more on students reflecting on what they know. (#7)

Although the teachers' understanding of knowledge-building principles is rudimentary, they were not just discussing practical methods but examining the classroom episode in terms of big ideas and problems (e.g., "what about assessment?" #1). This question is somewhat similar to "I need to understand," a problem-formulation discourse move to start inquiry. Teachers put forth initial "theories" (#2, #3, and #4) as they elaborated on others' ideas and grappled with the tension of structured versus emergent design, a key notion of knowledge building. The idea of giving students more agency (#5) was responded to with an effort to synthesize the different ideas (#6). This is followed by another teacher's reflection on how their inquiry is related to the principles of agency and idea improvement (#7). Such collaborative discourse was quite emergent and seemed important to help teachers move gradually to a deeper understanding of knowledge building. In subsequent interviews, one teacher said:

> Although we may be doing the same activities such as students asking questions. I see the differences now about why asking questions is valuable—It is about facilitating the whole community to make advancement. There is also something key about ownership and agency as students are the ones who pose the questions, and amazingly they are the ones who can even assess their own understanding. (Interview with a teacher, TYB)

The excerpt suggests that the teacher might now be examining her classroom work, considering not just "how" but also "why" the classroom processes in connection with the principles. From a focus on activity, teachers moved gradually toward the emphasis on principles. Figure 14.2 shows an example of how one teacher spontaneously created an artifact to show her interpretation (model) of principles that sparked a collective inquiry among other seconded teachers at the design meeting.

Teacher-Researcher Collaboration and Community Building

Over time, less emphasis was placed on formal divisions of labor, and more emphasis on socio-cognitive dimensions and community building. With the wide range of expertise, the design is to have teachers support and scaffold each other as they work on shared problems. During the workshops and meetings, teachers were provided opportunities to share their experiences with their peers; they also

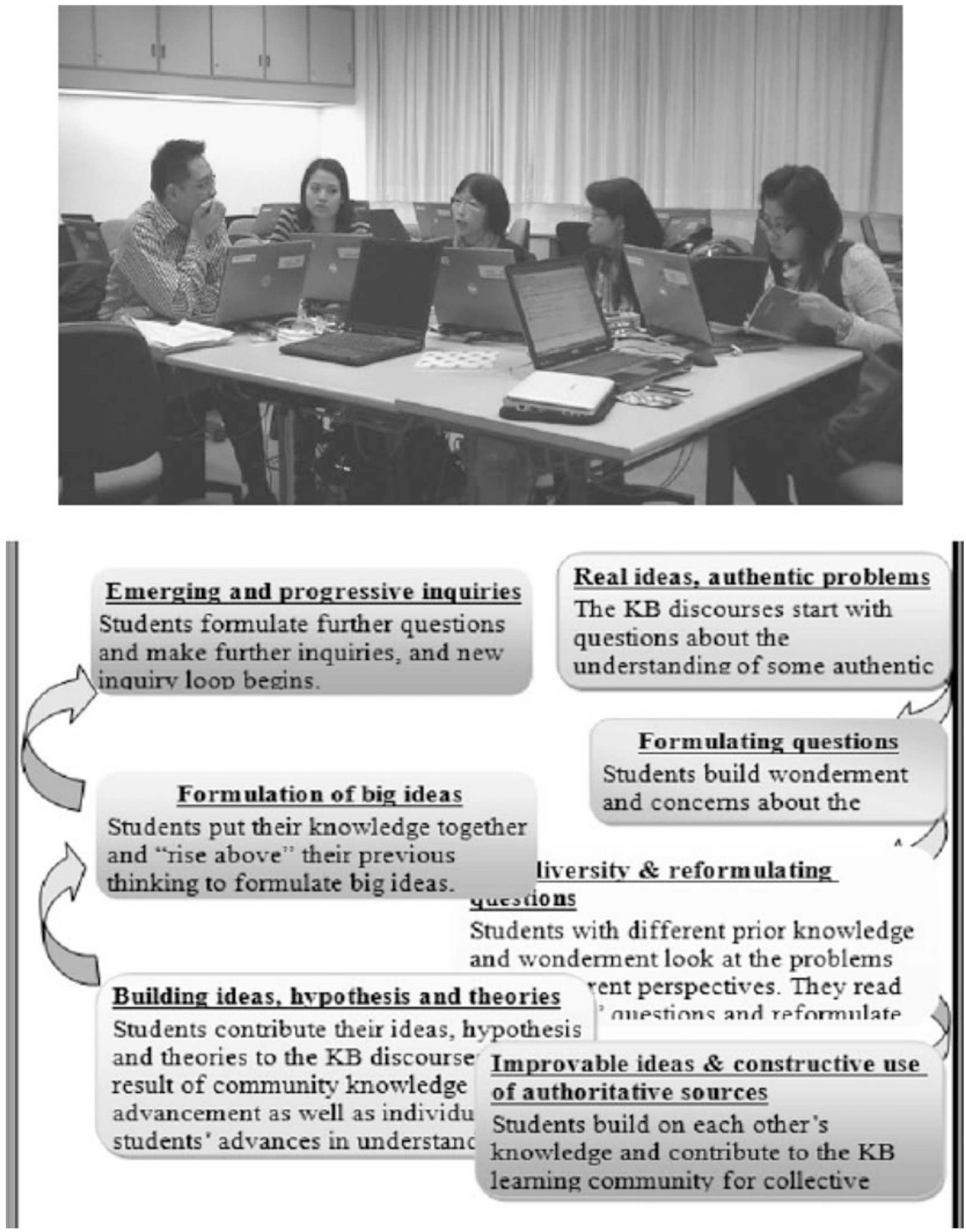

Fig. 14.2 Teachers creating an artifact for inquiry into knowledge-building principles and practice

worked on building knowledge together using a teacher database. For multiple zones of proximal development, year 2 teachers might share with newcomers the problems they encountered and strategies employed when they first started with knowledge building while they tried to further what they needed to know by working with the more advanced teachers. Seconded teachers act as peer coaches who work at the edge of their competence, providing models for new teachers while they work with their peers and researchers to improve their designs. Changes seemed to be emergent and voluntary, with some teachers spontaneously grouping together to open their classrooms for visits from network teachers, identifying intriguing examples of student discourse for inquiry, or videotaping their own lessons as shared artifacts. At the same time, there were also unexpected surprises, as when some strong teachers stopped participating.

Another theme was to work toward creating new knowledge using a design-based approach. While these teachers were from different curriculum areas, many were interested in designing assessments to foster knowledge building. For example, one seconded teacher spontaneously examined what she did in year 1, tried a new design in year 2, and brought back ongoing student forum work for group discourse. The collaborative inquiry led to another round of designs that employed more technological affordances (i.e., reference notes) while tapping into the idea of collective cognition. Her design efforts were scaffolded and advanced by others' questions. Meanwhile, another teacher in the group developed a related design but one more relevant to his classroom context with low-achieving students. During the process, teachers and researchers were co-inquirers and co-designers—these teachers scaffold their students to reflect; they created assessment artifacts while they were advancing their knowledge about concurrent assessments of knowledge building.

Technology-Enhanced Inquiry

The technology used in KBTN includes Knowledge Forum and its related suite of assessment tools (Table 14.2). Although KBTN teachers could use the basic functions of Knowledge Forum, they did not understand how the technology affordances are connected to the principles for fostering collaboration. One strategy is to have teachers work on a teacher database during meetings, as teachers usually do not have time to write on the forum. Phase two set aside time during teacher workshops to encourage teachers to write on the database. Teachers were asked to work on Knowledge Forum to inquire into some authentic problems or to use rise-above notes to track progress. One new teacher commented, "I thought writing notes was easy and here when I am trying to build on what others have written and to articulate my views and synthesize some ideas, I began to see more what my students have to be working on."

In order for teachers to use the technology, it must be ecologically compatible with classroom and school norms. Teachers need to find out whether their students benefit from the innovations; assessment

Fig. 14.3 Using the Applet tools for formative assessment of student participation on Knowledge Forum

of student work on Knowledge Forum thus becomes important. Teacher development design includes working with teachers to use the assessment tools in ways that connect with both principles and classroom needs. The software Analytic Toolkit (ATK) and Applets, which accompany Knowledge Forum, can provide overviews of student work, using server logs to identify usage statistics. ATK basic indices—write, read, revision, scaffolds, links, and keywords—can be used by teachers for formative assessment with students. Another set of assessment tools used by KBTN teachers are the Applets for Social Network Analyses—these analyses provide information on note-reading and build-on density to show if students are interacting with each other. The ATK and Applets are tools for researchers and teachers, and they can also be used by teachers and students to assess their own progress. KBTN teacher development activities include helping teachers use these tools in ways to further their understanding of knowledge building. For example, teachers use these tools to find out whether their students were developing more connectedness as a class community (Fig. 14.3). Although there are different levels of uptake, some seconded teachers have developed repertoires in using these assessment tools and integrated them into their classroom work.

Phase Two (2006–2008): Analysis and Ongoing Evaluation

The network began with seven teachers as seconded teachers; since its second year, the project has had about 40–50 teachers participating. While there is considerable fluctuation, more than 25 teachers have continued with the practice for more than 3 years. Although the number is modest, this continuity suggests that the use of CSCL pedagogy has become more regular and integrated into the practice of some teachers.

Changes in the Quality of Student Discourse

Teachers joining the project were facilitated to implement knowledge-building curricula supported with Knowledge Forum. Students from Grades 4 to 12 worked on different curriculum areas and inquiry topics in science, humanities, and language, including environment, energy, human body, sustainable development, poverty, community, identity, political participation, and reading novels. These topics have been adapted into the curriculum in relation to the requirements of schools and the Education Bureau.

There were 40–50 teachers each year, and most worked with one class, although some led more than one class or collaborated with other teachers. We selected the classroom work that lasted for at least 3–4 weeks for analyses of participation and quality. In the first 2 years, there were many databases with scattered and fragmented notes; some databases included only one or two notes per student. By year 4, more classrooms were participating actively, with students contributing from 4 to 20 notes each.

The quality of student discourse on the forum was examined using a scheme developed jointly by the researcher and the teachers, arising from the need to provide some overview of the quality of stu-

Table 14.3 Changes of the quality of student discourse on Knowledge Forum for KBTN classes (2006–2010)

Year	Quality rating of student discourse				Number of classes
	Fragmented	Knowledge sharing	Knowledge construction	Emerging knowledge creation	
2006–2007	12 (30%)	18 (45%)	7 (17.5%)	3 (7.5%)	40
2007–2008	28 (41.0%)	23 (33.7%)	7 (10.8%)	10 (14.4%)	68
2008–2009	8 (12.7%)	37 (58.7%)	12 (19.1%)	6 (9.5%)	63
2009–2010	10 (18.9%)	20 (37.7%)	15 (28.3%)	8 (15.1%)	53

dent discourse to guide further classroom work. The coding scheme, adapted from types of knowledge-building discourse (van Aalst, 2009), consists of four levels: (a) fragmented and assignment-oriented, (b) knowledge-sharing, (c) knowledge-construction, and (d) emerging knowledge-creation discourse. The new scheme was tested with some databases (Chan & Fu, 2011) and extended to the range of classroom databases. At the lowest level, students wrote fragmented or unconnected responses to teacher questions with short exchanges; the next level called knowledge sharing refers to superficial interactions with conversational exchanges and the sharing of opinions and information. Toward a more productive discourse, knowledge construction involves the co-construction of ideas identified with statement of problem, questions, and explanation and the constructive use of information. There were some discourse threads that reflect emerging knowledge creation with meta-discourse, emergent questions, and awareness of community dynamics with reference notes as well as rise-above notes.

The various classroom databases were examined for the quality of student discourse on Knowledge Forum. Typically, each of these classes consisted of several views (discussion areas), and only the view with the best discourse was coded to represent what students could do. Table 14.3 shows the patterns of discourse over the years 2006–2010. By the end of year 4, fewer classes showed students writing fragmented responses or providing answers to teacher questions as was observed in the preceding years. There was also a reduction in knowledge sharing discourse and an increase in knowledge-construction discourse patterns. Although this rating scheme only provides an overview, the analysis helps to identify key patterns that distinguish information-sharing from knowledge-construction discourse and that can be used by teachers. At the same time, it provides a basis for further research currently being undertaken to unravel the discourse patterns, to examine how discourse is created in the social context, and to explore how teachers may use it to scaffold student discourse.

Changes of Student Participation

As the seconded teachers are the key players in the network, it would be useful to examine how or if they have changed over the years. Following the analyses employed in the study of knowledge-building teachers, the participation patterns of their students were examined to identify any changes. Three quantitative indices, derived from the Applet tools, were included: (a) the students' contribution to the community, based on the number of notes written; (b) their awareness of the contribution of others, based on the density of note reading; and (c) their connectedness with others' notes, based on the density of linked and build-on notes (Zhang et al., 2011). The density of a network is determined by the number of lines between nodes divided by the maximum number of all possible lines, the value being between 0 and 1. The increased note-reading and build-on density suggests that the classroom communities of these seconded teachers were becoming more connected (Table 14.4); these indices are comparable to those of knowledge-building teachers in Canada (Zhang et al. 2011).

Table 14.4 Changes of student contribution toward more connectedness based on the Knowledge Forum Applet indices for seconded teachers

Teacher	Number of notes written		Note-reading density (%)		Build-on density (%)	
	2008–2009	2009–2010	2008–2009	2009–2010	2008–2009	2009–2010
TLC	5.5	19.2	41.66	85.71	13.76	32.63
TTH	19.9	25.2	94.2	95.4	27.36	33.23
TPY	12.2	12.5	95.15	100	33.28	37.98
TSW	10.1	4.2	82.07	97.89	17.63	26.84
TSY	6.7	17.7	66.31	90.64	16.29	31.41
TWS	5.0	14.8	80.55	88.06	19.66	43.37

Shifts in understanding.

KBTN provides a rich test bed for different analyses to understand knowledge-building innovation. Currently, analyses are being conducted on teacher beliefs and practice, and there are several possible areas that may contribute to the teachers' growth; these areas reflect teachers' shifts in understanding and suggest areas for further inquiry:

(a) Pedagogical model. A knowledge-building inquiry pedagogy model was developed and adopted, incorporating the principles and featuring four phases appropriate to the sociocultural context: (a) creating knowledge-building norms and cultures, acculturating students to collaborative dynamics in classrooms; (b) problem-centered collective inquiry, extending classroom discourse and inquiry within the forum; (c) synthesis and rise-above, working toward community knowledge by synthesizing notes and creating new views for rise-above; and (d) embedded and concurrent assessment, conducting assessments to foster knowledge building. This pedagogical model was first employed by one or two teachers, was refined, and is now widely practiced within the network. While Scardamalia and Bereiter (2006) argue against activity structure, these cyclical phases are principle-based that align with the sociocultural contexts. Empirically, they were derived from failed cases and iterations in which teachers introduced Knowledge Forum without first working with classroom norms, and the other phases were gradually developed over the years based on teachers' classroom experiences.
(b) Principles of assessment and assessment artifacts. The idea of designing e-portfolio assessment to examine and foster assessment has been developed in research studies (Lee et al., 2006; van Aalst & Chan, 2007). Within the KBTN, this model was examined, tested, and refined in multiple sites, with adaptation and appropriation being used to determine how it might best suit different curricula and school levels. The e-portfolio was relatively complex, and iterative design efforts were developed with designs that were more applicable to the classrooms. For example, several teachers now work with students to come up with what they consider to be good examples of discourse and from there to derive the principles by which they could assess their own discourse.
(c) Knowledge-building in nonscience domains. The knowledge-building model has been used almost exclusively in elementary science in the international literature. Traditionally, social sciences and language teachers usually focus on argumentation. The KBTN language teachers have moved beyond the usual genre of argumentation to examine how knowledge building that focuses on theory revision might work in nonscience areas. Some examples include having students work on concepts such as "filial piety" or "poverty," viewing them as objects of inquiry, and moving from naïve, common sense ideas to more sophisticated notions. It is not yet clear what these lines of inquiry might yield; however, they involve more than sharing good practice and may include building new knowledge and make possible research into the intertwining areas of argumentation and knowledge building.

While there were some advances and, in particular, growth of some teachers, there were also many challenges. Primarily, knowledge building itself is a complex model, and scaling up in ways that preserve its nature yet remain applicable to a large number of teachers is challenging. Relying on expert teachers as key resources for spreading innovation is the dominant strategy, but how peer coaching works is relatively unexplored. However, through failed and successful attempts, uneven patterns and wide variations, surprises, growth, and attrition, there has been emergent growth in the teacher network with many teachers sustaining the practice over the years and developing new innovations.

The Micro-Context: Knowledge-Building Practice in the Classroom

This section reports on classroom design and illustrates how research can be integrated into the classroom level by focusing on principles, technology, and sociocultural dynamics. For macro-level reforms to succeed, classroom design and processes and how they can be supported by meso-level changes must be examined. Barab and Luehmann (2003) note the need to examine how teachers accommodate changes to research models for sustained innovative practice in the science curriculum. There are various other cases of knowledge-building teachers (e.g., Chan (2008) and van Aalst and Troung (2010)); this particular case has been selected because the teacher has sustained the practice and has remained close to the model while appropriating it to suit the local context. Although Mr. K's practice is not the most typical among other teachers, it shows possibility and vision, and it serves as an impetus for others to make changes as they spread the innovation.

Background

Mr. K is a chemistry teacher who has sustained knowledge-building pedagogy in his classroom for over 8 years (2002–2010). He is a key KBTN member, both as a classroom teacher and as a teacher associate providing support to new network teachers. While knowledge building is conducted mostly in elementary science classrooms, Mr. K introduced knowledge building to his senior form (Grade 12) chemistry students in 2002 following the work of another teacher. After the initial round, Mr. K implemented knowledge building with a cohort of Grade 10 students. Interestingly and fortuitously, this coincided with the global SARS crisis and a 5-week school suspension in Hong Kong. Whereas many teachers in Hong Kong used the Internet merely for information delivery during this period, Mr. K's students worked on Knowledge Forum, inquiring into chemistry problems of which some were related to the SARS problem (e.g., chlorine bleach as a disinfectant). This was an important early experience for Mr. K—with limited teacher instruction, the students took on major collective cognitive responsibilities in pursuit of understanding. In the following years, Mr. K continued his practice, which varied in complexity depending on organizational constraints such as workload. His practice was enriched by his KBTN participation, and he, in turn, contributed to the teacher network. The following section uses his most recent two iterations of Grade 10 classroom design.

Classroom Design Integrating Principles with the Sociocultural Context

As discussed before, the knowledge-building inquiry pedagogy model was a special feature developed in KBTN and was implemented in this chemistry classroom (Fig. 14.4). Table 14.5 shows further how the principle-based curriculum design was appropriated to the sociocultural context of Hong Kong classrooms. Primarily, the teacher started with creating a collaborative knowledge-building culture helping students to make their ideas public followed by research and collective inquiry on Knowledge Forum. Students continued to improve and advance community knowledge through creating higher-level ideas and meta-discourse using Knowledge Forum affordances, as well as advancing their collective knowledge through concurrent and embedded assessment with new emerging questions. It is useful to note that emphasis was given to emergent and cyclical inquiry rather than linear steps to follow (Fig. 14.4). Scardamalia has proposed a set of 12 principles; the KBTN teachers in Hong Kong have focused on five of these principles most applicable in the classrooms. The following is an interpretive account to illustrate how the teacher employed a principle-based design while appropriating the model to the sociocultural context.

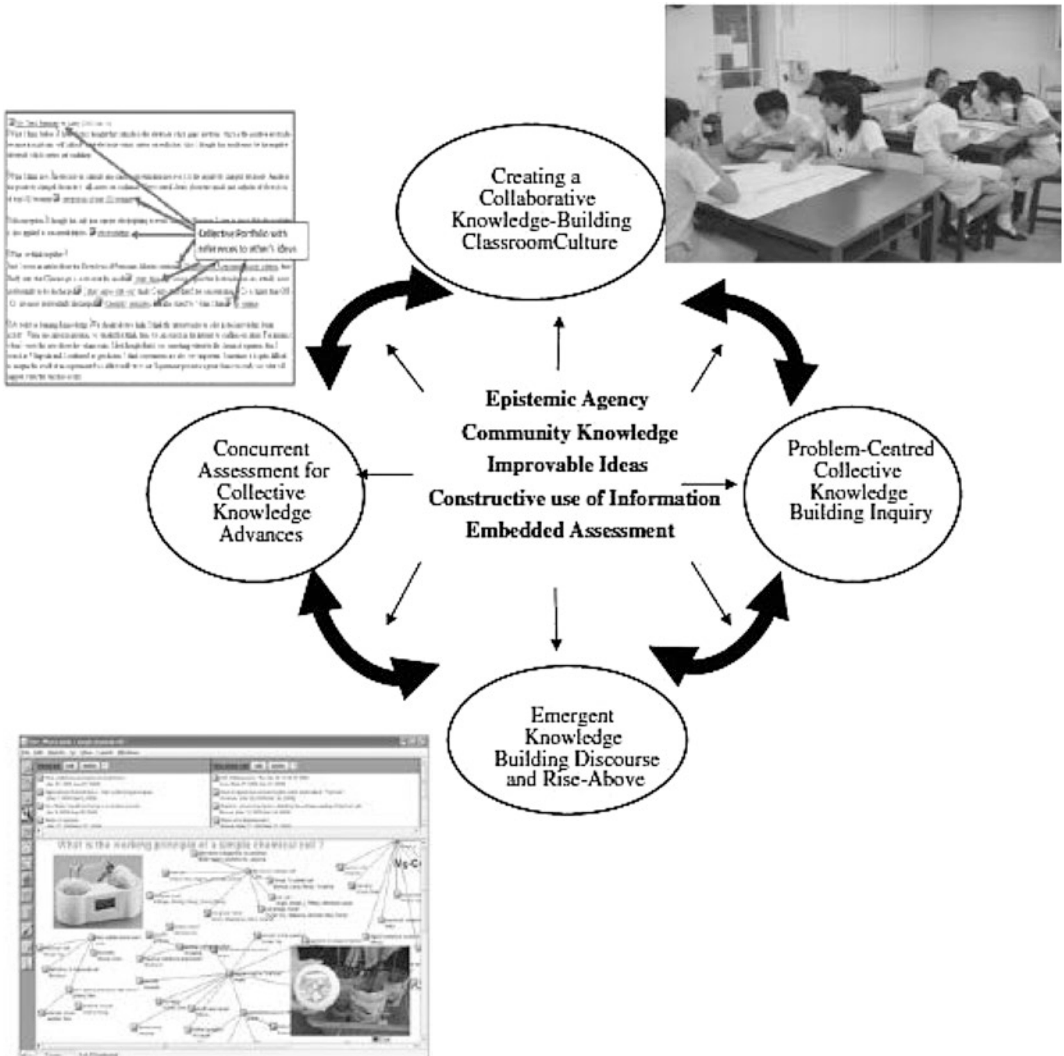

Fig. 14.4 Knowledge-building inquiry pedagogy model developed in KBTN and implemented in a chemistry classroom

Epistemic Agency

In Hong Kong classrooms, where students are used to teacher-centric knowledge transmission, KBTN teachers, including Mr. K, usually start by changing classroom norms through classroom discourse, in what some would call phase one of the model. The teacher encouraged students to start to engage in discourse in dyads, groups, and class communities. This is quite different from knowledge-building classrooms in Canada, where students start their inquiries directly on Knowledge Forum. The same pattern is adopted in both Hong Kong and Singapore classrooms, reflecting the role of socio-contextual influences in classroom innovation.

Reform-oriented teachers are familiar with the idea that students need to have ownership. This principle further emphasizes the epistemic dynamics of individual and collective cognition (Scardamalia 2002). Often, teachers set problems for their students to answer, solve, or explain, as Asian students

Table 14.5 Principle-based curriculum design appropriated with the sociocultural context of Hong Kong classrooms

Knowledge-building inquiry themes	Principle-based pedagogy
Creating a collaborative knowledge-building classroom culture	Hong Kong students used to transmission mode acculturated into the practice of putting forth their ideas to the public for inquiry and improvement
	Students articulated ideas for inquiry, raised questions, commented on others' views, elaborated explanations; core curriculum ideas as well as routine school materials turned into objects of inquiry
Problem-centered collective knowledge-building inquiry	For spatial-technological constraints, Hong Kong students worked on knowledge forum at home
	Teacher provided models initially (e.g., I wonder)—Students posed authentic problems, made conjectures, co-constructed explanations
	Knowledge forum affordances (e.g., scaffolds) prompted epistemic agency for theory revision. Students made constructive use of information and worked on improving their collective ideas for theory building
Emergent knowledge-building discourse and rise-above	Competition common in Hong Kong classrooms is melded with collaboration
	Model-based explanatory inquiry—Students initially worked in own groups to construct the "best" chemical cell; they then explained and compared different models putting their knowledge together supported with forum affordances
	Students worked collectively on "rise above," "references," and meta-discourse for coherent explanations and building community knowledge
Concurrent assessment for collective advances	Integrate collective assessment with domain understanding needed for public examination
	Students viewed notes on forum, assessed and reflected on their initial beliefs and conceptions, and tracked their changing ideas supported with conceptual-change scaffolds on knowledge forum
	Students grappled with alternative models sparking idea improvement, wrote e-portfolio with meta-discourse for advancing collective knowledge, and raised new emergent questions for continued collective inquiry

expect good teachers to do. Mr. K's strategy involves modeling through examples, gradually relinquishing cognitive responsibility to the students. Although the researcher had suggested that students put forth their own ideas and questions, the teacher initially posted problems on Knowledge Forum but tweaked them in ways that encouraged students to gradually begin posing problems of their own. It is not clear whether this was intended or emergent; however, it is perhaps another example of a teacher appropriating the knowledge-building model in relation to social-cognitive processes and sociocultural context.

While the initial questions were either shallow or textbook-based, the teacher worked with students to help them to pose authentic problems that needed to be explained using chemistry principles (e.g., silver tarnish and redox). They examined differences between their ideas and those of others and worked to resolve them to spark knowledge advancement. In phase two, when they collaborated further on Knowledge Forum, cognitive technological dynamics supported their epistemic agency—KF scaffolds (e.g., I need to understand, my theory, new information, putting our knowledge together) are not merely *sentence openers*; they are *epistemic scaffolds* to help students pose problems, put forth preliminary theories, construct and refine them, and synthesize and put their knowledge together. Epistemic agency continues to be a challenge given the important role of teachers in Asian classrooms—Hong Kong students might be actively engaged in knowledge construction, but they need to shift further toward engaging in knowledge-creation efforts as part of a scientific community.

Community Knowledge

The major shift needed to establish a knowledge-building classroom is to help students understand that rather than working as individuals, they can act as a community to make advancements collectively. Mr. K and other KBTN teachers had the challenge of getting their students, who are used to a competitive Asian school system, to accept one that prizes individual and collective growth equally. At the beginning, some students might have felt that sharing their best ideas with others on Knowledge Forum would hurt them in examinations, and teacher discourse at the KBTN addressed this. From the start, Mr. K used group concept maps, posters, and knowledge-building walls to make ideas public, a strategy developed simultaneously in knowledge-building classrooms in other countries. As students continued their inquiries on Knowledge Forum, they gradually seemed to realize that individual and collective knowledge growth interact and go together. Phase three includes a synthesis of different ideas in “rise-above” notes and reflective summaries that further capture and scaffold students’ community knowledge. Competition is common in Asian classrooms. It seems paradoxical, but Mr. K cleverly *melded* competition with collaboration—student groups first competed on constructing the best chemical cells, and then these different models were put on Knowledge Forum as objects of inquiry, for the class’ collective knowledge advances about chemical cells.

For ongoing analysis of and feedback on his classroom design, the teacher, as did other KBTN seconded teachers, employed ATK and Applets to track the participation and connectedness of the class community. The integration of CSCL technological and assessment tools into classroom practice helped him to gauge whether his class was improving as a closely knit social network, and he discussed such assessment information with his students as he reflected on the design.

Idea Improvement

This principle emphasizes viewing ideas as objects of inquiry—the quality and coherence of all ideas can be improved upon through collective work. Mr. K encouraged students to put up their ideas for inquiry so the community could work on improving the ideas and explanations. Different practices in Mr. K’s classroom, ranging from building onto others’ ideas for theory refinement, rise-above notes, and reflective summaries, all reflect the focus that ideas can be improved. Idea improvement has metacognitive and epistemic aspects—students examine ideas and consider what needs to be improved and how (e.g., how can these ideas be better? What else do we need to know?)

In some ways, idea improvement is an interesting principle for Asian teachers and students with the typical Chinese learners’ appreciation of the importance of effort (Watkins & Biggs, 1996). The KBTN teachers, including Mr. K, tweaked in ways to include both cognitive and social aspects; Mr. K emphasized that all ideas are improvable (object for inquiry) and that students could improve and should help each other to improve their ideas. Although improvable ideas is an epistemic concept different from the notion that students should improve themselves, the perplexing congruence of cognitive and socio-affective dimensions may work together. A delicate balance exists in how teachers interpret improvable ideas so they do not just assimilate that to the common notion of improvement but to keep working at the pursuit for epistemic quality.

Constructive Use of Authoritative Information

Knowledge building for creation of ideas involves knowing the present state of knowledge as well as working at the cutting edge. This principle emphasizes students’ use of authoritative resources along with other information as resources for idea improvement and theory revision. Knowledge Forum also includes scaffolds such as “new information” on which students can base their elaboration and revision of their theories. With the emphasis on learning how to learn and project-based learning, teachers in Hong Kong are quite familiar with the notion of information search, but they need to advance such understanding for more emphasis on using information for theory building.

Mr. K encouraged his students to make constructive use of information, providing evidence as they explained their theories. Generally, the class started with students posing questions and problems, and, as they worked to solve the problems, they would seek information from Internet chemistry databases, including Wikipedia, in support of their knowledge-inquiry processes. At the beginning, students tended to copy information from the Web directly as answers to their peers' questions, and after a short exchange, discourse stopped, and inquiry was considered as completed. The teacher and the KBTN group worked on these debilitating strategies and student beliefs. Classroom discourse was conducted on students' different ways of using authoritative information and how they could use such information to elaborate and revise their theories for further inquiry. It is another challenge as Asian students usually view textbooks and teachers as authoritative sources. Analyses of e-portfolio on Knowledge Forum indicate that some students began to question the textbook information as they pursued new understanding ("I have not considered those other factors…. Our textbook often shows electrode smoothly covered with the metal, but it is not so in real life").

Concurrent and Embedded Assessment

This principle emphasizes assessment as a way to advance community knowledge. Often, assessment is an external measurement; here, it is used to foster and scaffold collective inquiry. While the other four principles have all been widely discussed elsewhere in the knowledge-building literature, this principle has attracted much attention from Hong Kong teachers and has been advanced through the collective efforts of KBTN teachers.

Mr. K and other KBTN seconded teachers attached much importance to assessment throughout the process. Typically, ATK was used to track student progress for formative evaluation. KBTN seconded teachers also developed the practice—explicit criteria of participation were developed with students so they could understand what was expected of them in terms of reading, building on, and contributing to others for community advancement.

Mr. K first adopted the e-portfolio from another network teacher and then adapted it into different forms as he interacted with other KBTN teachers. In the current design, his goal was to use assessment to examine and foster conceptual change. In the first iteration, the assessment scaffolds (e.g., what are some important ideas about X that you have learned?) focused much on the content of what students had learned, and the e-portfolio did not show the process clearly. These not-so-successful attempts then led to revision of the assessment design refined to include the conceptual-change scaffolds (e.g., what I thought earlier, what we discussed, what we now thought, what I have learned). This revision helped the students to reflect on their initial conceptions as they considered individual and collective advances. While this portfolio design was co-constructed with the researcher-teacher community based on the notion of collective cognition, it also aligned well with the needs of Hong Kong teachers and students for deep domain knowledge for examination purposes. Although the assessment approach has been useful, there is also the challenge of how KBTN teachers can tackle the tension between developing cultures of emergent assessment versus designing guided assessment tasks. This is an issue of continuing challenge among teachers in KBTN.

Analysis and Ongoing Evaluation

Classroom innovation in knowledge building involves teachers reflecting continually on the processes of their knowledge-building classroom designs. The process of inquiry also includes examining student progress and outcomes, as teacher development needs to be examined in relation to student growth. Formal analyses have been conducted with data sources including Knowledge Forum participation, Knowledge Forum discourse, conceptual-change tests, examination scores, and student and teacher interviews (for details, see Chan and Lam (2010)). A summary is provided here: data analyses show that students participated actively on Knowledge Forum (number of notes, 21.5; note-reading density, 99%; build-on density, 28%). Significant differences were shown on conceptual-change scores from pretest to posttest with a comparison class. Results also showed that the extent to which students were engaged in Knowledge Forum (ATK indices) was correlated with the quality of the collective inquiry (based on e-portfolio), which in turn predicts the conceptual-change scores. Discourse analyses suggest that articulation of "misconceptions," question-explanation sequence, and constructive use of information were important discourse patterns. Interestingly, the teacher took the initiative to analyze examination results and found that student participation and engagement on Knowledge Forum were correlated with their public exam results in chemistry.

Many teachers were hesitant to adopt innovative approaches for fear that they might harm exam results that measured different competencies. However, throughout his involvement, Mr. K has found that when his students wrote more and collaborated more with others, they obtained better examination results. This is an intriguing phenomenon that might be related to the teacher's belief that deep collaborative inquiry does not necessarily contradict with what is required in examination, a major challenge for CSCL/learning science research to be implemented in classrooms. This is not a widespread belief, and other KBTN teachers have dropped out of the project due to exam pressures. These perplexing variations highlight the need to understand teacher beliefs in relation to the sociocultural-historical milieu of the classroom systems.

From the perspective of coordinated changes across levels, Mr. K's classroom innovation was supported at the school level as it coincided well with the government's call for pedagogical and technological innovation. His practice was nourished by the teacher network at the meso-level, and he, in turn, enriched the network through sharing experiences and building his knowledge with others. His innovation can be sustained because it is principle-based and appropriated for the contextual dynamics of the Hong Kong classroom. Over the years, the teacher's sustained practice is supported with design-based research leading to continual improvements in the innovation. Such practice fits well with the notion of social infrastructure considering beliefs, practice, technical-spatial characteristics, and connections with the outside community (Bielaczyc, 2006).

Mr. K has a strong academic background and he is now engaged in thesis research. The diffusion of his sophisticated model to other teachers will certainly take much time. As with most Chinese teachers that value classroom organization and structure, the teacher constantly grappled with tensions of carefully guided design versus emergent understanding and culture. Knowledge building requires teachers to surpass themselves, but given the strictures and pace of Hong Kong curricula, whether these expert teachers can appropriate the necessary space to grow and not just plateau at a certain performance level also bears consideration.

Key Themes and Lessons Learned for Integrating CSCL Research and Practice

This paper has addressed the limited impact that research has on classroom practice and has examined issues related to how CSCL research can be integrated into classroom systems for educational impacts. A case study of implementing and scaling up knowledge building in Hong Kong classrooms has been illustrated at the macro-, meso-, and micro-levels (institutional support, teacher network, and classroom practices, respectively). Figure 14.5 is a schematic representation of context, processes, and dynamics at different levels for classroom innovation. Three main themes have emerged—context and systemic changes, capacity and community building, and innovation as continual inquiry. These themes will now be discussed to address questions of designing collaboration for educational innova-

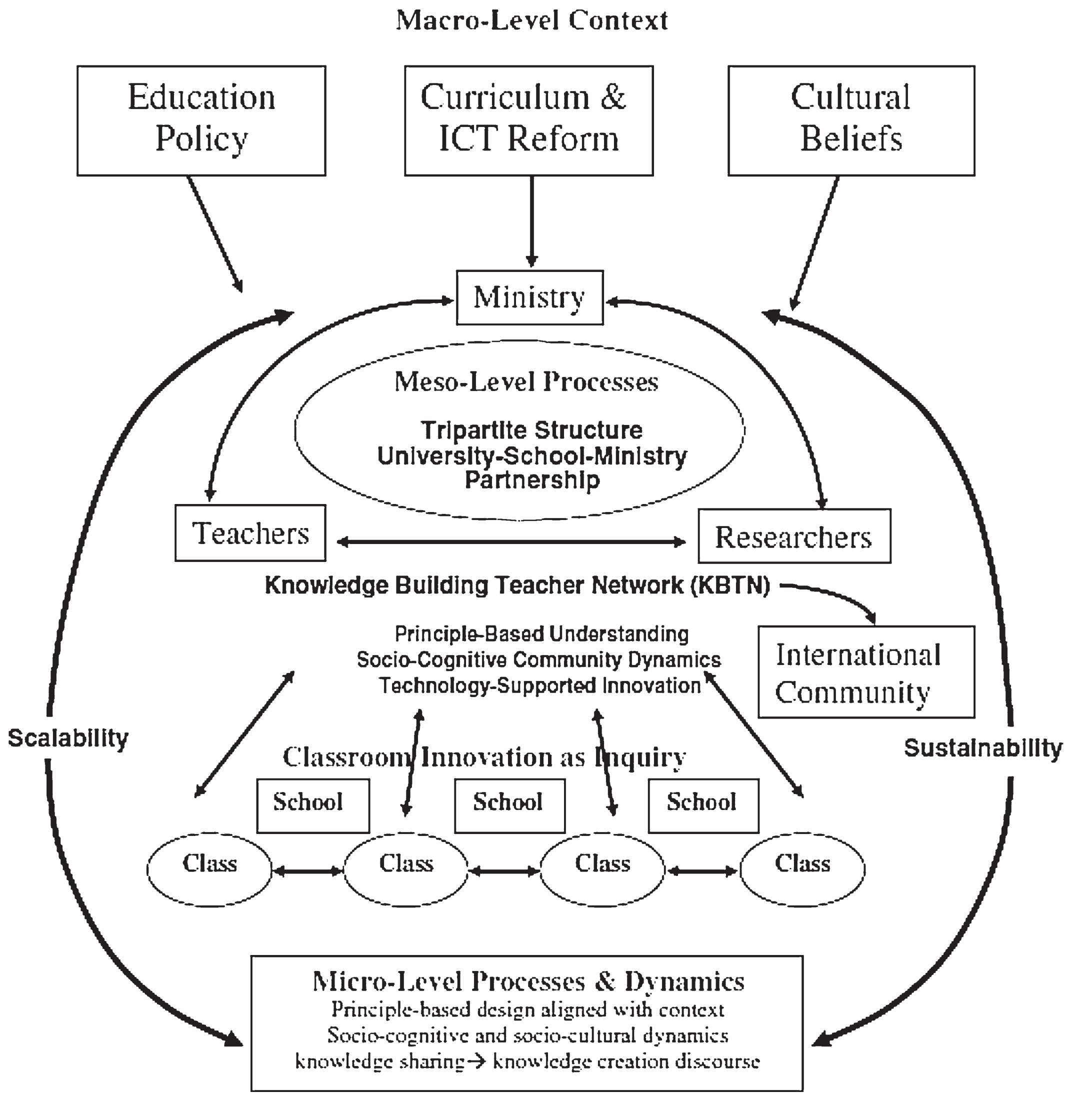

Fig. 14.5 Contexts and dynamics for sustainable knowledge building in Hong Kong classrooms

tion and to explore conditions facilitating knowledge creation and sustained innovation for educational impact.

Context and Systemic Changes

The first theme is that designing collaboration for classroom innovation is complex; changes are emergent, and facilitating conditions would include examining and aligning goals and processes that occur at multiple levels. While the macro-level provides the initiative, actual change takes place at the evolving meso- and micro-levels with feedback to different levels. The following discussion examines different levels, but emphasis will be given to coordination and alignments for facilitating classroom practice.

Education Policy, Curriculum Reform, and Cultural Beliefs (Macro-Level Processes)

At the outset, policy context sets the stage for innovation and change by institutionalizing as well as encouraging school-based pedagogical and technological development (Dede & Honan, 2005; Goldman, 2005). Against the macro-contexts of major policy changes for education and ICT reforms, the Knowledge-Building Teacher Network was developed to implement the educational model of knowledge building and to advance both research and practice. KBTN is designed to help teachers, principals, parents, and policy-makers view the research model as consistent with the goals advocated in education reform initiatives, such as communication, collaboration, inquiry, and technology-enhanced learning. For educational impact, CSCL research must be aligned with the goals of education reforms.

Researchers have suggested that ministries of education are often unwilling to fund research into questions in which they have no interest (Schoenfeld, 2006). As such, one consideration of policy-research-practice synergy is to examine how to identify and reframe questions so that they align with ministry goals while still advancing the research agenda. CSCL research can drive educational reforms, and examining the nature of collaborative learning and how CSCL pedagogy and tools can work in the classroom is important to research and practice. Just as macro-context and institutional contexts influence research and classroom implementation, innovative models and new insights derived from the classrooms may also influence government policy decisions.

Macro-level processes include institutional changes as well as historical-cultural-epistemological values and norms influencing changes at other levels. While ministry-defined education reform goals for the twenty-first century emphasize skills, school communities often see these pronouncements as clichés that may weaken the existing curriculum, and collaborative learning is viewed as merely conversation rather than as a knowledge-building process. Lessons learned from this study suggest that insights from CSCL and learning sciences research—which emphasize deep knowledge for inquiry-based learning—could help to allay teachers' concerns, with KBTN bringing these findings into the schools. As discussed before, the revamping of curricula in accord with new reform goals often must proceed alongside a continued emphasis on examinations, even though these ideas seem incompatible. This is not the case in Asian schools alone—researchers in the West have also had to address the problem of developing collaborative inquiry while dealing with institutional constraints and increased emphasis on standards and testing. The various tensions and constraints related to macro-level societal, political, and cultural concerns and alignments are challenges that need to be considered everywhere.

Enabling Structure and Partnership (Meso-Level Processes)

Collaboration and partnership are key components of systemic change—improvement efforts should involve participation and support from people at multiple levels. While macro-level policy and institutional changes may set the stage, wide gaps exist between educational policies, research findings, and the classroom.

University-school partnerships adopted for large-scale educational innovation (e.g., Fishman et al., (2004) and Laferrière, Erickson, & Breuleux, (2007)), and here with KBTN, can facilitate useful meso-level processes for aligning changes and creating partnership and collaboration. While ministries, schools, and universities can be seen as distinct groups with different cultures and diverse interests, they may intersect with each other as they advance toward their respective goals. The government's reform goals may be carried out in schools with the support of expertise from university members; researchers may receive government funding and endorsement to introduce new ideas with access to school sites; teachers may meet ministry reform benchmarks with professional development support from universities.

Meso-level processes involve mapping, translating, interpreting, and linking the discourse of different parties and communities. The KBTN efforts include adaptation of macro-level emphasis and contextualizing research discourse at the pedagogical sites, such as interpreting educational reform goals in line with a knowledge-building model, working with teachers to align school demands and requirements, setting up technology that fits classroom and teacher needs, designing pedagogy that meets the assessment and examination demands prevalent in Asian schools, and helping teachers to understand changes in student collaboration and discourse. Different parties may work together in building new knowledge despite having different goals. Scardamalia describes a knowledge-building principle she calls *symmetrical advances* (2002), which may be employed to describe such phenomena of collaboration across different sectors.

Alignment of Cognition, Design, and Context (Micro-Level Classroom Processes)

Integrating CSCL in classroom practice requires careful orchestration including coordination of curriculum, pedagogy, and technology affordances (Dillenbourg et al., 2009) and consideration of the social infrastructure of classroom innovation (Bielaczyc, 2006). Zhang (2010) argues for the importance of bridging macro- and micro-level beliefs and practices. Looi et al. (2011) note that it is not enough just for researchers to conduct their question of interest, but they need to consider how different parts can be coordinated to fit the classroom ecology. Studying CSCL research-based innovation in Asia is particularly interesting due to the tensions and dilemmas involved. While Chinese and Asian students have been described as collectivist, they are still, paradoxically, highly competitive and place much emphasis on individual achievements.

One of the lessons learned about sustained practice is that there needs to be acknowledgment and accommodation of the model in light of macro- and meso-level emphases. This paper has described one teacher's emphasis on principle-based design but notes that he also addressed sociocultural and contextual constraints and dynamics; for example, the traditional emphasis on assessment in Hong Kong is capitalized on and adapted by the teacher network into innovative designs of e-portfolios for different subject areas. Designing for collaboration for classroom innovation requires integrating and adapting CSCL pedagogy and technology in ways that align with students' beliefs as well as appropriation to the sociocultural contexts. Classroom design needs to be informed by principles to retain the spirit of the research, but activities may vary based on macro- and meso-level processes and constraints, contextual dynamics, and sociocultural milieu. While this paper illustrates these transforming processes using the example of Hong Kong classrooms, this theme is important for research-based innovation in other classroom systems.

Building Capacity and Community Building

A major challenge associated with research impacting on classroom practice is the capacity gap (Fishman et al., 2004) and the need to build up human and social capital (Resnick, 2010). How do teachers come to adopt the innovation facilitated by different people coming into contact with each other and using new technologies? This theme examines the social-cognitive, epistemological, and spatial-technological dimensions of capacity building and the alignment of changes across these dimensions and within multiple contextual levels.

Socio-Cognitive and Community Dynamics

Communities of practice have now become major approaches to teacher professional development. For collaboration and innovation to take place, it is necessary to create opportunities for teachers to reflect on their ideas and interact with their peers, including articulating conflicts and difficulties.

Teachers are busy and have little time to work with researchers on classroom innovation. Institutional support, in the form of macro-level policy and meso-level school culture, ethos, and norms, is needed; for example, the KBTN employed a teacher secondment scheme to ensure that teachers would have sufficient release time to work on research-based school projects. Infrastructure and resource support are needed for teachers to engage in innovation.

Consideration also needs to be given to the socio-cognitive dynamics of community building. KBTN consists of multiple levels of expertise; teacher leaders, seconded teachers, teacher associates, intermediate teachers and newcomers, and multiple zones of proximal development provide the opportunity to spark knowledge advances. There are different patterns and trajectories of growth as well as tensions and contradictions as some teacher groups developed fast and others dwindled. The conflicts and failed attempts in the early years of the project seemed useful as teachers need to work through contradiction for revision of their models and practices, and such inquiry needs to be supported in a community. Furthermore, communities are important in that these teachers are engaged in new endeavors against a background of strong demands for examination. As they share their practice, they also obtain support from others who are embarking on similar ventures.

A more challenging aspect of research-based innovation and teacher development is that teachers need to move beyond sharing experience to collective knowledge building. KBTN encourages network teachers to understand and own the innovation by engaging in knowledge building, just as they would hope their students do—write on a teacher knowledge-building database and engage in knowledge-building discourse to tackle difficult classroom innovation problems. Teachers need to experience collaborative inquiry and building knowledge to understand and to engage in socio-cognitive dynamics of working as emergent communities, both within the teacher network and within larger networks. Some teachers in KBTN are connected with other networks locally as well as internationally (Laferrière & Law, 2010); the challenge and direction is to create these networks as productive mutually supportive communities.

Principle-Based Understanding and Epistemological Shifts

Inquiry-based classroom innovation is difficult for teachers because it is not aligned with macro-level cultural beliefs or school norms and ethos. Teacher professional development often focuses on know-how, such as how to carry out some lesson activities or how to use a piece of software. Scardamalia and Bereiter (2006) note the importance of principle-based innovation; innovation requires epistemological change among teachers. This case study shows that in the beginning, KBTN teachers merely assimilated new innovation into their existing repertoire—some were posting questions on the forum and asking students to answer as assignments. Principle-based innovation is challenging but important and fruitful—the principles discussed at teacher meetings were implemented in classroom design, with feedback examined through the lens of principles; some teachers began to use principles to help students to become aware of their work on Knowledge Forum. As discussed above, the example at the micro-level also shows how the teacher can adapt his activities to the social underpinning of classroom while focusing on the key principles.

Design principles have been commonly used by researchers working on collaborative and inquiry-based learning in classrooms. The idea of principle-based innovation is to focus further on teachers' understanding concerning the nature of the model for innovation. Principles may make the complicated constructs more accessible to teachers for interpretation and integration into classroom life. This study refers to a set of knowledge-building principles, but the notion of principle-based understanding would be applicable to other CSCL research-based classroom innovation as well. For capacity building, moving from activity to principles is important—as teachers understand more, they may begin to *own* the innovation and become better able to sustain the practice and to adapt it across contexts.

Knowledge-building work in Toronto has demonstrated the role of the principle-based approach with a group of highly experienced knowledge-building teachers (Zhang et al., 2011). Teacher development in Asian classrooms could provide an opportunity to examine the extent to which a principle-based approach would work for new teachers or those from other cultures. Inquiry into principle-based understanding may address controversies between structured and emergent pedagogies—for example, overscripting (Dillenbourg, 2004), guided instruction or inquiry learning (Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006), and participant structures or principles (Bereiter & Scardamalia, 2008)—and may shed light on CSCL pedagogy.

Technology-Supported Inquiry and Innovation

How do teachers come together to learn about technology as they engage in innovation? This study highlights the importance of examining technology-enhanced innovation in relation to the complex sociocultural milieu of the classroom and epistemological issues. At the beginning, many KBTN teachers referred to this ministry-funded project as the Knowledge Forum project. Some teachers held the view that this project was about learning a new piece of technology to help their students to write more. As noted before, in one interview excerpt, one teacher seemed to feel that her students would learn more if she alone learned more about the software. There was a lack of understanding that CSCL research-based innovation required a fundamental change in their beliefs and practices; teachers' understanding of technology and collaboration situated in a sociocultural milieu needs to be examined to effect classroom innovation.

Research has shown that teachers go through different phases in adopting technology; communities of practice are useful for scaffolding and connecting technology use with principle-based understanding. One approach is to engage teachers in using technology in ways that are aligned with principles, pedagogy, and assessment, thus affording them deeper insights. KBTN teachers were encouraged to contribute to the Forum to help them experience how technological affordances connect with pedagogy. Tool development for the assessment of knowledge building is not just for research analysis; the tools can be placed in the hands of teachers and students so that they might take agency to reflect on their work. A major theme in teacher development is that of helping teachers to focus less on their teaching and more on student thinking; technology can be developed to facilitate such a direction in ways related to a deeper understanding of principles as it relates to teachers' classroom needs. To develop teacher capacity for classroom innovation, teachers need to develop deeper views of the integral relations of principles, pedagogy, and technology.

Classroom Innovation as Inquiry for Knowledge Creation

This theme considers reconceptualizing research and practice gaps when designing CSCL research for educational innovation. A key idea is to examine classroom innovation as an inquiry process across multiple contexts toward the creation of usable knowledge.

Design-Based Research and Hybrid Culture

A common belief is the dichotomy between scientific research and applied research. Methodologically, design-based research has been advanced in the learning sciences to put research into classrooms. In design research, the design and outcomes of each iteration are used to identify the refinements needed for the next cycle and to refine theory and design (Collins et al., 2004). KBTN includes multiple groups of teachers with various peripheral and legitimate degrees of participation. Teachers engaged in different forms of design-based research seemed more able to move further in shifts of understanding. The seconded teachers worked together on innovative approaches to improve assessment designs;

responses to these approaches were used to improve subsequent designs. In the case of Mr. K, his classroom design was developed over years with progressive approximation as he worked toward the goal of designing assessments to foster collaboration. Examples of new teachers engaging in design-based research provide other information illustrating the problems facing new teachers as they learn new CSCL-based pedagogy. The problems, hurdles, "misconceptions," and slow changes through the design as inquiry process help to illuminate that CSCL-based pedagogy is more than a simple intervention but requires an analysis of sociocultural aspects and changes in classroom culture. Design-based research is apparently an important methodology linking research and practice, but it is also complex and resource-intensive, and questions have been raised about the different ways to examine design-based research (Krange & Ludvigsen, 2009). It would be fruitful to examine different approaches to design-based research and how it might be best conducted.

Design-based research helps to bridge the chasm between teachers and researchers. Bereiter (2002) postulates the notion of a hybrid culture in which teachers and researchers work together—it is not necessary that researchers become teachers or vice versa, just that they work jointly and that each uses his or her expertise to tackle the common problems. For example, KBTN researchers are interested in theories and analytical schemes related to collaborative discourse, and teachers are interested in helping students produce better writing. The common problem, at a deeper level, is how to characterize knowledge building and how to scaffold students toward a more productive knowledge-creation discourse. CSCL tools and analysis schemes developed by researchers could be considered from a teacher perspective, while teachers could provide insightful information on how discourse is created in the social milieu. The discourse scheme that was developed based on KBTN work (Table 14.3) provided an overview of teachers' databases and opened up possibilities for further research into discourse moves. The key lesson is that researchers do not just ask schools and teachers to adopt pedagogy developed in other classrooms; they work together with teachers to create new usable knowledge. Co-inquiry and knowledge creation—not the imposition of ready-made innovation—is a key theme in designing and facilitating collaboration in professional communities.

Classroom Innovation as a Process of Inquiry

Goldman (2005) discusses educational innovation as a process of inquiry into practice. When innovation is a process of inquiry, effectiveness at different levels needs to be coordinated (Means & Penuel, 2005); for example, micro-level student interactions within the classroom learning environments need to be examined for classroom improvement, with the results fed back to the teacher network and evaluations informing the macro-context of the system. In particular, student growth must be a focal point, and teacher development must be grounded in student work. With a focus on innovation as inquiry, KBTN teachers and researchers work jointly using data on students' forum participation to understand more about student participation modes and discourse patterns; these analyses provide useful feedback for ongoing improvement of classroom design as well as design for teacher professional development. Teachers' understanding is examined to understand how their epistemology influences student collaboration. Teacher change is examined in relation to changes in student participation, and case studies of teacher growth are conducted to examine how teachers engage in principle-based understanding, make epistemological changes, and move toward more collaborative pedagogy.

While a design-based approach is useful for micro-level classroom research, CSCL in classrooms also provides opportunities for diverse methodological approaches that can be examined at multiple levels. CSCL researchers and teachers may work together to advance different research goals in synergistic ways. KBTN provides a rich test bed for CSCL inquiry, methodologies, experiments, and discourse analyses—the wide range of collaborative discourse contained in the multiple Knowledge Forum databases, for example, provides a rich data corpus for research analyses and advances.

Examining and inquiring into the processes of innovation at different levels are challenging but may enrich research methodology and create new and usable knowledge.

Conclusions

Researchers lament that there is limited impact of research on educational practice. This paper examined the problem of how CSCL research may be integrated into classroom systems in the context of implementing knowledge-building innovation in Hong Kong. The case study in Hong Kong illustrates how the macro-context of educational reform can bring about meso-level changes in the emergence of a teacher network to support innovation and how the research-based innovation can be practiced in the classroom when the teacher aligns the model with the socio-cognitive and sociocultural underpinning of the classroom.

CSCL for educational reform involves more than designing the best tools or providing CSCL technology for teachers and students; it involves complex and emergent changes that need to be coordinated across different levels. This account suggests that political forces, social mechanisms, cultural influences, technology use, and socio-cognitive dynamics interact in different ways, impacting innovation. It is important to address macro-level political considerations while developing meso-level enabling structures and aligning them with micro-level classroom changes. In particular, a teacher network may provide a meso-level structure that coordinates and regulates macro-level political, institutional, and cultural influences on micro-level classroom processes and student change. There are also lessons learned relating to building capacity in order to forge a hybrid culture to transcend gaps for community building. This paper also considered teacher development as knowledge creation, with teachers working collectively to build knowledge. Integration of new pedagogy and technology into the classroom needs to be considered in relation to sociocultural-historical and epistemological aspects of classroom life; principle-based understanding is important for innovation to sustain. Various examples have been provided as to how CSCL classroom innovation draws upon theoretical ideas while simultaneously inspiring research and analyses such as characterizing knowledge-building discourse and suggesting new ways of considering CSCL assessment and tools.

The contribution of this paper has been to highlight issues, questions, and possibilities, which can open up a discussion on how CSCL research may be examined in classroom and school systems for educational impact. It may be interesting to consider how lab-based studies of collaboration may be examined in classrooms; for example, researchers have now examined micro- and macro-scripting and educational perspectives (see Fischer et al. (2007) and Hakkinen and Makitalo-Siegl (2007)). Examining classroom innovation may shed light on the nature, design, and conditions for the emergence of collaboration in complex settings and extend our understanding of how socio-cognitive, cultural, and systemic forces impinge on collaboration. The contrast of principle-based versus activity-based approaches (Scardamalia and Bereiter 2006) and guided instruction versus emergent inquiry (Hmelo-Silver et al., 2007; Kirschner et al., 2006) raises many theoretical issues of design of CSCL pedagogy and is in need of further exploration. Examining CSCL in classrooms suggests analyses to examine discourse beyond the small group level to the discourse created in classroom communities. How CSCL technology can be developed for both formative and summative assessments, and for both examining and scaffolding collaborations, would be additional fruitful questions. Designing collaboration for classroom practice calls for further inquiry into how design-based research works, as well as for the development of a wider range of research methodology and analyses from different paradigms.

Since this paper is written to explore a range of issues about how CSCL research may be integrated into classroom practice, it has not focused on the details of data analyses, and many areas have been only briefly examined. The teacher network is one possible way to spread classroom innovation; this paper has considered some of the challenges of scaling associated with this approach. The experience of implementing knowledge building in Hong Kong classrooms provides an actual example of how various parties can work together to create possibilities that take into consideration the macro-, meso-, and micro-levels with emergent changes for sustained growth. Examining how collaboration and innovation may be designed and facilitated in complex settings over prolonged periods may help to address knowledge creation needed for the twenty-first century. While the examples are drawn from Hong Kong classrooms, the issues and questions are relevant to other communities and can, hopefully, enrich our understanding of how to synergize policy, research, and practice in CSCL. Diverse CSCL research can inform school practice significantly, while examining CSCL in classrooms may raise new theoretical questions on how collective knowledge creation may emerge in knowledge communities.

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Part III

A Theory of Group Cognition

Investigation 15. A Paradigmatic Unit of Analysis

Gerry Stahl

Abstract

This essay poses the question: Can CSCL represent a new paradigm of educational research within the learning sciences? It begins by looking at the historical relationship of the two related research communities: computer-supported collaborative learning and the learning sciences. It presents them from the perspective of the author as a participant in those communities during 20 years (1995–2015). It reviews the institutional history of their relationship within the International Society of the Learning Sciences. Trends in the history of philosophy and social theory are then reviewed to motivate an innovative contemporary paradigm. A "post-cognitive" educational paradigm is proposed that focuses on group interaction as the unit of analysis that is most central to CSCL. Finally, the author's CSCL research agenda is described as an illustration of a candidate approach. In conclusion, it is proposed that CSCL research should focus on the analysis of group processes and practices and that the analysis at this level could be considered foundational for the learning sciences.

Keywords

Post-cognitive · Educational paradigm · Research community · Shared understanding · Collective intentionality · Group agency

A Participant's View of LS and CSCL

The learning sciences (LS) and computer-supported collaborative learning (CSCL) are not easy to clearly distinguish. There are no objective or fixed definitions of these two fields. They are best understood as communities of researchers. Despite their fluidity, they do seem to evolve in a certain direction over time. The shifting nature of the communities appears differently to different participants and

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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is often negotiated in discussions among them. In this essay, I discuss the CSCL and LS communities from the perspective of my own participation in them. I start with some personal and community background because research is always oriented in response to personal and political commitments of the people and communities involved. This does not contradict the "objectivity" of the research—for it must still meet accepted standards of rigor and accept the implications of scientific findings—but provides a context of significance necessary for relevance, motivation, and shared understanding. Theory is always situated.

CSCL is transdisciplinary, requiring a mix of academic backgrounds. I came to CSCL from philosophy and computer science. In the 1960s and early 1970s, I studied twentieth-century continental philosophy and social theory at MIT, Northwestern, Heidelberg, and Frankfurt, but supported myself as a math teacher and computer programmer. In the early 1990s, I studied computer science academically, specializing in AI, design theory, HCI, and CSCW at the University of Colorado in Boulder. Upon graduation in 1993, I decided to apply computer science to educational innovation. When Tim Koschmann spent a year at Boulder during 1997/1998 while I was starting my career as a research professor, I participated in his course on CSCL and he introduced me to local conversation analysts, whose courses I also attended. Koschmann was instrumental in organizing the first seven CSCL conferences and editing the seminal CSCL book (Koschmann, 1996). I participated in all the CSCL conferences, starting in 1995, and also the ICLS conferences from 1998 on. During 2001/2002, I lived in Germany for a year and worked on a European Union CSCL research project. That year, I met many of the Europeans active in the CSCL community and visited their labs, workshops, and conferences.

Koschmann convinced me to be program chair of CSCL 2002 in Boulder. At the closing session of CSCL 2002, those present agreed to found a new organization, the International Society of the Learning Sciences (ISLS), to provide an institutional framework to bring together the CSCL and ICLS conference series and also the *Journal of the Learning Sciences* (*JLS*). It was decided that Timothy Koschmann, Janet Kolodner, and Christopher Hoadley would share leadership of the society. I agreed to be on the founding board, to draft the bylaws, to set up the website, and to design a logo.

The contested relationship of CSCL to LS soon flared up at CSCL 2003 in Bergen, when the legal incorporation of ISLS was announced there. The central participants in the CSCL community were largely European members who had been active in the AI-in-Education community. They felt that Roger Shank had betrayed the AI-in-Education community when he hosted their conference at Northwestern in 1991 and used that occasion to proclaim himself the leader of a new field, which he called "the learning sciences." Kolodner was seen as his protégée, who had extended his technical contribution in AI models of case-based reasoning and was the founding editor of *JLS*, the journal of LS. At the time, virtually all articles in *JLS* had been by North American authors and represented a strongly cognitivist approach. The International Conference of the Learning Sciences (ICLS), the conference series for LS, was held exclusively in the USA until 2008 and had been dominated by a few American schools, primarily prestigious departments of education at US universities (e.g., Northwestern, Georgia Tech, Michigan, Washington, UCLA, Indiana, Berkeley, Stanford, Vanderbilt, Pittsburgh).

So at the Bergen conference, a group of European CSCL researchers raised harsh questions about whether ISLS was an attempt by American LS leaders to take over the field of CSCL and its conference series, which was finally being held in Europe in 2003—after Euro-CSCL 2001 in Maastricht was retroactively recognized as an official CSCL conference. Kolodner, Koschmann, and Hoadley were unable to satisfy the concerns raised. There was lively discussion among the conference attendees, and a smaller group of us drafted a position paper overnight. The outcome was to proceed with the establishment of ISLS, but to set up a CSCL Committee within ISLS to represent the CSCL community. The CSCL Committee would exercise control over CSCL matters, like the CSCL conference series. During the same conference, the idea of a CSCL journal (*ijCSCL*) was proposed; Hans Spada suggested that I found it with the co-editorship of Friedrich Hesse. Pierre Dillenbourg had already established a CSCL book series published by Springer. These initiatives helped to form links and establish parity between LS and CSCL.

ISLS gradually became established. Hoadley was the first president, and subsequent presidents included several prominent European and American CSCL researchers, including some who had raised the original critical questions at the 2003 conference in Bergen, Norway. Kolodner served as Executive Director of ISLS throughout its formative years. The tension between CSCL and LS gradually dissipated; the CSCL Committee lingered on, primarily playing a symbolic role. ISLS, ICLS, and *JLS* gradually made concerted efforts to become more international and to broaden their leadership. Although the assumption has generally been that the two communities have largely merged, my sense is that the theoretical differences between them and between the two conference series have not much altered during the intervening decade. The conflict between CSCL and LS may have been more than a political clash between overlapping communities; it may also represent a rejection by many CSCL researchers of the extreme commitment to cognitivist theory and methodology by prominent LS proponents at that time.

It is hard to define the difference between CSCL and LS other than, perhaps, in terms of the people involved. This is because both communities profess openness to the same range of theoretical and methodological frameworks, although both promote certain preferred orientations in subtle and unspoken ways. For instance, most researchers in both fields claim to accept the situated nature of learning and the sociocultural perspective, but if you look closely at their analyses, you find that they both often rely on methods and approaches that predate and may contradict these theoretical positions. While many researchers publishing in CSCL venues still employ cognitivist methods—such as interpreting isolated utterances as expressions of mental representations, empiricist controlled experiments manipulating objective conditions, or coding along predetermined categories—it may be that the CSCL vision calls for a different research paradigm.

Did CSCL or LS Adopt a New Paradigm?

In the introduction to his edited volume of CSCL studies, Koschmann (1996) proclaimed that CSCL provided a new paradigm of research on instructional technology. He used Kuhn's principle that a paradigm must be "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity" (Kuhn, 1972, p. 10). A few years later, as Koschmann saw that there was no consistency in method among actual CSCL studies and that the vast majority of CSCL and LS studies had, in fact, not moved away from traditional approaches to measuring individuals' learning outcomes, he reconsidered that claim. He argued that:

> Traditional theories of learning treat learning as a concealed and inferred process, something that "takes place inside the learner and only inside the learner" (Simon, 2001, p. 210). CSCL research has the advantage of studying learning in settings in which learning is observably and accountably embedded in collaborative activity. Our concern, therefore, is with the unfolding process of meaning making within these settings, not so-called "learning outcomes." It is in this way that CSCL research represents a distinctive paradigm within IT. By this standard, a study that attempted to explicate how learners jointly accomplished some form of new learning would be a case of CSCL research, even if they were working in a setting that did not involve technological augmentation. On the other hand, a study that measured the effects of introducing some sort of CSCL application on learning (defined in traditional ways) would not. (Koschmann, 2001, p. 19)

In his keynote talk at CSCL 2002, Koschmann proposed that "CSCL is a field of study centrally concerned with meaning and the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts" (Koschmann, 2002, p. 17). It is important to note that “meaning making” is here taken as an intersubjective or “joint” practice or small-group process. Meaning is not conceived as a mental model somehow existing in the brains of individuals.

Koschmann then reviewed what he took to be a seminal CSCL paper by Jeremy Roschelle (1992) as an early instance of the CSCL paradigm, because Roschelle focused on the analysis of meaning-making practices (such as conversational moves in a dialog) in a context of joint activity (dyads working collaboratively on challenges) mediated by a designed activity (a software simulation of the relationship of velocity and acceleration).

Koschmann focused on the version that Roschelle published in *JLS*—which Koschmann himself later republished in his CSCL edited volume (Roschelle, 1996). However, in terms of the relationship of CSCL and LS, the situation was rather more complicated as well as more interesting than what Koschmann reported. First, Teasley and Roschelle (1993) presented an analysis involving the co-construction of a “joint problem space” (JPS) by students, using Roschelle’s dissertation data. The JPS was an explicit transformation of the cognitivist conception of a mental problem space in Newell and Simon (1972) into the intersubjective realm of situated interaction. Newell and Simon’s notion of cognitive production rules (mental mechanisms) was reconceptualized by Teasley and Roschelle as socially distributed, turn-taking, collaborative completions (discourse moves). The unit of analysis was transformed from the individual mind to the small group interaction (dialog and joint attention through pointing).

Stephanie Teasley was instrumental in bringing a post-cognitive framework to this analysis in her collaboration with Roschelle, while they were both interns at the Institute for Research on Learning (IRL) in Palo Alto. IRL was a hotbed of post-cognitive innovation, inspired by theories of conversation analysis, ethnomethodology, activity theory, situated action, and situated learning. Teasley (then named Behrend) and Roschelle first presented their analysis with coauthor Janice Singer at the CSCW 88 and ITS 88 conferences (Behrend, Singer, & Roschelle, 1988; Singer, Behrend, & Roschelle, 1988). These papers grew into the version later published as Teasley and Roschelle (1993), presented at a NATO-sponsored workshop in Italy in 1989 (the first event ever to use the term “CSCL”!).

It was these early versions of the paper that really emphasized the intersubjective practices of meaning making in the context of joint activity. The authors explicitly juxtaposed their perspective to cognitivism: “Thus, in contrast to traditional cognitive psychology, we argue that collaborative problem solving takes place in a negotiated and shared conceptual space, constructed through the external mediational framework of shared language, situation and activity—not merely inside the cognitive contents of each individual’s head” (Roschelle & Teasley, 1995, p. 70).

In the *JLS* article reporting on this research, Roschelle argues that the ability of the dyad to “share” knowledge in a cognitive sense (as convergent mental contents) could be demonstrated by an analysis of the collaborative sense in which the students “share” a joint meaningful world (are engaged with co-constructed meanings and artifacts). Tying the analysis of intersubjective meaning making to the problematic of cognitive convergence (as encouraged by *JLS* editor Kolodner) had the potential of appealing to the *JLS* audience, because it put the argument in cognitive terms they could relate to without disrupting their paradigm. However, this made the argument more complex and detracted from its ability to stand as a clear example of a post-cognitive paradigm.

Koschmann concluded that CSCL could be a new paradigm if studies would maintain a focus on how groups of learners collaboratively achieve new understandings in the presence of computational artifacts. However, in most CSCL studies (as in LS studies) there is a conflict between the espoused and the applied theories of learning or between the motivating theoretical concerns and the bottom-line methods of analysis. After Roschelle and Teasley’s publications, most actual instances of research by the CSCL and LS communities fall back on old traditions in educational psychology or other forms of measuring and correlating learning outcomes of individuals—sometimes despite the researchers’ best stated intentions and even the inherent needs of their research questions. (This observation is based on ten years of reviewing all the submissions to *ijCSCL* as well as searching the broader literature for instances of analysis at the group unit of analysis.)

Measuring the effectiveness of dialog or collaboration is never a straightforward affair. It is highly dependent upon the details of the setting and the group practices. Methodological concerns related to this were expressed early in founding documents of CSCL, for instance, by Dillenbourg, Baker, Blaye, and O'Malley (1996, p. 189). Here they distinguish the CSCL vision of research on "collaborative" learning from the cognitivist tradition of research on "cooperative" learning (e.g., Johnson & Johnson, 1989, 1999; Slavin, 1980):

> For many years, theories of collaborative learning tended to focus on how *individuals* function in a group. More recently, the focus has shifted so that *the group itself has become the unit of analysis*. In terms of empirical research, the initial goal was to establish whether and under what circumstances collaborative learning was more effective than learning alone. Researchers controlled several independent variables (size of the group, composition of the group, nature of the task, communication media, and so on). However, these variables interacted with one another in a way that made it almost impossible to establish causal links between the conditions and the effects of collaboration. Hence, empirical studies have more recently started to focus less on establishing parameters for effective collaboration and more on trying to understand the role that such variables play in mediating interaction. In this essay, we argue that *this shift to a more process-oriented account requires new tools for analyzing and modeling interactions*. (Italics added)

In the first volume of the *International Journal of CSCL* (*ijCSCL*), Suthers (2006, p. 321) [Investigation 4] proposed a research agenda for CSCL: "To study the accomplishment (a post hoc judgment) of intersubjective learning we must necessarily study the practices (the activity itself) of intersubjective meaning making: how people in groups make sense of situations and of each other." He agreed on the need for CSCL research to focus on analysis of group processes. He immediately noted, however, that few studies published in the CSCL literature have addressed *intersubjective* meaning making directly; all but a few analyze data taken as related to individual minds.

The motivating vision of CSCL presented here suggests that research in this field should focus on the small-group unit of analysis. CSCL is a response to the potential of computer technology networked though the Internet to bring learners together and to support their collaborative knowledge building. The potential is not just to provide innovative tools and broadened sources of information to individual learners, but to allow cognition itself to evolve from individual efforts to group efforts [Investigation 7]. The rigorous analysis of computer-supported collaborative learning requires a new research paradigm oriented primarily to the small-group unit of analysis as the locus of intersubjective meaning making.

There are many pressures against research adopting a new paradigm and new tools for analyzing interactions. For one, the study of interaction processes and group practices requires analytic skills that are not generally taught in standard college courses on research methods and statistics. There are also external influences: The public wants stories that meet common sense images of science based on popular notions of traditional science, such as mechanistic Newtonian physics. Politicians and funding sources want simple numeric results that they can cite as clear measures of return on government or grant investments in education. Academic hiring and promotion committees want publications in well-established conferences and journals to justify their decisions. Conferences and journals rely on peer review by scholars trained in traditional notions of rigor. Systems of social rewards—which largely define behaviors in academic research communities—militate against methodological innovation, even as they reward superficial adherence to the latest trends.

It is hard to determine how many publications in CSCL or LS break free of the cognitivist paradigm's stronghold on publication. For instance, studies of CSCL publications (e.g., Akkerman et al., 2007; Jeong & Hmelo-Silver, 2010; Jeong, Hmelo-Silver, & Yu, 2014; Kienle & Wessner, 2006; Lonchamp, 2012; Tang, 2014) bring their own paradigmatic blinders or filters. They sometimes eliminate from consideration any paper that does not focus on "empirical" data analysis, often excluding ethnographic case studies and certainly theoretical articles. They generally miss many of the most influential papers or more innovative approaches. Many highly rated journals in the educational field advertise that they only publish papers that conform to traditional empiricist methodological standards. The stances of these journals in turn influence the attitudes of reviewers for other journals and conferences. Attempts to categorize publications in CSCL and LS often succumb to a similar fate, imposing implicit or explicit criteria on the selection of papers to be categorized.

We have seen that it is hard to determine the extent to which a post-cognitive paradigm is making headroads in CSCL and/or LS research. What would a CSCL paradigm look like that systematically thematized the mutual engagement of small groups in meaning making and problem-solving, as suggested by Koschmann, Roschelle and Teasley, Suthers, and Dillenbourg, Baker, Blaye, and O'Malley?

The following sections of this investigation explore the implications of the post-cognitive theories that are so often espoused within the CSCL and LS communities, but relatively rarely carried through in the published analyses. First, recent post-cognitive theories are traced back to their roots in the history of philosophy, noting the historic junctures that provide the ontological and epistemological motivations for various alternative methodologies. Then, Vygotsky's argument for the foundational role of intersubjective collaborative learning for educational theory is summarized. Next, the nature of a post-cognitive paradigm is illustrated by the example of the VMT CSCL research project. Finally, it is concluded that CSCL should more consistently focus on analysis of group cognition, which, moreover, may be considered foundational for learning generally.

The Post-cognitive Philosophical Paradigm

The post-cognitive CSCL paradigm studies *meaning making as a joint (or group) activity*. For instance, the analysis by Teasley and Roschelle (1993) in terms of the collaborative activity of constructing a joint problem space was an early instance of this new paradigm. However, the analysis of the same data in terms of "cognitive convergence" reduced the meaning making to measures of traditional individual mental phenomena—externally influenced by computer images and internally involving increasingly similar mental representations of those images in the heads of the students.

To grasp the significance of this distinction between cognitive and post-cognitive, consider the schematic history in Fig. 15.1 of a strand within Western philosophy and social theory that contributed to the theoretical foundation of this paradigm shift.

Philosophy began with the classic Greeks locating knowledge in eternal ideas, rather than in the social norms of the *polis* or the traditions of mythology. Descartes relocated these ideas in the individual mind and thereby created the epistemological problem: How can ideas in the mind correspond to valid knowledge of the nonmental world? Locke and Hume gave opposing views in response to Descartes, emphasizing individual human reason or individual human experience. Various mixtures of these philosophies motivated scientific paradigms of rationalism, empiricism, positivism, and behaviorism—with their objectivist methods. Kant overcame the conflict between rationalism and empiricism by arguing that the human mind constructs what it can know of the world by structuring sense perception with categories of space, time, and causality. Thus, Kant provided the philosophic basis for the paradigms of constructivism and cognitivism: People construct knowledge, so an analysis of human behavior and learning must take into account the role of cognition in making sense of the world (vs. positivism and behaviorism in the human sciences).

Note that up to this point, human nature and human cognition were posited as based in the individual person, as fully determined from birth ahistorically or universally—not dependent on one's biography, growth-related processes, or social context. Remember that the views that minds develop

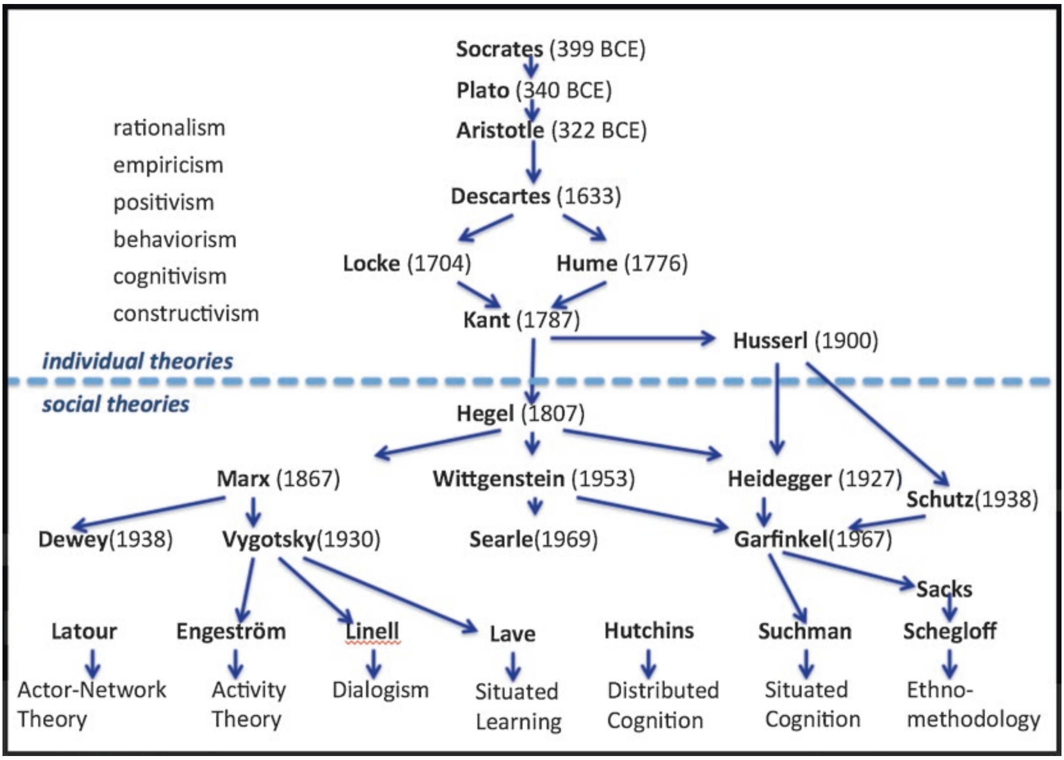

Fig. 15.1 The evolution from individualistic to social theories in philosophy and social science. A major paradigm shift in theory occurred two centuries ago, but has still not affected most CSCL and LS analyses

(Freud), that social relations transform (Marx), or that humanity evolves (Darwin) all came after Hegel—inspired by his dynamic philosophy. The outmoded pre-Hegelian, ahistorical view survives in our culture as common sense and as a pervasive ideology of individualism. It also survives in the empiricist and rationalist assumptions about science and research methodology, which persist in positivist notions of objectivity and reductionism to individual cognition.

Hegel (1807/1967) argues that human consciousness emerges through productive activity in the social and physical world: Individuals are formed as such (i.e., as self-conscious individuals) through the interaction with each other and with artifacts (tools and products of work) in the world. Hegel describes the emergence of self-consciousness from within the process of mutual recognition of self and other.

Marx (1867/1976) builds on this analysis of social interaction. He situates Hegel's idealist analysis in the historical context of capitalism. For Marx, individuals in capitalist society are analyzed as results of their interactions as wage laborers, owners of the means of production, or consumers of commodities. The "cell form" of social analysis is the interaction between worker and owner that produces artifacts for the market. Marx critiques the traditional notion of the abstract individual as an ideology that obscures concrete human reality as fundamentally social.

In the cognitive paradigm, one assumes that an interaction which takes place in a CSCL setting can be analyzed in terms of individuals, who can be characterized independently of the interaction context, for instance, by characterizing their mental states and internally stored knowledge. The sense making that takes place is attributed to the individuals, who then may compare their private understandings, personal opinions, or mental representations. By contrast, in the post-cognitive theories listed across the bottom of Fig. 15.1, interaction is primary. For instance, Linell (2009) describes his post-cognitive dialogical approach as follows:

> In the analysis of sense-making as it occurs in communication and interventions into the world, as well as in solo thinking or the reading of texts, etc., we must start out from the encounters, interactions, events etc. as the basic phenomena; they are primary, not secondary or derived. This idea makes dialogism different from mainstream psychology, which is based on the assumption—self-evident for its adherents—that individuals are there first, and then they sometimes interact with other individuals. Interaction for them is "external," that is, of a secondary nature. Dialogists, by contrast, assume that individuals have become what they are in and through interaction.

Toward a Post-cognitive Educational Paradigm

A related set of attempts to propose contemporary approaches to education, sociology, and psychology embody new paradigms of research in keeping with the post-cognitive philosophical paradigm. Some of them are included in Fig. 15.1. They focus methodologically on group interaction and study dynamic processes rather than just pre- and posttest learning outcomes of individuals. Most of them are inspired by Vygotsky or, more generally, by Marx, Heidegger, and Wittgenstein. They include Bruner (1990), Cole (1996), Engeström (1987), Garfinkel (1967), and their colleagues or followers, each of whom emphasizes different aspects of the paradigm.

Vygotsky adopts Marx's ontology: The primary unit of analysis is the interaction among people situated in social relationships and mediated by artifacts. Artifacts are both physically present in the world and meaningful to people (overcoming the physical vs. mental cleavage of Descartes). Vygotsky's notion of artifact includes both tools and language. Their meaning is not projected from individual minds, but is intersubjectively emergent from social interactions, as in the dialectical analyses of Hegel and Marx. Consider Vygotsky's programmatic attempt to show how the individual mind is grounded in activity within the physical and social world. His description of the genesis of the pointing gesture illustrates a typical early experience of meaning for a small child; it shows how the meaning of this artifact (the pointing gesture) is created in the intersubjective world and only subsequently incorporated (internalized) in the child's personal sense-making repertoire:

> We call the internal reconstruction of an external operation *internalization*. A good example of this process may be found in the development of pointing. Initially, this gesture is nothing more than an unsuccessful attempt to grasp something, a movement aimed at a certain object, which designates forthcoming activity…. When the mother comes to the child's aid and realizes this movement indicates something, the situation changes fundamentally. Pointing becomes a gesture for others. The child's unsuccessful attempt engenders a reaction not from the object he seeks but from another person. Consequently, *the primary meaning* of that unsuccessful grasping movement *is established by others*…. The grasping movement changes to the act of pointing. As a result of this change, the movement itself is then physically simplified, and what results is the form of pointing that we may call a true gesture. (Vygotsky, 1930/1978, p. 56, italics added)

Here we see the *genesis of the meaning* of a pointing gesture. The meaning of the pointing gesture is not some mental schema stored in the mind of an interpreting subject, but an intersubjectively understood practice originally generated through interaction and subsequently repeatedly applied during interaction as a resource for maintaining joint attention of group members. The recognized, practical, and formalized gesture becomes an artifact: It embodies meaning in the physical world. The meaning is a reference to that which is pointed at. The baby intended some object; the mother recognized that the baby intended that object; the baby recognized that the mother recognized this. The multiple mutual recognition entails that the baby and the mother recognize each other as people who can have intentions and who can recognize intentions of other people. This is a first glimmer of self-consciousness, in which the baby becomes conscious of his own and other people's intentionality. (Of course, the baby cannot represent or express this self-consciousness in any mental, verbal, or conceptual sense, but only adopt it behaviorally.)

The key point for us here is not so much the birth of intentionality, social recognition, or self-consciousness. It is the analysis of an artifact, such as the pointing gesture, a ubiquitous form of reference, or deixis. In the origin of this gesture, we already see the basis for intersubjective, *shared understanding* of an artifact's meaning. The subsequent usage of this pointing gesture is premised upon the mutual recognition of an underlying relationship of shared attention, which emerged within the mother-child interaction.

The view of shared intention as co-constructed in the world stands in sharp contrast to the rationalist assumption that individuals first have private personal intentions—as though produced by logical calculations of self-interest by a homunculus in their heads—which they subsequently express in speech or action. Marx, Wittgenstein, and Heidegger—and their successors—soundly reject this cognitive assumption (see, e.g., Dennett, 1991; Dreyfus, 1992; Suchman, 2007). Heidegger (1927/1996), for instance, replaces Descartes' dichotomy of mental and physical with a philosophy of human being there together in the world. One's comportment in the world precedes one's reflection upon objects in the world. People understand the shared world through their involvement with and their care for the world with other people who also inhabit that world, not initially through mental representations and logical plans. Human involvement is fundamentally processual or temporal: We aim at our projects for the future, based on having been thrown by our social past into our shared situation in the present.

In their seminal post-cognitive analysis of agency, drawing on contemporary philosophy and social science, Emirbayer and Mische (1998, p. 962) conceptualize agency in Heideggerian temporal terms. Applied to the group unit of analysis as "group agency," their post-cognitive concept could inform CSCL analysis (as in Charles & Shumar, 2009; Damsa, 2014). It is important to reconsider the notion of agency (and causality)—as Latour (1990, 1992) does by extending it to other people and artifacts in networks of actors. The traditional, mechanistic conception of agency contributes to the difficulty of overcoming cognitive habits of thought. A post-cognitive paradigm could include group cognition, collective intentionality, and group agency.

The Need for a Post-cognitive CSCL Paradigm

A paradigm shift can be motivated by anomalies in established theories (Kuhn, 1972; Lakatos, 1976). Anomalies are findings that cannot be easily accounted for in a prevailing theory. They suggest the need for a change in theory. Consider two anomalies in the cognitive paradigm of measuring learning outcomes of individual minds: one from the research of Vygotsky and one from recent CSCL research.

In Vygotsky's well-known discussion of the "zone of proximal development," he cites a study in which children "could do only under guidance, in collaboration and in groups at the age of three-to-five years what they could do independently when they reached the age of five-to-seven years" (1930/1978, pp. 86f). CSCL can be seen precisely as such an effort to stimulate students within their zones of proximal development—on tasks they cannot yet master individually but are close to being ready to learn—under guidance, in collaboration and in groups. If the desired results of this do not show up as learning outcomes measurable in individuals (outside of their group context) for several years, then the key effect will be systematically missed by traditional methods of testing individuals. The failure of the cognitive paradigm of instructional research to account for processes in the zone of proximal development—so central to learning—should be considered an anomaly, suggesting the need for a paradigm shift.

In his less quoted section on "Problems of Method," Vygotsky (1930/1978, pp. 58–75) called for a new paradigm of educational research almost a century ago. Arguing that one cannot simply look at visible posttest results of an experiment, he proposed a method of "double stimulation" where a child is confronted by both an object to work on and an artifact to mediate that work. Vygotsky does not call for a controlled experiment that compares learning outcomes with and without the furnished artifact. "The experiment is equally valid," he points out, "if, instead of giving the children artificial means, the experimenter waits until they spontaneously apply some new auxiliary method or symbol that they then incorporate into their operations." Taking this approach in a collaborative setting requires an attention to the children's interaction and the sense making that is involved in creative, unanticipated collaborative accomplishments. It involves understanding the unique trajectories of different *groups*, which cannot be statistically aggregated or sorted into standardized categories. This suggests the need to analyze interaction at the group level, rather than just the individual as the cognitive subject.

Relatedly, a number of CSCL studies have repeatedly documented "productive failure" (Barron, 2003; Kapur & Kinzer, 2009; Pathak, Kim, Jacobson, & Zhang, 2011; Schwartz, 1995). This is one of the most intriguing findings of CSCL to date. However, it has so far been analyzed in terms of individual student learning outcomes, rather than group practices within zones of proximal development. When a number of small groups of students work on a challenging problem, the groups sometimes fall into two categories: (a) groups that fail to solve the immediate problem but excel at solving future, related problems and (b) groups that succeed at solving the immediate problem but are less successful than the first groups at solving subsequent related problems. The robust and repeatable result of these experiments presents an anomaly for traditional educational theory. One could speculate that in the "failure" groups students are further developing their zone of proximal development or that these groups are co-constructing helpful new meanings, whereas the groups that solve the immediate problems are focused on efficiently applying their existing skills. The analysis of group processes effecting outcomes this way would require a post-cognitive perspective, focused on the cognitive accomplishment of the group as such.

A CSCL Researcher's Agenda

As an example of a CSCL research project conducted within a post-cognitive paradigm, I describe my own work during the past decade and a half. It is post-cognitive in that it analyzes the group processes that constitute collaborative learning in a computer-mediated setting. It neither defines learning in terms of outcomes nor interprets utterances in terms of mental phenomena. Without denying the reality of either individual consciousness or societal practices, it nevertheless focuses on the temporal sequentiality of small-group interaction.

The Virtual Math Teams (VMT) Project has been a collaborative effort with researchers from the Math Forum, Drexel University and Rutgers University at Newark, as well as with visiting scientists and colleagues abroad. The project is extensively documented in four books (Stahl, 2006, 2009, 2013c, 2016), nine doctoral dissertations, and many other presentations (http://gerrystahl.net/vmt/pubs.html), including in a number of investigations in this volume.

VMT is a design-based research (DBR) project, intended to develop theory and research methodology through exploring and designing technology and pedagogy for supporting online collaborative learning of mathematics. As a research prototype, the VMT environment has been used in over a thousand student-hours at the Math Forum (http://mathforum.org), as well as independently by researchers in Turkey, Israel, Singapore, Brazil, and New Jersey. The final version of VMT's software and curriculum features a collaborative version of GeoGebra (http://geogebra.org), a popular dynamic

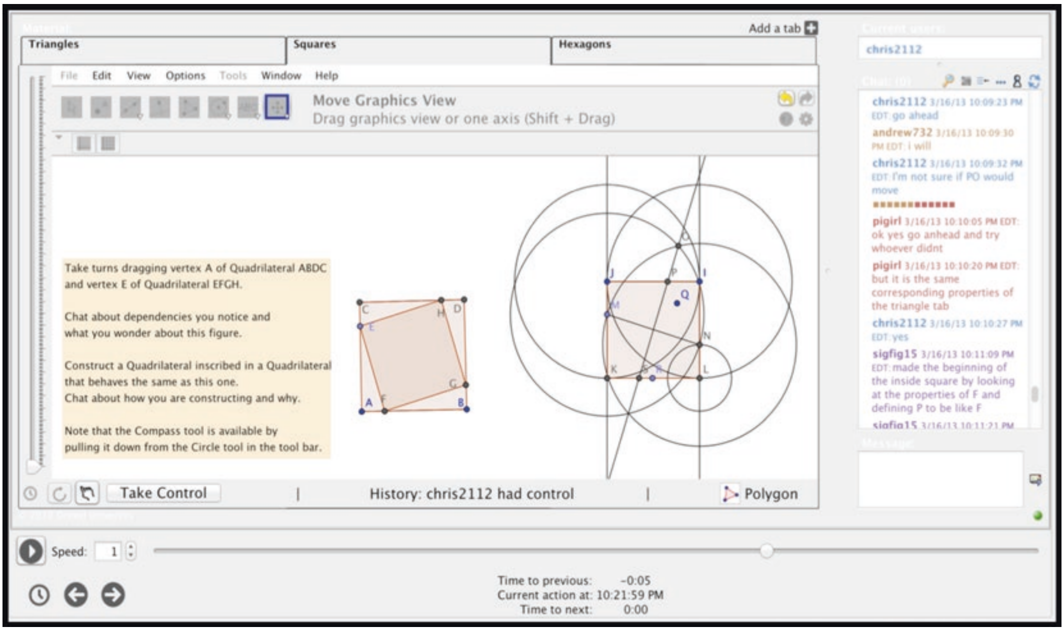

Fig. 15.2 The VMT Replayer, with VCR-type controls below the VMT environment

mathematics application. The VMT Project converted the GeoGebra app to a multiuser approach, so that actions by one student are synchronously shared with others in the group.

In a typical session, three to five middle-school or high-school students collaborate synchronously online for about an hour. Often, the same group will work on a series of challenging problems during five to ten weekly sessions in an after-school or in-class setting organized by a teacher who has completed the Math Forum's teacher-professional-development program associated with VMT. Students interact through text chat and GeoGebra actions (see Fig. 15.2). A VMT Replayer shows researchers or teachers what everyone in the group saw and allows a viewer to step through an entire session with the controls added across the bottom. In this screenshot, the group is in the midst of constructing a solution to a challenging problem of inscribed polygons, repeatedly used in the VMT Project. (Interestingly, the researchers had not previously seen or thought of the particular solution collaboratively developed by the group in Fig. 15.2.)

The VMT environment is instrumented to provide the data necessary for analysis of group processes. In order to track a group's meaning making, one must have a complete record of all group interaction. Otherwise, one does not know if unrecorded events contributed in unknown ways to the shared understanding. This requirement involves two aspects: (a) controlling the interaction so that no group communication takes place outside of the recorded setting and (b) recording the interaction in a complete, detailed, and undistorted manner. Technologies of recording data can make possible new paradigms of research. For instance, conversation analysis only came into existence with the tape recorder for capturing and replaying speech.

Recording group collaboration in a face-to-face classroom is "messy" and often impractical: There is so much noise that clear speech capture is difficult; transcription is laborious; and nonverbal communication through action and gesture is impossible to capture completely. Traditional analyses generally proceed by coding and counting. Recordings of speech utterances are transcribed as sentences. Then sentences attributed to the individual speaker are categorized according to some standardized schema. The number of sentences falling into each category is compared for different individuals, groups, or experimental conditions. In the process of recording, transcription, and aggregation, many researcher interpretations are introduced (Suchman & Trigg, 1991) and any sense of temporal or dialogical process is lost. In particular, given an a priori coding scheme, it is unlikely that any unforeseen and surprising results (like causes of productive failure or creative group moves) will still be identifiable. Due to established methodologies and other research habits, there have been practical barriers to LS making the paradigm shift to studying group interaction. CSCL can overcome these barriers because the computer-mediated collaborative setting makes problem-solving processes observable and automatically fully recordable.

Since students collaborate online in the VMT environment, all communication and action is mediated by the VMT technology. It is therefore possible to capture a complete record of everything that is visible to the student group itself. The same technology is used to replay the session for researchers, who can then slow it down or proceed posting by posting and action by action, viewing exactly what the students in the group all viewed (as in Fig. 15.2). In addition, a convenient summary log is automatically generated in spreadsheet formats (see Fig. 15.3). The spreadsheet automatically logs all text chat postings and dynamic geometry actions of each student. It can easily be filtered by event type or reformatted for log excerpts in publications. Columns for each student give a visual impression of the interactional flow.

The text chat is reproduced just as posted by the students, and the GeoGebra actions are listed in detail. The data of the actual interaction is available and the process of interpretation begins with the analysis, not with the data capture and transcription. Researchers can share the replayer files and spreadsheets, so that others can check any analytic descriptions for plausibility.

	A	B	C	D	E	F	G	H	I	J
1	Line	Date	Start Time	Post Time	Duration	EventType	andrew732	pigirl	sigfig15	chris2112
742		3/16/13		23:49.6	0:00:01	Geogebra:Squares			tool changed to Move Graphics View	
743		3/16/13		23:49.7	0:00:00	Geogebra:Squares			release control	
744	155	3/16/13	23:50.9	23:52.3	0:00:01	chat			it works	
745	156	3/16/13	23:56.7	23:57.3	0:00:00	chat		nice		
746	157	3/16/13	23:54.2	23:58.7	0:00:04	chat	wow, great			
747	158	3/16/13	23:59.3	24:08.1	0:00:08	chat		can you simply explain how you made it		
748	159	3/16/13	24:14.3	24:26.6	0:00:12	chat				If you notice on the example, Length CE is equal to GB
749	160	3/16/13	24:27.6	24:51.3	0:00:23	chat				so you can use to compass tool to make a circle around B with point G on it such that as you move E, G moves correspondingly
750	161	3/16/13	24:53.5	24:59.4	0:00:05	chat				Then make a line going through EG
751	162	3/16/13	24:59.6	25:08.0	0:00:08	chat				and a circle with cenger E point G
752	163	3/16/13	25:08.2	25:13.3	0:00:05	chat				and a circle with cetner G point E
753	164	3/16/13	25:13.5	25:32.7	0:00:19	chat				so that a line perpendicular to EG and through the intercepts of the circles is the midpoint line
754		3/16/13	25:33.5	25:34.3	0:00:00	awareness				[fully erased the chat message]
755	165	3/16/13	25:34.5	25:35.3	0:00:00	chat				of EG
756	166	3/16/13	25:35.5	25:58.1	0:00:22	chat				and whatever points on that line intercept the outside sqaure would then make up the other two points of the inner square
757	167	3/16/13	26:03.4	26:05.8	0:00:02	chat			okay good	
758	168	3/16/13	26:34.4	26:36.5	0:00:02	chat		that makes sense		
759	169	3/16/13		26:55.2	0:00:18	system			Now viewing tab Hexagons	
760	170	3/16/13	26:49.0	26:55.6	0:00:06	chat		can we move to "hexagons"?		
761	171	3/16/13		27:00.0	0:00:04	system				Now viewing tab Hexagons
762	172	3/16/13		27:06.4	0:00:06	system		Now viewing tab Hexagons		
763	173	3/16/13		27:46.6	0:00:40	system	Now viewing tab Hexagons			
764	174	3/16/13	27:57.8	27:59.8	0:00:01	chat			ill drag	
765		3/16/13		28:02.2	0:00:02	Geogebra:Hexagons			take control	
766		3/16/13		28:02.3	0:00:00	Geogebra:Hexagons			tool changed to Move	
767		3/16/13		28:10.3	0:00:08	Geogebra:Hexagons			updated Point A	
768		3/16/13		28:30.6	0:00:20	Geogebra:Hexagons			updated Point G	
769		3/16/13		28:32.3	0:00:01	Geogebra:Hexagons			tool changed to Move Graphics View	

Fig. 15.3 A spreadsheet of a segment of VMT interaction among four students

The VMT system's ability to generate data, which (a) provides an automatic record of the actual interaction and (b) documents the complete group interaction, has made it useful to a number of researchers. Using this data source, they have been able to analyze group processes, rather than just individual actions or outcomes. Here are some examples of theoretical insights and methodological innovations emerging from the VMT Project before the integration of GeoGebra, when a generic shared whiteboard was used for mathematical figures:

- Sarmiento and Stahl (2008) extended the notion by Teasley and Roschelle (1993) of a Joint Problem Space, observing how students co-construct such a shared conceptualization and how it incorporates a temporal structure, integrating past collaborative sense-making results into current discussions aimed at a projected future problem solution.
- Çakir, Zemel, and Stahl (2009) [Investigation 12] observed how a student group integrated their visual/graphical reasoning, numeric/symbolic expression, and mathematical discourse in their problem-solving work within the VMT chat and whiteboard media—moving successively from one discourse to another.
- Zhou, Zemel, and Stahl (2008) looked at the important role of questioning as a common driving force in collaborative interaction, eliciting responses, and providing a guiding group agency.
- Zemel, Çakir, and Stahl (2009) analyzed "reading's work" as a contribution to the analog of conversational turn taking as it is materialized in online text chat.
- Zemel and Koschmann (2013) [Investigation 5] studied how deixis and linguistic reference work within interactions in the VMT environment.
- Koschmann, Stahl, and Zemel (2009) examined the nature of several key group practices in VMT collaboration.
- Wee and Looi (2009) investigated pivotal moments in group processes of mathematical knowledge building in VMT chats.
- Medina and Suthers (2013) and Medina, Suthers, and Vatrapu (2009) probed the nature of representational practices in a series of one VMT group's session, observing how practices primarily contributed by one student are later associated with the other students, as they become adopted as group practices.
- Trausan-Matu, Dascalu, and Rebedea (2014) analyzed the polyphonic nature of VMT chats, graphing the intertwining of dialogical voices in a number of groups.

More generally, the concept of group cognition emerged from the early analyses of the VMT Project, as did the importance of interaction analysis (Stahl, 2006). In turn, the theory of group cognition clarified the importance of incorporating a domain-oriented shared workspace like GeoGebra and the need to record all interaction for analysis. These issues were reflected upon in Stahl (2009). The coevolution of theory, research, and design characteristic of design-based research (DBR) was highlighted in Stahl (2013c), with chapters on eleven aspects of the project, including theory, methodology, pedagogy, technology, subject domain, history, and philosophy.

The idea of focusing on the group unit of analysis or group cognition does not exclude analyses at either the individual or the community units of analysis. There are important and different phenomena and processes at each of these (and other) levels. In fact, it is often most fruitful to analyze cognition on multiple levels and to see how the processes at the different levels work together. However, the simultaneous and integrated study across levels is a current challenge for CSCL [Investigation 2]. A variety of *interactional resources* are typically at work bridging the levels (Stahl, 2013a, 2013b; Stahl & Öner, 2013). Since incorporating GeoGebra into VMT, our research has included designing sequences of curricular resources to guide collaborative exploration and bridge levels by tying individual and group knowledge to established knowledge of the mathematics community (Stahl, 2012, 2015).

In VMT case studies, topics in mathematical combinatorics or dynamic geometry centrally figure as interactional resources that bring together individual, small-group, and community cognitive processes. *Sequentiality*, *co-attention*, and *shared understanding* have emerged from these studies as fundamental theoretical categories for understanding and studying collaborative learning [Investigation 19]. By observing group interaction in VMT, we can see how student groups enact these mechanisms and thereby integrate individuals into groups, adopting community practices as *group practices*. For instance:

- In Stahl (2011) [Investigation 23], two students solve a high-school math problem that has stumped them for some time. The problem-solving steps that the dyad goes through as a team are strikingly analogous to how proficient math students solve problems individually. In the discourse captured in this case, one can see how the *group* integrates contributions from the two *individual* participants to accomplish a task in accordance with *community* standards of practice—illustrating the productive interplay of cognitive levels. A sequence of ten discourse moves (similar to extended adjacency pairs in Schegloff, 2007) by the group details their *sequential organization* of the problem [Investigations 23 and 25].
- In Stahl, Zhou, Çakir, and Sarmiento-Klapper (2011) [Investigation 17], three students develop techniques for helping each other to see what they are seeing in the diagram they have drawn for a math problem. This *persistent co-attention* to a shared object of analysis allows the team to solve their problem as a group.
- Similarly in Çakir and Stahl (2013) the students are able to work together because they effectively manage their *shared understanding* of the problem.
- Stahl (2016) follows a group of three young girls longitudinally through eight hour-long sessions in the VMT chat room with a multiuser version of GeoGebra. It describes the display of mathematical reasoning by the team discussing the dependencies of a series of dynamic geometry figures. By analyzing the network of mutual responses, it tracks the intersubjective meaning-making process and observes how the team develops its abilities by adopting *group practices* of collaboration, mathematical discourse, and dynamic geometry.

When a group enters the VMT environment, it is presented with a challenging math problem, which is designed to guide the group interaction in an academically productive direction [Investigation 21]. The problem acts as a problem-solving resource for the group. The group must interpret the problem statement, elaborate the way in which they want to conceive the problem, and determine how to proceed [Investigation 5].

A math problem, for instance, can serve as an effective interactional resource for bridging across cognitive levels. Typically, it introduces content—definitions, elements, procedures, principles, practices, proposals, theorems, questions—from the *cultural* traditions of mathematics and from school curriculum. In so doing, it recalls or stimulates *individual* cognitive responses—memories, skills, knowledge, calculations, deductions. It is then up to the *group* interaction to bring these together, to organize the individual contributions as they unfold in the ongoing interaction in order to achieve the goals called for by the community, institutional, disciplinary, and historical sources. In this way, the group interaction may play a central role in the multilevel cognition, interpreting, enacting, and integrating elements from the other levels, producing a unified cognitive result, and thereby providing a model for future community practice or individual skill.

Group cognition is not the same as individual cognition. Certainly, it relies upon individual cognition to make essential contributions; however, one cannot say that all of the cognition is reducible to the individual unit, because the work of assembling the high-level argumentative structure typically occurs at the group unit of analysis. Surely, putting together problem-solving arguments (incorporating planning, synthesis, and deduction) must be considered a cognitive activity as much as the memory or computation that goes into making the detailed contributions to individual steps. This group cognition may be considered to involve students in their zone of proximal development, with the expectation that they may later be able to conduct such extended problem-solving argumentation individually, based on their group experiences.

In addition, the individual discourse contributions are not meaningfully separable from the group processes. They are largely responses to what has gone before in the group interaction. These contributions are expressions that would not have occurred without the preceding opening for them and the elicitation of them by the group process. Many of the contributions are largely reactions at the group level, which reference and interrelate resources available in the discourse context more than they introduce new elements from the personal perspective and individual background of the actor. They are also prompts for reactions by others. The important knowledge-building achievement is emergent in this give and take at the group level, rather than a simple collection of expressions of isolated individual cognitive accomplishments.

Note that the emergence of group cognition is quite different from the emergence of complexity from the nonlinear interaction of simple rules in chaos theory; group cognition emerges primarily through the intertwining of subtle linguistic phenomena of indexicality and sedimented shared meaning inherent in sequentially organized utterances of multiple voices [Investigation 2].

Of course, coherent and impressive examples of group cognition—such as solving a math problem that the group members would not have been able to solve on their own—do not occur every time that people come together in conversation. In fact, the research field of CSCL has repeatedly documented that desirable forms of collaborative knowledge building are disappointingly rare. The VMT research summarized above indicates some reasons for this. First, it is difficult to set up a group interaction where everything relevant to the cognition at the group level of analysis is captured in a form adequate for detailed analysis. It took years to iteratively design, develop, and deploy the VMT group sessions to successfully generate adequate data of successful group cognition. Secondly, the group interaction must be directed and guided to focus on an appropriate cognitive task. Certain challenging math problems, carefully presented, seem to provide effective interactional resources for stimulating interesting episodes of group cognition. Additionally, groups must work consistently to ensure the presence of certain preconditions of effective group cognition. They must persist in building *longer sequences* of responses to each other, they must maintain continuous *co-attention* to a shared focus of discussion, and they must build and sustain a *shared understanding* of the topic of conversation [Investigation 19, Investigation 23].

The VMT studies listed above are focused on the small-group unit of analysis. This is consistent with other contemporary attempts to shift away from an exclusive concern with individual cognition, for instance, in actor-network theory, ethnomethodology, distributed cognition, and activity theory. In the VMT project, most analysis has focused on the under-researched unit of the small group (Stahl, 2006, 2009). However, recent work on VMT looks at the interactions among the individual, small-group, and community units of analysis (Stahl, 2013a, 2013c). This has the potential of bridging to other analytic approaches in LS and CSCL, although it raises new methodological issues about studying the interrelationships of the different levels.

The Foundational Relationship of CSCL to the Learning Sciences

The post-cognitive educational paradigm assigns an analytic priority to group cognition, as the level at which fundamental processes of learning take place. Applying this to the study of learning is motivated by Vygotsky's developmental principle:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (*interpsychological*), and then *inside* the child (*intrapsychological*). This

> applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher [human mental] functions originate as actual relations [interactions] between human individuals. (Vygotsky, 1930/1978, p. 57)

Cognitive phenomena such as specific forms of learning develop first in group interaction and then only subsequently—through complex and extended transformations—emerge as individual skills or outcomes. In this sense, collaborative learning may be considered not just an optional and rare mode of instruction, but rather a foundation of all learning. Group cognition is a basis of human cognition: individual, small group, and community.

Already in the introduction to *Group Cognition*, it was proposed that:

> Small groups are the engines of knowledge building. The knowing that groups build up in manifold forms is what becomes internalized by their members as individual learning and externalized in their communities as certifiable knowledge. At least, that is a central premise of this book. (Stahl, 2006, p. 16)

Accordingly, the analysis of group processes is foundational for the study of learning because these processes mediate between individual and community learning. One can argue, as Vygotsky and his followers often do, that group cognition underlies and grounds all cognition. Human thinking—including planning, conceptualizing, narrating, analyzing, and problem-solving—involves language to identify, distinguish, and express itself. Vygotsky studied the development of children's thinking and speaking, concluding that spoken language (learned in dialog within family groupings) gradually over years led to silent self-talk, which then eventually morphed into mental thought. Accordingly, thinking individuals evolved (both as a species and in each case) from group participants, adopting as their own many practices that were acquired in interaction with others. While it is difficult to know about the early origins of cognition, the priority of group cognition seems apparent in the kinds of learning targeted by most CSCL research projects.

While the existence of many small groups may be ephemeral and teams may form for limited time spans, groups are typically the units within which cognitive advances are made, particularly the kinds of challenging, ill-structured, complex forms of learning aimed at by CSCL interventions. For instance, the collaborative learning of dynamic geometry by the Cereal Team and the solving of tricky problems of mathematical combinatorics by other VMT student groups were cognitive accomplishments that the individual team members often would not have been able to achieve on their own. The analysis of their interaction documented that the individuals ended up with deeper understandings as a result of their participation in the team's collaborative learning.

Other CSCL projects explore similar results in fields of scientific conceptualization, ecological interdependencies, or argumentation about controversial social issues. In such realms of learning, the challenge is beyond the ability of most individual students, but can be approached with well-designed CSCL resources, tools and supports, as well as the interaction of multiple student perspectives and skills. Experiences of collaborative learning can direct the cognition of participants as well as provide models of reflection for subsequent individual thinking.

For a different kind of example, consider how knowledge building took place within the communities of CSCL and LS themselves, as illustrated in the discussion of their history at the start of this investigation. A sociocultural description of how they changed might argue that individual researchers apprenticed to the research communities and gradually adopted the prevalent social practices of data analysis and publication (Lave & Wenger, 1991). As the researchers innovated, the communities were modified in turn. However, theories at the level of the individual and the community run into the problem of structuration (Giddens, 1984)—how these two levels influence and respond to each other. If one considers what took place at the CSCL 2003 conference, one sees that community-level institutions like ISLS and *ijCSCL* were structured through processes of group interaction. There were tensions between political groupings representing different constituencies, and each of these groupings engaged in internal and external interaction. Ad hoc groups sprung up and committees were established to define the community structures. As people interacted within small groups in this context, they changed their individual identities and modified social practices of their field. Through such mechanisms, the group processes mediated and transformed both the individual and community processes, helping to define individuals' identities and institutional practices. In this sense, as the engines of structuration, the group unit of analysis is foundational for the study of change and learning at multiple levels.

The group cognition paradigm argues for scientific study at the small-group unit of analysis (Stahl, 2010) in addition to the individual and community units. Too often, traditional educational researchers reduce group-level phenomena either to individual-psychological constructs or to societal institutions and practices. But, as we have documented in VMT case studies, there are often important practices and processes taking place at the small-group unit of analysis that are not reducible to the mental behaviors of an individual or to the institutions or established practices of a community.

The term "group cognition" does not mean there is some kind of "group mind" at work or anything other than the interaction of the students in a group. Rather, it means that the analysis of cognitive achievements may be most appropriately conducted at the group unit of analysis—in the VMT context, in terms of the collaboration recorded in the interplay of the text-posting and geometric-drawing actions shared by the group.

For instance, a specific student utterance or text posting is not to be ascribed to hypothesized mental processes of the student (what one assumes the student may be thinking, feeling, or trying to accomplish). Rather, it is taken as a situated response to what came before (such as actions or utterances by other students) and as an invitation to subsequent group action [Investigation 23]. That is, it is analyzed as a dialogical move situated in ongoing group interaction. Methodologically, a study of group cognition aims to understand interactional responses within the group rather than cognitive motives of individuals' actions.

CSCL could fully embrace the group cognition paradigm, as illustrated in the VMT Project. This would be appropriate since CSCL was created in response to the potential of networked computers to bring people together into functional groups to collaborate. More specifically, CSCL is oriented to the potential of bringing students together to learn collaboratively. This effort should focus on the group-level interactions in which problem-solving, knowledge building, and other forms of collaborative learning take place.

CSCL is not the science of some existing, objectively observable phenomenon, like physics or psychometrics are often assumed to be. It is the search for a new form of learning—taking advantage of technologies that are yet to be developed and group processes that are difficult to observe and have largely gone unnoticed. Therefore, it cannot be studied in the manner of a summative assessment, by comparing measureable learning outcomes. It is more of a design science, using design-based research to transform "existing situations into preferred ones" (Simon, 1981). In DBR, the vision of CSCL itself is a product of research.

To guide redesign in iterative research projects, it is not sufficient to "predict" the percentage increase in outcomes that is attributable to a particular, currently available technological condition. What is needed is insight into how groups of students in realistic situations may actually make sense of and take advantage of possible technologies, as well as what barriers groups may encounter in trying to use them. This means looking at how groups of students actually interact with various technological artifacts and observing their intersubjective meaning-making processes, their enacting of the technologies, and their collaborative problem-solving as mediated by the technologies.

Of course, not all groups of students will act the same way under similar conditions. Groups are unique—with students at different zones of proximal development for different skills and with interactions highly situated within unreproducible discourse trajectories. Therefore, statistical generalization is not a relevant goal in such research. What one seeks, rather, is a detailed understanding of the practices that are actually found to be at work in observed cases [Investigation 16].

According to ethnomethodology, communities necessarily use shared practices or member methods (Garfinkel & Sacks, 1970). Otherwise, intersubjective sense making would not be possible—any more than communication would without a common language. Therefore, the practices that one observes in a single case may be representative of widely used practices. Researchers familiar with a domain—such as experienced math educators—can often tell what seems like a typical group behavior within that educational arena.

LS and CSCL have made significant progress in recent decades, as documented by Evans, Packer, and Sawyer (2016) and Sawyer (2014). However, it may be timely to pursue a new research paradigm explicitly—one in which CSCL plays a foundational role. For the CSCL and LS research communities to make the major paradigm shift advocated here will involve significant retooling and adoption of new methods. It will also require increased collaboration with colleagues in social science who are more familiar with analyzing interaction and language and with formulating rigorous descriptive accounts of group interactional processes. Fortunately, the requisite technological recording capabilities are available and the evocative research questions are at hand.

The settings studied by LS and CSCL today are complex. Many diverse studies can contribute to an understanding of the learning taking place. Such studies can pose a broad spectrum of research questions, each with its own theoretical framing and methodological approach. Certainly, traditional quantitative and qualitative analyses at the individual unit of analysis can provide important parts of the picture, as can considerations of social practices and community participation. However, it is also necessary to consider the temporal processes of group interaction, through which the individual and the community are often mediated and through which learning takes place as a process, not just as an outcome.

Too often, CSCL is treated as a secondary niche within LS. This is probably because commonsensical attitudes assume that individual learning is the primary goal and that collaborative learning is just one of many possible approaches. However, if one understands that individual learning is actually secondary and dependent upon group cognition, then CSCL should be viewed as foundational to human learning.

In his reconsideration of the CSCL paradigm, Koschmann (2001, p. 21) concluded that "we have yet to develop a consensus within the CSCL community with regard to what it means to learn and how to study the process." I have argued here that a paradigm-shaping research question for LS would *treat learning as essentially an intersubjective, interactional process* and would *study it by investigating the dynamic developmental processes through which individual, small-group, and community cognitive practices emerge*.

Within CSCL, the seminal analysis by Teasley and Roschelle (1993) pursued a specific version of this question by asking how dyads of students created a joint problem space around a computer representation of velocity and acceleration. The VMT Project followed a different approach to the same question by exploring how students co-construct interactional, group-cognitive, and mathematical practices in small online groups mediated by collaborative-dynamic-geometry tasks and tools (Stahl, 2013c, 2016). Taking approaches like these, research in a post-cognitive CSCL paradigm could lead research in LS by working out the interactional foundations of all learning through taking advantage of technologies, pedagogies, and understandings afforded by CSCL.

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Investigation 16. Adopting Group Practices

Gerry Stahl

Abstract

The analysis of *group practices* can make visible the work of novices learning how to inquire in science or mathematics. These ubiquitous practices are invisibly taken for granted by adults, but can be observed and rigorously studied in adequate traces of online collaborative learning. Such an approach contrasts with traditional pre-/post-comparisons that miss sequential interactional processes or that reduce group phenomena to individual or social factors. The analysis of the enactment of practices by small groups in CSCL contexts can systematically inform the design, testing, and refinement of collaborative learning software, curriculum, pedagogy, and theory. The research of the Virtual Math Teams Project resulted in a new way of viewing collaborative learning. According to this view, CSCL can be reconceptualized as the design of technology to foster the adoption of group practices by student teams.

Keywords

Group practice · CSCL theory · CSCL methodology · design-based research

A New Method for CSCL

As a CSCL researcher, participant in all previous CSCL conferences, and former Editor of *ijCSCL*, I have consistently observed that almost all published studies of collaborative learning reduce it either to individual mental representations or to cultural social practices; the small-group unit of analysis is under-researched (Stahl, 2006a). This may be partially because it is difficult to find data that adequately documents collaborative learning by reliably capturing all the discourse, gestures, and artifacts that enter into *group* (i.e., small group, collaborative) knowledge-building processes (Stahl, 2013a). Furthermore, the methods of traditional educational psychology research are inadequate for

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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investigating many core CSCL issues because they focus on individual cognition and assume that utterances can be categorized objectively (i.e., without interpretation based on understanding the sequential meaning making) (Stahl, 2014). My conclusions are controversial within the CSCL research community because they methodologically eschew prevalent cognitivist and positivist assumptions associated with methodological individualism (Stahl, 2016b).

Throughout the history of CSCL as a research community, the methodological tension of the field has been informally described as an opposition of "quantitative" versus "qualitative" approaches (Jeong, Hmelo-Silver, & Yu, 2014; Suthers, Dwyer, Medina, & Vatrapu, 2010). Habermas refines this with the epistemological distinction between calculative and sense-making orientations, which pervades modern science (Hammond, 2015). Sfard (1998) saw the contrast as (individual) acquisition versus (cultural) participation. Viewed in terms of the unit of analysis, "socio-cognitive" psychology focuses on representations in individual minds and "sociocultural" anthropology centers on socially defined practices. In other words, there has been no methodological focus on the small-group unit of analysis—precisely where one would naturally expect to observe collaborative learning in CSCL (Stahl, 2009). Some psychologists recognize that individual learning can be influenced by groups (Cress, 2008) and some sociologists show how social practices are enacted and maintained in group interaction (Garfinkel, 1967; Giddens, 1984). However, as noted by Schwarz and Baker (2017), even these studies rarely analyze empirical data of collaborative learning in ways that display processes of small groups building knowledge or acquiring practices.

Quantitative and qualitative methods are appropriate for measuring net changes due to hypothesized independent variables. However, CSCL needs ways to analyze the group processes that bring about such changes and that establish group practices—in order to guide iterative design-based research (DBR). To not only judge the statistical effectiveness of CSCL interventions in promoting collaborative learning but also to identify specific problems and to suggest innovative functionality during DBR cycles, it is necessary to analyze, understand, and theoretically conceptualize temporal group processes as such, in their sequential unfolding (Stahl, 2013b). Moreover—as anyone knows who has successfully implemented CSCL in classrooms or created effective technological support for it—many cycles of trial and refinement of approach as well as of technology design are necessary to develop effective CSCL pedagogy and tools: DBR as an integration of theory, design, research, and practice.

Traditional methods provide evidence *that* change has taken place (between a pre and a post state), without describing *how* the change took place, beyond speculation based on assumptions from folk theories of cognition (Stahl, 2016b). For instance, groundbreaking CSCL studies (Kapur & Kinzer, 2009; Scardamalia & Bereiter, 2014; Schwartz, 1995) indicated that important learning took place at the group level, without being able to show how it happened. A number of researchers have proposed that unique cognitive processes take place at the small-group level (Barron, 2003; Dillenbourg, Baker, Blaye, & O'Malley, 1996; Hutchins, 1996; Rogoff, 1995), but they have not collected the required data for a systematic analysis at the group unit.

Sfard (2008) argued that learning math is a matter of acquiring many *practices* that are passed down in the culture of mathematics. Vygotsky laid the basis for collaborative learning theory by proclaiming that practices are acquired socially (e.g., in dyads or small groups) first and subsequently adopted by individuals. This notion of practices—when applied at the group unit of analysis—provides a way of conceptualizing regularities of group-cognitive processes. My colleagues and I set out to generate and analyze CSCL interactions in which we could observe such small-group practices emerging.

Studies of Group Practices

In 2002, we initiated the Virtual Math Teams (VMT) research project at the Math Forum. We gradually developed a prototypical CSCL DBR project, which investigated mathematical education with small teams of students in a custom online collaboration environment. The VMT software was instrumented to collect comprehensive interaction data and to provide it to researchers in useful formats. Later, we developed and incorporated a multiuser version of GeoGebra to provide computer support more specifically for dynamic geometry math content.

My published books draw successive lessons from the phases of this research: *Group Cognition* (Stahl, 2006a) proposes analyzing knowledge-building phenomenon at the small-group unit of analysis. *Studying VMT* (Stahl, 2009) describes our scientific approaches to supporting and analyzing small-group problem-solving in the VMT context. *Translating Euclid* (Stahl, 2013b) discusses the many facets of DBR for supporting constructionist CSCL using VMT.

Finally, *Constructing Dynamic Triangles Together* (Stahl, 2016a) follows utterance by utterance a team of students developing mathematical understanding through an eight-hour longitudinal case study, as the group progressively masters collaborative online dynamic geometry. It identifies about sixty "group practices" that the team explicitly, observably enacts. We found that these practices successively contribute to various core aspects of the group's abilities: to collaborate online; to drag, construct, and transform dynamic geometry figures; to use GeoGebra's software tools; to identify and construct geometric dependencies; and to engage in mathematical discourse about their accomplishments.

The notion of *group practices*, as it emerged in this research, provides a foundation for a new way of viewing, analyzing, theorizing, and supporting CSCL. Group practices mediate between individual cognition and community culture (Stahl, 2006a, p. 16; 2013b, Ch. 8). They can be observed and analyzed in small-group interactions. Thereby, the theory of group practice provides a research-based solution to the obstinate issues of meaning making, intersubjectivity, structuration, and connecting levels of learning (Giddens, 1984; Stahl, 2012b, 2016a) while focusing analysis on the small-group unit, as central to collaborative learning. Intersubjective meaning making and knowledge sharing take place via group practices like turn taking, pointing, questioning, and drawing. Individuals can transform the group practices into personal skills and mental abilities. Practices can also pass back and forth between small-group and classroom or cultural levels.

The group practices identified in VMT studies are all based on captured interaction data. These practices arose in observable breakdowns or interactional difficulties and were each enacted explicitly in student discourse. Ethnomethodologically speaking, the practices are observably issues for the participants themselves (Stahl, 2012a). They can be identified through close analysis of discourse and other forms of interaction, such as geometric sketching or pointing within the online VMT environment.

The identification of group practices has substantial implications for the design of CSCL software, curriculum, scripting, pedagogy, and experimental interventions. In DBR, one develops an initial prototype environment and tries it out with groups of students. Based on observation of problems, the prototype is iteratively redesigned and refined. By observing breakdowns in group interaction and the gradual enactment of new group practices in response to the breakdowns, a designer can identify problem areas and constructive processes that need additional support. The analysis of group practices provides a systematic analysis method for driving CSCL design—something that has long been lacking in CSCL (Tim Koschmann, Marlene Scardamalia, personal communications).

Although DBR is a popular approach to the development of educational software, especially in CSCL, there is little agreement on how to evaluate trials in a way that contributes systematically to redesign. The theory of group cognition proposed that one could make collaborative learning—or group cognition—visible (Stahl, 2006a, Ch. 18), based on the principles of ethnomethodological description (Garfinkel, 1967). This is because meaning making is an intersubjective or small-group process, requiring group members to make their contributions visible to each other and therefore also to researchers (Stahl, 2006a, Ch. 16). As the editor's introduction to an important book on ethnomethodology (Garfinkel, 2002) explains, "the sounds and movements that comprise social action are meaningful creations that get their meaning from the shared social contexts of expectation within which they are enacted…. Intended meanings, however, can only be shared if they can be successfully displayed before others in expected ways" (p. 57).

This investigation's analyses of the meaning-making process focus on the sequential response structure (or "adjacency pairs") of utterances, which build on previous utterances and elicit further possible, anticipated, or expected responses—in keeping with the approach of conversation analysis (Schegloff, 2007). The analysis reconstructs the web of situated semantic references: "The meaning of the interaction is co-constructed through the building of a web of contributions and consists in the implicit network of references" (Stahl, 2009, p. 523). The analysis of this discourse data makes visible how small groups negotiate and adopt group practices.

The Structure of Group Discourse

Note that meaning is constructed by more than one individual through the elicitation-response pair. That is why interaction analysis is considered to take place at the small-group unit of analysis. If one attributed the meaning of a single utterance to the mental state of the individual making the utterance, then that would be an analysis at the individual unit and would imply some form of access to the individual's mental state. Single utterances can rarely be adequately interpreted in isolation; they typically include indexical elements that reference prior utterances and other elements of the interactional situation (Zemel & Koschmann, 2013) [Investigation 5]. Therefore, they must be analyzed in terms of their sequential position with respect to utterances of other people.

Most published sequential analyses of conversation are limited to brief excerpts; this investigation's analysis of hour-long sessions—especially considered within the larger context of the VMT Project—goes beyond the analysis of even so-called longer sequences (Stahl, 2011) [Investigation 23]. Analysis of longer sequences is more important in studying geometry instruction than in most conversation analysis. While ethnomethodologically informed conversation analysis (Garfinkel, 1967; Goodwin & Heritage, 1990; Sacks, 1965/1995; Schegloff, 2007) is interested in how meaning is socially constructed in the momentary interaction, we go beyond the ethnomethodological focus. We are here concerned with both (a) longer chains of meaning making and (b) how the meaning-making process itself changes as the group learns to collaborate and to engage in mathematical discourse.

(a) Perhaps geometry's greatest contribution to the development of human cognition was to systematize the building of *chains of reasoning*—presented as deductive proofs or specially structured constructions of graphical figures (Latour, 2008; Netz, 1999). Euclid's proofs could extend to over forty steps, each specified in a prescribed technical language and accompanied by a diagram representing a correspondingly complicated construction. The cognitive capacity to follow—let alone to invent—such a sequence of deduction or construction required the development of meta-cognitive planning and agentic regulation skills (Charles & Shumar, 2009; Emirbayer & Mische, 1998; Stahl, 2005). These skills have since the time of the early Greek geometers become ubiquitous in literate modern society (Ong, 1998). They underlie our scientific worldview and technological lifestyle. Sophisticated planning skills have become second nature (Adorno & Horkheimer, 1945) to us and we now assume that people are born with rational skills of planning and arguing.

It has taken seminal studies of philosophy (Heidegger, 1927/1996) and psychology (Suchman, 2007) to dispel the common rationalist assumption (Dreyfus, 1992) that our actions are the result of previous mental planning, rather than that reasoning is generally posterior rationalization (Stahl, 2013b, Ch. 3), and that we must learn how to make up these explanations after our actions as little retroactive stories (Bruner, 1990), in order to understand and justify them. We would like to see how young, novice teams could develop such sequential reasoning skills, guided by experiences involving geometric construction, analysis, and planning. We hypothesize that studying geometry can be an occasion during which significant steps of learning about deductive reasoning can take place. We look at transcripts of discourse and interaction by virtual math teams for the adoption of group practices that involve group agency of sequences of task steps.

(b) Following a chain of development of group agency over time involves the longitudinal analysis of longer sequences of interaction or comparison of excerpts at different points in a temporally extended learning process. Analysis of a single moment can reveal how participants take their activity as instructional or can display signs of having learned something new (Koschmann & Zemel, 2006; Zemel, Çakir, Stahl, & Zhou, 2009). However, it can be more informative to compare and contrast interactions at different times to reveal how groups and their participants have taken up previous experiences in current interaction (Sarmiento & Stahl, 2008) and *how that makes a difference to their current meaning making*.

We would like to observe the evolution of group practices and individual skills or understandings over time. Our analytic goal can be called a "learning trajectory." Such a learning trajectory has been characterized as follows:

> A researcher-conjectured, empirically supported description of the ordered network of constructs a student encounters through instruction (i.e., activities, tasks, tools, forms of interaction and methods of evaluation), in order to move from informal ideas, through successive refinements of representation, articulation and reflection, towards increasingly complex concepts over time. (Confrey, Maloney, Nguyen, Mojica, & Myers, 2009, p. 346)

Note the central role of instruction here. Instruction is conceived here as the provision of a carefully designed learning environment. As Lehrer and Schauble (2012) put it, "The benchmarks of learning tend not to emerge unless someone carefully engineers and sustains the conditions that support them" (p. 705). Particularly in our study of the Cereal Team (see case studies 3 and 4) we analyze how the VMT environment guides the student team's learning trajectory as they adopt group practices that enable them to refine their representations, articulations, and reflections over time.

Theory of Group Practices

Our focus on *group practices* as foundational to collaborative learning is in keeping with the "practice turn" in contemporary social theory and epistemology (Schatzki, Knorr Cetina, & Savigny, 2001). According to Reckwitz (2002), a practice is "a routinized type of behavior which consists of several elements, interconnected to one another: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge" (p. 249). Social practices form our background, tacit knowledge as proposed by twenty-first-century philosophy (Stahl, 2016b) as an alternative to eighteenth-century rationalist (Descartes, 1633/1999) and cognitivist (Kant, 1787/1999) philosophies [Investigation 15].

Practice theory was propounded by Bourdieu (1972/1995). He uses the term "habitus" for our systems of durable, transposable dispositions—or organization of conventionalized, routinized, objectified, and embodied habits. As with other concepts, I construe practices primarily at the small-group unit of analysis, rather than as habits of individual bodies or cultural conventions of whole communities—in contrast to Bourdieu and his followers. Group practices are what make collaboration possible: "The homogeneity of habitus is what—within the limits of the group of agents possessing the schemes (of production and interpretation) implied in their production—causes practices and works to be immediately intelligible and foreseeable, and hence taken for granted" (Bourdieu, 1972/1995, p. 80).

Only because group members share the ability to use the same group practices, can the members understand each other's actions and their references to those actions. The intersubjectivity of the group is based on this shared meaning [Investigation 18]. The sharing of meaning is a product of the group interaction that adopts the practice; it is produced in the interaction as the members construct the meaning together (Stahl, 2015b). Group practices are proposed—whether verbally or in action—and then discussed, negotiated, accepted, put into regularized practice, generalized across instances of practice, and incorporated into the group's habitus. Then we may say that the group—and often its members—has learned. The analysis of group practices provides a vital key to theorizing, supporting, analyzing, and facilitating computer-supported collaborative learning.

Collaborative learning certainly involves individual cognition and sociocultural influences. Resources from the individual and cultural levels are necessarily introduced into the group interaction, made sense of, negotiated, shared, and adopted through small-group processes. The adoption of group practices *mediates* the multiple levels involved in learning (Stahl, 2013a, 2013b). The analysis of group practices provides a powerful new method to study CSCL. By automatically capturing the complete interaction within inquiring online groups of students, CSCL research has the potential to observe and analyze the subtle development and use of group practices for the first time.

Enacting Group Practices

In analyses of VMT interactions, group practices largely account for the group's teamwork and for its ability to construct knowledge or problem-solve as a group. The enacting of cultural or community practices as their own group practices—facilitated by teachers, texts, scripts, interactional resources, and knowledge artifacts—is how small groups acquire skills from their social context and how the group participants exchange and appropriate each other's perspectives and skills as individual learning (Stahl, 2013b, Ch. 8). *The answer to the question of how the group learns is that it successively adopts various practices and incorporates them in its ongoing interaction.* As Vygotsky (1930/1978) proposed, such small-group learning generally precedes learning by "isolated individuals" (still surrounded by texts, motivations, and objectives from family members, workplace colleagues, classroom friends, and other small groups).

As observed in our studies, the adoption process often follows a general pattern (Stahl, 2016a):

- First, the group encounters a "breakdown" situation in which they do not know what to do.
- Then someone makes a proposal for action. There may have been a preceding series of proposals, some ignored or failed (see Stahl, 2006a, Ch. 21), and others rejected by the group.
- The proposal may be followed by a negotiation process as group members question, refine, or amend the original proposal through secondary proposals.
- Finally, there is often an explicit round of agreement.
- Perhaps most importantly, the new practice is put to work in overcoming the breakdown situation.
- In the future, the practice may be simply applied without discussion. Of course, there could also be instances of backsliding, in which the group fails to apply a previously adopted practice where it could help.

This general pattern is not a rational model of mental decision-making. Rather, it involves tacit behavior, where a breakdown leads to explicit knowledge, followed by negotiation and eventually a return to tacit practices (Stahl, 1993, Ch. 4). The adoption process is driven by interpersonal interaction engaged in the world, not by logical deductions in individual minds.

The catalog of group practices compiled from analysis of VMT data agrees well with lists of social practices enumerated in the literature (Stahl, 2016a). For instance, we identified online versions of practices defined by face-to-face conversation analysis: sequential organization (response structure), turn taking, repair, opening and closing topics, indexicality, deixis, linguistic reference, and recipient design (Zemel, Çakir, & Stahl, 2009). Other group practices correspond to practices CSCL has previously investigated: joint problem spaces, shared understanding, persistent co-attention, representational practices, longer sequences, and questioning [Investigation 17]. Within both our work and other CSCL reports, practices in mathematics education include: mathematical discourse and technical terminology, pivotal moments in problem-solving and the integration of visual/graphical reasoning, and numeric/symbolic expression and narrative [Investigation 12].

The idea of centering CSCL analysis on group practices emerged from study of VMT data. Publications that present that data discuss the theory, methodology, and implications of the focus on group practices extensively. To ground this investigation in that data, we point to four case studies that analyze group practices:

Study 1: A Group Practice of Referencing

Pointing, referencing, or deixis forms a ubiquitous class of gestures essential for maintaining collaboration, including online (Stahl, 2006b). In Log 16.1 from team C in the VMT Spring Fest 2006, three students use a whiteboard integrated with VMT's chat tool to explore arrays of hexagons. In line 709, Jason halts discussion until he can "see" what student 137 has proposed. Qwertyuiop has drawn an

Log 16.1 Excerpt from Study 1

line	time	student	chat post
705	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:45	qwertyuiop	What's the shape of the array? a hexagon?
707	19:16:02	137	Ya.
708	19:16:15	qwertyuiop	ok...
709	19:16:41	Jason	wait-- can someone highlight the hexagonal array on the diagram? i don't really see what you mean...
710	19:17:30	Jason	hmm.. okay
711	19:17:43	qwertyuiop	oops
712	19:17:44	Jason	so it has at least 6 triangles?
713	19:17:58	Jason	in this, for instance
714	19:18:53	137	How do you color lines?
715	19:19:06	Jason	there's a little paintbrush icon up at the top
716	19:19:12	Jason	it's the fifth one from the right
717	19:19:20	137	Thanks.
718	19:19:21	Jason	there ya go :-)
719	19:19:48	137	Er... That hexagon.

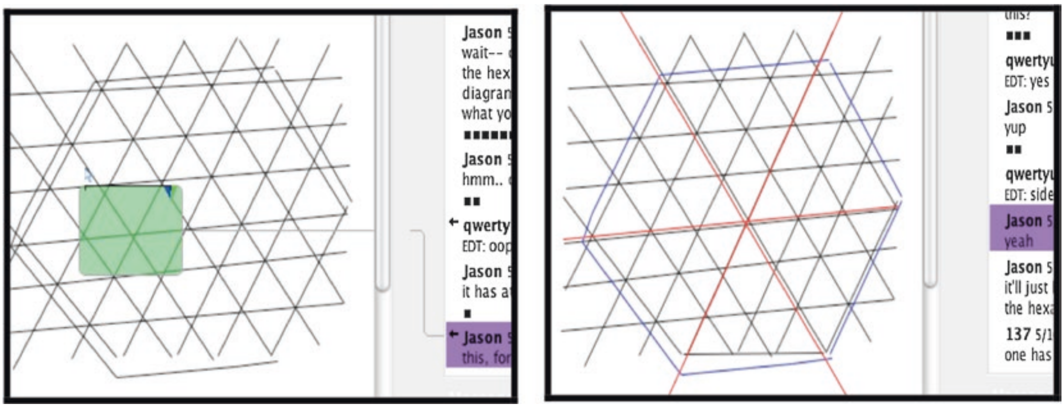

Fig. 16.1 A large hexagon outlined with extra black lines and pointed to by a green square (left). The large hexagon divided in six sectors by red lines (right)

array of lines to check his understanding of 137's post (Fig. 16.1). As analyzed in Stahl (2013b), Sec. 8.1), this leads to work by the group to establish practices for making focal geometric figures visible to each other by coloring lines that outline or divide up the figures [Investigation 17].

In the minute from his interruption of the mathematical talk at Line 709 to his resumption in Line 713, Jason demonstrates that he sees the hexagon that has been outlined by 137 in black lines (Fig. 16.1, left), by making a new mathematical proposal and pointing from his chat posting to a small hexagon using the VMT pointing tool. Soon thereafter, the group divides the larger hexagon into six triangles using a practice involving colored lines (Fig. 16.1, right). We also see the sharing of tool-use practices as Jason guides 137 in coloring lines in the VMT whiteboard, after which 137 colors his outline blue. Later, the group makes more complicated relationships within the array easily visible with colored lines, allowing the group to derive formulas working collaboratively step by step.

Study 2: Group Practices over Time and Across Individuals

In a longitudinal analysis of another VMT team—team B in Spring Fest 2006—Medina, Suthers, and Vatrapu (2009) identify several group practices and show how they are enacted and repeatedly used across all four of their VMT sessions (see Fig. 16.2).

In each session, a different participant initiates interaction by first producing a whiteboard drawing that the other two subsequently orient to through chat. In their sessions 2 and 3, the practice of *inscribe-first-solve-second* is iteratively enacted and composed with two additional practices—*modulate-perspective* and *visualize-decomposition*. In Session 2, Quicksilver's use of color and perspective emerges in the joint work in support of both representational and problem-solving practices. In Session 3, Bwang appropriates color to draw out the particular decomposition previously articulated by Aznx (Fig. 16.2). This demonstrates both shared understanding and individual adoption of the shared group practices.

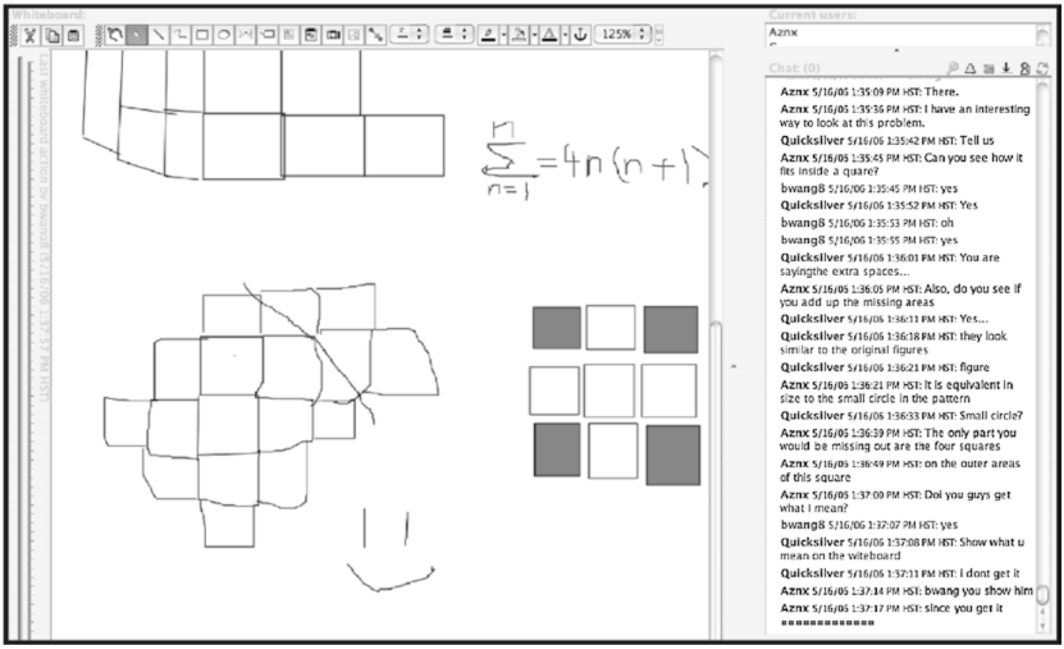

Fig. 16.2 A growing pattern of squares forming a diamond shape, with corners filled in with colored squares to simplify calculations

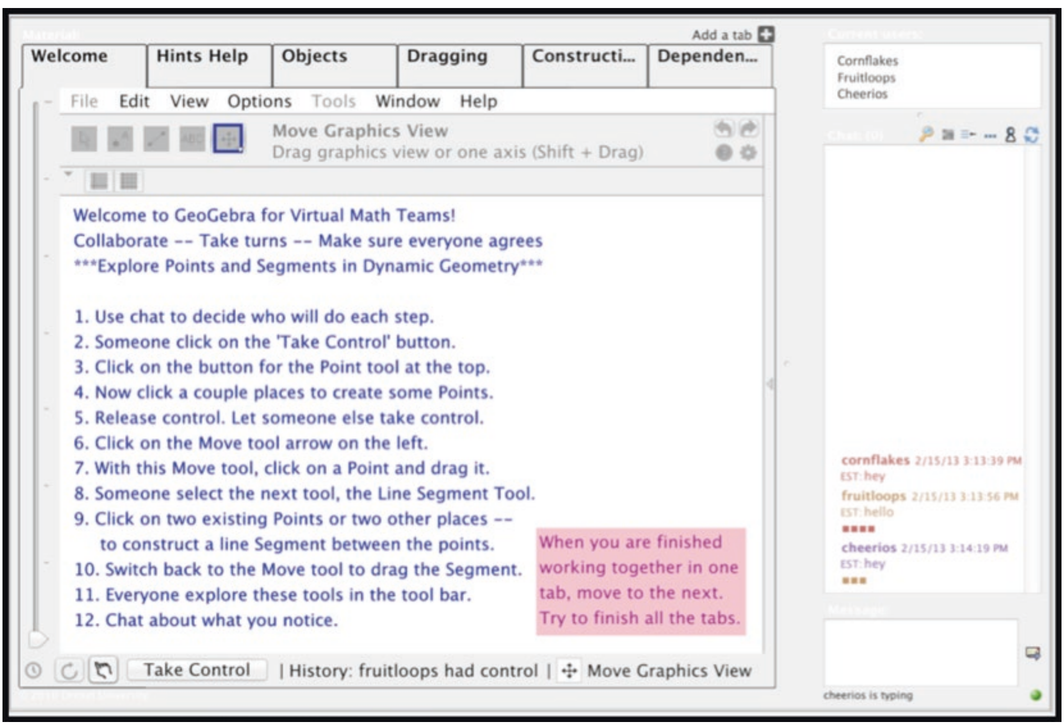

Fig. 16.3 Students greet each other at the start of their use of VMT

Log 16.2 Excerpt from Study 3

Line	*Time*	*User*	*Message*
3	13:39.4	cornflakes	hey
4	13:57.0	fruitloops	hello
6	14:19.1	cheerios	hey
7	14:45.6	cheerios	whose froot loops
8	14:53.9	cornflakes	xxxxxxxx [name *removed from log for privacy*]
9	15:10.8	cheerios	whose takimg control
10	15:20.1	cheerios	taking*
…			
21	16:18.4	cheerios	so whoses doing what
22	16:44.4	fruitloops	who wants to take control?
23	17:30.6	cheerios	xxxxxxxx do you want to [name removed for privacy]
24	17:52.2	fruitloops	no... cornflakes you take controll.....
25	18:01.7	fruitloops	who wants to do what steps?
26	18:02.9	cheerios	cornflakes take control
27	18:03.6	cornflakes	no cheerios you can
28	18:14.6	cheerios	cornflakes
29	18:25.4	fruitloops	cornflakes
30	18:33.6	cornflakes	NO
31	18:40.0	cheerios	why not
32	18:52.3	fruitloops	i just took control. lets takes turns
33	19:01.9	cheerios	alright
34	19:03.0	cornflakes	ok

Study 3: A Group Practice Supporting Collaboration

It is particularly informative to observe novices confronting a completely new challenge. In the start of WinterFest 2013, teams of middle-school students faced VMT's multifaceted software interface and a new form of mathematics, dynamic geometry. Here is the opening interaction of a group of three fourteen-year-old girls we call the Cereal Team (Fig. 16.3 and Log 16.2, analyzed in Stahl (2016a), Session 1).

Note that the group carries over practices of greeting (lines 3, 4, and 6) and correcting typos (line 10) from talking and texting to VMT. However, the group has no idea how to start computer-supported collaboration by taking control of the software and responding to the instructions. Each student strenuously resists leading the online group work. Finally, Fruitloops suggests, "Let's take turns" (Line 32). Although suggested in the instructions, this suggestion has to be stated explicitly and agreed upon by all to become an effective group practice; thereafter, each session begins by a student taking her turn, and the group work proceeds smoothly.

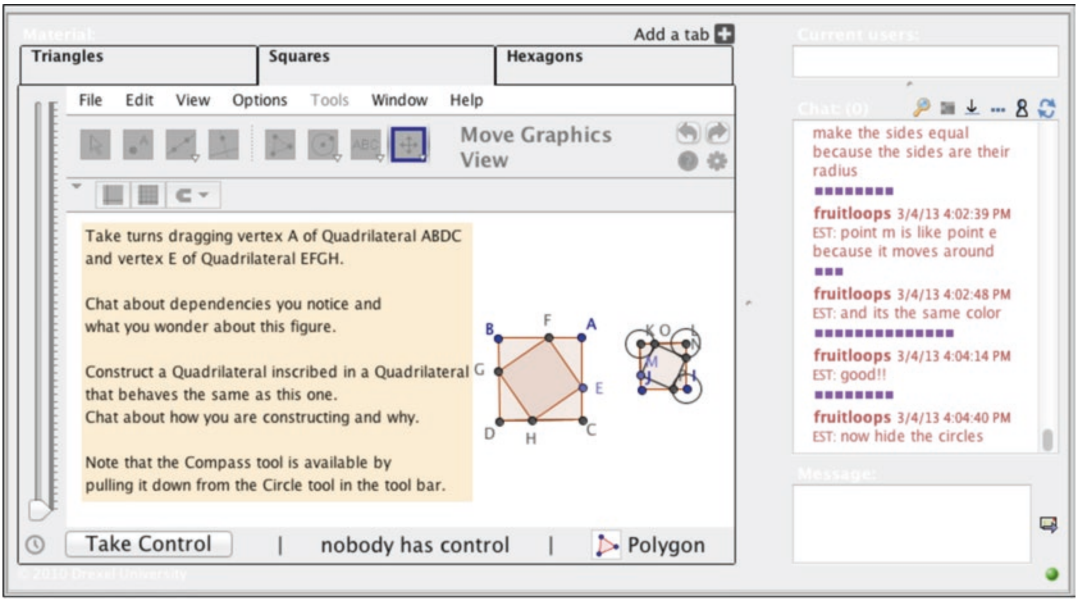

Fig. 16.4 The team was given example square ABDC with inscribed square EFGH and the team constructs square IJKL with inscribed square MONP

Study 4: A Group Practice of Mathematical Problem-Solving

We analyzed the Cereal Team's adoption of many group practices during their eight hour-long sessions. One of their most impressive mathematical accomplishments is analyzed in Stahl (2016a), Session 6. The group explores a given dynamic figure of one square inscribed in another and then constructs its own figure with the same geometric dependencies (Fig. 16.4).

The analysis of this accomplishment and the group's discourse about it demonstrates the team's effective adoption of many mathematical, tool usage, and collaboration group practices. In particular, it makes visible how well the team members each learned the practices enacted by the group in previous sessions (Log 16.3, esp. Line 146).

The analysis of this excerpt requires observing the shared geometric manipulations, noting the reuse of previously acquired group practices and carefully studying the text chat. The data for this is comprehensively preserved by the VMT system.

Designing for Group Practices

We have just summarized very briefly four case studies that were examined in considerable detail in other reports on VMT sessions. From these summaries, we can glimpse several lessons for the design of CSCL pedagogy, curriculum, and technology.

Study 1 shows the importance of pointing practices (deictic reference) for establishing common ground. The VMT software provides tools for pointing from a chat posting to a region in the drawing area, for drawing lines around a region, and for coloring lines to highlight a region [Investigation 22]. The students use these to focus each other's visual attention on a referenced region. In an online environment, creating shared focus is a precondition of productive discourse. In the study's data, we can see how students discover the reference tools and how they inform other group members about them,

Log 16.3 Excerpt from Study 4

135	39:20.3	cornflakes	olets start by cinstructing a regular square
136	39:48.0	fruitloops	i think we should make perpendicular lines somehow
137	39:58.8	cheerios	use the perpindicular line tool
138	43:21.9	fruitloops	the first line segment would be like ab
139	43:27.7	cornflakes	yes
142	51:24.7	cheerios	how do u know ji is straight
143	55:40.6	fruitloops	i dont know what to do because the points arent the same color
144	56:38.2	fruitloops	now after you make the perpendicular lines try to make the circles\
145	57:48.7	fruitloops	i think you need to know use the polygon tool and make the square
146	59:10.6	fruitloops	now we need to use the compass tool lilke we did in the triangles tab
147	59:57.5	fruitloops	because af is equal to ec and dh and bc
148	00:42.4	cheerios	i made a line segment which was if than i used the perpendicular line tool and made 2 lines on each side then used the compass tool and clicked on each point and then the center vertex was i and then made a another circle except the center vertex is j and connected all the points

adopting group practices of using these tools. If other groups failed to find these tools when they were needed or failed to use them appropriately, this could suggest to technology and pedagogy designers to make these tools more visible and to guide students to find and use these tools. Analysis of the group practices in this study suggests retaining the reference tools in future versions and designing more activities that explore and exploit them.

Analysis of group practices in *Study 2* contributes to the theory of CSCL, group cognition, and group practice. For instance, it shows how abilities of one student become shared group practices and how these then become abilities of the other students. Each member of the group in this study contributes a practice that may have been an individual skill or may have been brought in from the larger sociocultural context. These become shared group practices, which then interact with other group practices, leading to innovations in collaborative mathematical cognition. Analysis focused on the creation, adoption, and application of group practices can provide detailed views of computer support, collaborative knowledge building, and the interplay of processes at different levels of description.

Study 3 is informative because it practically shows the creation of collaboration practices *tabula rasa*. Of course, the students are already teens with developed communication skills, but they are initially very reluctant to work together in the VMT environment (although they immediately start to explore it and work in it as individuals). The first thing that the screen of instructions (their script) says is "Collaborate–take turns–make sure everyone agrees." Eventually the group adopts this advice and uses turn taking as a visible group practice. The students talk about whose turn it is and who will take the next turn. However, the group has to go through an adoption sequence before it can enact this group practice to overcome the team's breakdown in action. The design of the wording of the instructions resulted from the observation by the designers of previous studies, which indicated the need for group turn-taking practices. Researchers can now debate whether the instructions need further revision based on Study 3 and parallel studies with the same or reworded instructions.

Study 4 is taken from another session by the team from Study 3, but now (five sessions later), this team of middle-school students is already achieving a geometry accomplishment that is challenging for most college-educated adults working individually. The chat excerpt reflects both geometry construction actions and mathematical reflections by the team. An analysis of the group practices here reveals the importance of the compass tool (technology), of creating equal-length line segments (mathematics), and of explaining what one does so everyone can agree (collaboration). The group is successful because the technology, instructions, and successive activities had been carefully designed to scaffold the adoption of the necessary group practices, based upon previous iterations of VMT trials.

Through analysis of the enactment of group practices while engaging in collaborative dynamic geometry, we determined that a central practice of dynamic geometry is the construction of dependencies. A *dependency* is a constraint on geometric objects that ensures invariance. For instance, in the exemplary Euclidean construction of an equilateral triangle, the sides of the triangle are constrained to be dependent on the radii of circles with equal radii, ensuring that the three sides of the triangle are of equal length to each other (Euclid's first proof). In dynamic geometry, one can drag a vertex of a triangle to make the triangle a different size or orientation; however, if the triangle has been constructed with the correct dependencies, the three sides will stay equal to each other, all getting longer or shorter together.

Geometric dependency is a very abstract notion, challenging for middle-school students to master, as can be seen in the extended analysis of the Cereal Team's group practices (Stahl, 2016a, 2016b). For instance, Öner (2016) [Investigation 9] specifically traces the team's struggle in their third session to move from a naïve view of geometry in terms of visual appearances to one of underlying constructed dependencies. Understanding the notion of dependencies in dynamic geometry can be operationalized in terms of identifying specific group practices of construction (which establish dependencies) and discourse (which references and reflects on the dependencies). This can then guide the researchers' analysis and design.

To learn more about effectively scaffolding group practices related to constructing and discussing dependencies, we designed activities and analyzed interaction data from trials. Our final curriculum (technology, teacher training, embedded instructions, geometry challenges, etc.) is all oriented toward fostering and supporting group practices of constructing dependencies and of discussing dependency (Stahl, 2015a). While aligned with Common Core introductory geometry curriculum, the sequence of activities is designed to foster the successive adoption of group practices that build on each other to facilitate increasingly advanced collaboration, mathematics, and argumentation. As designers, we configure activities to be used in ways we intend. However, we need to study how student teams structure their group practices in our designed environment to know how they enact our artifacts [Investigation 6]. What counts in CSCL is the actual student interaction—structured by group practices—which is always quite different from what the designers envisioned.

Just as we can see in Study 3 the team's difficulty in taking collaborative action before it has adopted the turn-taking group practice, we can repeatedly observe breakdowns in action in later sessions. Especially during periods of geometric construction, the Cereal Team seems to flounder excessively. These are indications that additional group practices should be scaffolded and encouraged. For instance, there are many small tricks to doing constructions in dynamic geometry, and perhaps the curriculum should introduce some of these more explicitly for adoption as group practices. In addition, students tend to avoid discussing in chat what they are doing in the construction area. It might, for instance, be helpful to model effective geometric construction techniques and collaborative discussion patterns in classroom periods before small-group sessions, depending on the educational context. These are new design decisions to be made for future iterations, based on analysis of recent interaction data suggesting which possible group practices are important to support.

Analyzing Group Practices

Group practices are often derived from social practices (of the classroom, school mathematics, the general culture, etc.), but must be enacted or adopted and used repeatedly by the group to become effective. Groups do this in different, unpredictable ways as a result of their massively overdetermined interactions. Every instance of collaborative learning is unique—it cannot be replicated or generalized. However, within a domain-like collaborative online dynamic geometry, certain group practices typically recur regularly. Group practices can constitute central structural elements of group knowledge-building interactions. They structure the interaction. They also structure the domain—as practices related to dependency structure dynamic geometry. The cataloguing of group practices identified in the analysis of a corpus of interaction data from CSCL interventions can contribute to research that is directly applicable to CSCL design to support team interactions in target domains.

Traditional experimental methods aim to contribute incremental additions to a body of scientific findings. However, they are typically summative evaluations that judge the adequacy of supposedly well-defined situations, rather than formative explorations of situations under development and evolution. Summative evaluation is appropriate for studying unchanging natural phenomena. However, CSCL is a design science involving complex human interaction within social contexts in flux. We do not assume that the current design of technology, crafting of pedagogy, preparation of students, or orchestration of collaboration is finalized and perfect—ready for summative evaluation. Rather, we are interested in discovering whether we are making progress along those intermingling dimensions and how we should tweak things for our next design iteration.

In an insightful and comprehensive new review of theory and research in the domain of argumentation in education, Schwarz and Baker (2017) summarize the results of published studies on a variety of aspects of their topic. Invariably, they have to conclude that "more research on argumentation in diverse learning contexts" is needed in each aspect (p. 239). The research they are reviewing consists primarily of attempts to contribute incremental additions correlating variables and effects. What would this even mean in a field where the technology, education theory, and sociocultural context are fluid and successive studies cannot really be comparable? Furthermore, the real point in DBR research is not to evaluate the effectiveness of collaborative learning under current conditions, but to discover avenues to pursue in redesign of our tools, scripts, and theories to create improved future conditions.

For a DBR science, case studies are generally more appropriate than summative evaluations (Yin, 2009). That does not mean that quantitative pre-post studies cannot be helpful in generating or checking hypotheses and suggesting phenomena to look for in detailed interaction analysis. In the VMT Project, we often used quantitative and qualitative methods to pursue specific questions. However, we found that the deepest theoretical insights and the best design suggestions derived from detailed interaction analysis of interesting case studies. The examination of group practices can provide a methodological focus for such investigations in the CSCL research context.

Group Practices in CSCL

The four case studies excerpted above illustrate the adoption and use of group practices for communicating (pointing), problem-solving (problem decomposition), collaborating (turn taking), software usage (compass tool, perpendicular line tool), and geometric construction (of perpendiculars, squares, equal-length lines). By studying the group interactions involved in these practices, we can see in detail just what practices are needed for collaborative mathematics, how groups adopt them, and how well they are supported in our successive prototypes. This is much more useful information for CSCL theory and DBR design than just confirming that groups get a certain result more frequently under certain broad conditions.

A methodological focus on group practices can suggest the design of technologies, curriculum, and pedagogy to support the adoption of key group skills. The analysis of the adoption and reuse of group practices in interaction data can pinpoint how concrete groups learn and achieve (or fail to achieve) group-cognitive accomplishments. The scaffolding of suggested group practices through the orchestration of teacher presentations before group sessions, help videos during sessions, and classroom reflections after sessions can guide and enrich the collaborative learning experience.

This new view of CSCL research suggests that CSCL should be reconceived or redefined as the design, analysis, and orchestration of technology, curriculum, and pedagogy to foster the adoption of productive group practices by student teams.

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Investigation 17. Co-experiencing a Shared World

Gerry Stahl, Nan Zhou, Murat Perit Çakir, and Johann W. Sarmiento-Klapper

Abstract

The ability of people to understand each other and to work together face-to-face is grounded in their sharing of our meaningful natural and cultural world. CSCL groups—such as virtual math teams—have to co-construct their online, shared world with extra effort. A case study of building shared understanding online illustrates several aspects of co-experiencing a digital world. Asking each other questions is one common way of aligning perceptions. Literally looking at the same aspect of something as someone else helps us to see what each other means. The co-constructed shared world has social and temporal as well as objective dimensions. This world grounds communicative, interpersonal, and task-related activities for online groups, making possible group cognition that exceeds the limits of the individual cognition of the group members.

Keywords

Questioning · Bridging · Seeing · World

The Shared World of Meaning

We all find others and ourselves within one world: reality. We learn about and experience the many dimensions of this world together, as we mature as social beings. Infants learn to navigate physical nature in the arms of caregivers; toddlers acquire their mother tongue by speaking with others; adolescents are socialized into their cultures; and adults master the artifacts of the built environment designed by others. The world is rich with socially endowed meaning, and we come to perceive and experience it as immediately meaningful.

G. Stahl (✉) · N. Zhou · M. P. Çakir
J. W. Sarmiento-Klapper
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net; Perit@metu.edu.tr

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Because we share this meaningful world, we can understand each other and can work together on concerns in common. Our activities around our common objects of concern provide a shared structuring of our world in terms of implicit goals, interpersonal relations, and temporal dimensions. These structural elements are reflected in our language: in references to artifacts, in social positioning, and in use of tenses. All of this is understood the same by us unproblematically based on our lived experience of the shared world and communal language. Of course, there are occasional misunderstandings—particularly across community boundaries—but these are exceptions, which prove the rule of shared understanding in general.

The "problem" of establishing intersubjectivity is a pseudo-problem in most cases [Investigation 18]. Human existence is fundamentally intersubjective from the start [Investigation 15]. We understand the world as a shared world, and we even understand ourselves through the eyes of others and in comparison with others (Mead, 1934/1962). Rationalist philosophy—from Descartes to cognitive science—has made this into a problem by focusing on the mind of the individual as if it were isolated from the world and from other people. That raised the pseudo-problem of epistemology: how can the (encapsulated, solipsistic) individual mind know about states of the (physical, as opposed to mental) world and about states of other minds? Rationalist philosophy (as described by Dreyfus, 1992) culminated in an information-processing view of human cognition, modeled on computer architecture: understanding is viewed as primarily consisting of a collection of mental representations (or propositions) of facts stored in a searchable memory (Newell & Simon, 1972), implemented in brain neurons.

Critiques of the rationalist approach (e.g., Dreyfus, 1992; Schön, 1983; Suchman, 1987; Winograd & Flores, 1986) have adopted a phenomenological (Heidegger, 1927/1996; Husserl, 1936/1989; Merleau-Ponty, 1945/2002), hermeneutical (Gadamer, 1960/1988), or ethnomethodological (Garfinkel, 1967) approach, in which understanding is grounded in being-in-the-world-together, in the lifeworld (Lebenswelt), in cultural-historical traditions, and in tacit social practices. This led to post-cognitive theories, with a focus on artifacts, communities-of-practice, situated cognition, distributed cognition, group cognition, activity, and mediations by actor-networks. Human cognition is now recognized to be a social product (Hegel, Marx, Vygotsky) of interaction among people, over time, within a shared world. Knowledge is no longer viewed as primarily mental representations of individuals but includes tacit procedural knowledge (Polanyi, 1966), designed artifacts (Hutchins, 1996), representational inscriptions (Latour, 1992), small-group processes (Stahl, 2006), embodied habits (Bourdieu, 1972/1995), linguistic meanings (Foucault, 2002), activity structures (Engeström, Miettinen, & Punamäki, 1999), community practices (Lave, 1991), and social institutions (Giddens, 1984). The critique of human thought as purely mental and individual is now well established for embodied reality. But what happens in virtual worlds, where the physical world no longer grounds action and reflection? That is the question for this Investigation.

Constructing a Shared Virtual World

The problem of shared understanding rises again—and this time legitimately—within the context of computer-supported collaborative learning (CSCL). That is because when students gather in a CSCL online environment, they enter a virtual world, which is distinct from (although embedded within) the world of physical copresence. They leave the world of nature, of physical embodiment, and of face-to-face perception. They enter a world that they have not all grown into together. However, this does not mean that “shared understanding” is just a matter of overlapping opinions of mental models for online groups either.

In the Virtual Math Teams (VMT) Project, we have been studying how students interact in a particular CSCL environment designed to support online discourse about mathematics. In this Investigation, we will illustrate some of our findings about how interaction in the VMT environment addresses the challenge of constructing a shared virtual world, in which small groups of students can productively engage in collaborative mathematics.

We will present a case study of Session 3 of Team C in the VMT Spring Fest 2006. Here, students aged 12–15 from different schools in the USA met online for 4-h-long sessions. Neither the students nor the researchers knew anything about the students other than their login user names and their behavior in the sessions. A researcher joined the students in their group sessions, but did not engage with them in the mathematics. Between sessions, the researchers posted feedback in the shared whiteboard of the environment. The VMT Project is described and discussed in (Stahl, 2009); its theoretical motivation is presented in (Stahl, 2006). The VMT environment is shown in Fig. 17.1. The complete chat log of Session 3 of Team C is given in the Appendix to this Investigation.

In the next four sections, we illustrate the following aspects of building shared understanding: (a) asking each other questions is one common way of resolving or avoiding troubles of understanding and aligning perceptions; (b) literally looking at the same aspect of something as someone else helps us to see what each other means; (c) the co-constructed shared world has social and temporal as well as objective dimensions; and (d) this world grounds communicative, interpersonal, and task-related activities for online groups.

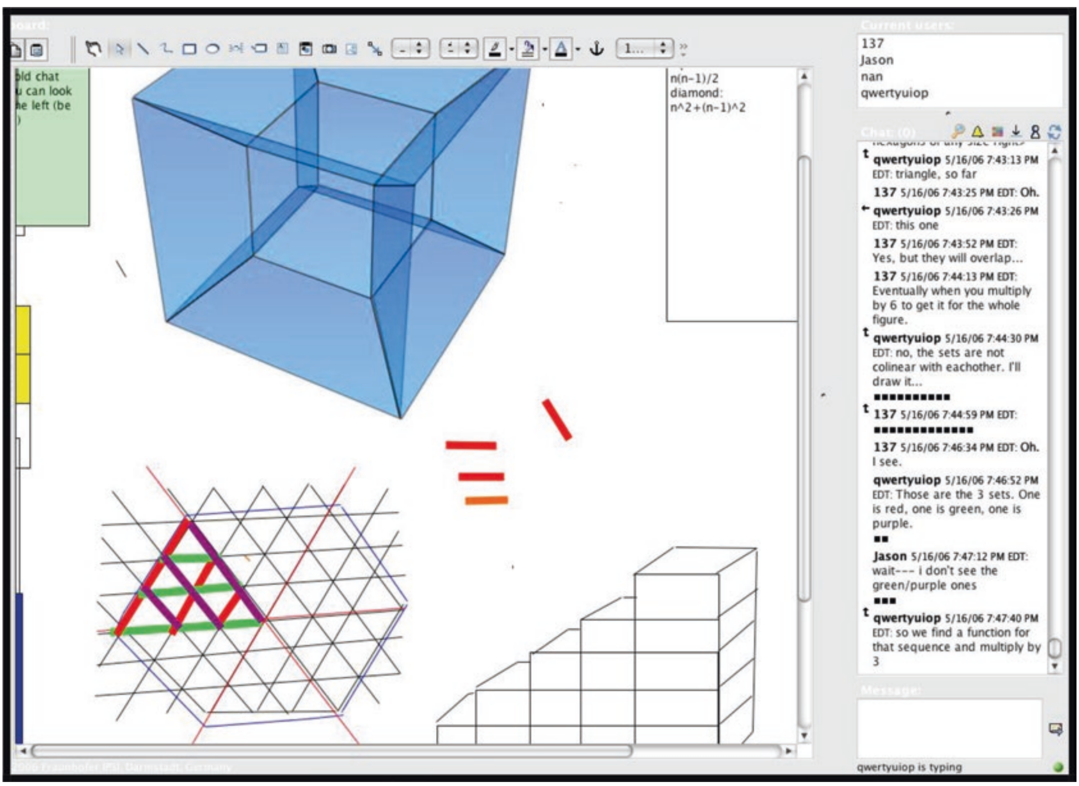

Fig. 17.1 The VMT environment during Session 3 of Team C

Log 17.1 Question by Qwertyuiop

Chat index	Time of posting	Author	Content
685	19:06:34	Qwertyuiop	Has everyone read the green text box?
686	19:06:44	Jason	1 sec
687	19:06:45	137	Yes…
688	19:07:01	Jason	Alright I'm done

Log 17.2 Question by 137

694	19:11:16	137	Great. Can anyone make a diagram of a bunch of triangles?
695	19:11:51	Qwertyuiop	Just a grid?
696	19:12:07	137	Yeah…
697	19:12:17	Qwertyuiop	OK…

Log 17.3 Question by Nan

698	19:14:09	Nan	So what's up now? Does everyone know what other people are doing?
699	19:14:25	137	Yes?
700	19:14:25	Qwertyuiop	No—just making triangles
701	19:14:33	137	I think…
702	19:14:34	Jason	Yeah
703	19:14:46	Nan	Good:-)
704	19:14:51	Qwertyuiop	Triangles are done

Questioning to Share Understanding

We have analyzed how questions posed in the VMT environment often work to initiate interactions that resolve troubles of understanding and deepen shared understanding (Zhou, 2009, 2010; Zhou, Zemel, & Stahl, 2008). This is in contrast to the rationalist assumption that questions are requests for propositional information. We will here review a number of questions from Session 3 of Group C and indicate how they lead to shared understanding. Unfortunately, due to space limitations, we will not be able to provide the full context for these questions or a detailed conversation analysis.

The question by Qwertyuiop in Log 17.1 (line 685) serves a coordination function, making sure that all the students have read the feedback to Session 2 before any work begins in the new Session. This is an effort, taking the form of a question, to maintain a shared experience by having everyone take this first step together.

Log 17.2 is part of a complicated and subtle process of co-constructing shared understanding. It is analyzed in detail in Investigation 12. The student named 137 has attempted to construct a grid of triangles in the whiteboard (similar to those in the lower left corner of Fig. 17.1). He or she has failed (as expressed by the ironic "Great") and has erased the attempt and solicited help by posing a question. Qwertyuiop requests clarification with another question and then proceeds to draw a grid of triangles by locating and then tweaking three series of parallel lines, following much the same procedures as 137 did. Qwertyuiop's understanding of 137's request is based not only on the "Yeah…" response to his/her "just a grid?" question but also on the details of the sequentially unfolding visual presentation of 137's failed drawing attempt.

Log 17.4 Proposal by 137

705	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:45	Qwertyuiop	What's the shape of the array? a hexagon?
707	19:16:02	137	Ya
708	19:16:15	Qwertyuiop	Ok…
709	19:16:41	Jason	Wait—can someone highlight the hexagonal array on the diagram? I don't really see what you mean…
710	19:17:30	Jason	Hmm… okay
711	19:17:43	Qwertyuiop	Oops
712	19:17:44	Jason	So it has at least 6 triangles?
713	19:17:58	Jason	In this, for instance

Log 17.5 Request by 137

714	19:18:53	137	How do you color lines?
715	19:19:06	Jason	There's a little paintbrush icon up at the top
716	19:19:12	Jason	It's the fifth one from the right
717	19:19:20	137	Thanks
718	19:19:21	Jason	There ya go :-)
719	19:19:48	137	Er… That hexagon

In Log 17.3, the moderator, Nan, asks a question to make visible in the chat what members of the group are doing. Qwertyuiop is busy constructing the requested grid in the whiteboard, and the others are presumably watching that drawing activity and waiting for its conclusion. The students do not express any indication that there is a problem in their understanding of each other's activities. However, due to the nature of the virtual environment—in which the attentiveness of participants is only visible through their chat and drawing actions—Nan cannot know if everyone is engaged during this period of chat inaction. Her question and the responses to it make visible to her and to the students the fact that everyone is still engaged. The questioning may come as a minor interference in their group interaction, since Nan's questioning positions her as someone outside the group (not part of "everyone"), exerting authority by asking for an accounting, although it is intended to increase group shared understanding ("everyone know what other people are doing").

See What I Mean

Studies of the use of interactive whiteboards in face-to-face classrooms have shown that they can open up a "shared dynamic dialogical space" (Kershner, Mercer, Warwick, & Staarman, 2010) as a focal point for collective reasoning and co-construction of knowledge. Similarly, in architectural design studios, presentation technologies mediate shared ways of seeing from different perspectives (Lymer, Ivarsson, & Lindwall, 2009) in order to establish shared understanding among design students, their peers, and their critics. Clearly, a physical whiteboard that people can gather around and gesture toward while discussing and interpreting visual and symbolic representations is different from a virtual shared whiteboard in an environment like VMT.

We have analyzed in some detail the intimate coordination of visual, narrative, and symbolic activity involving the shared whiteboard in VMT sessions (Çakir, 2009; Çakir, Stahl, & Zemel, 2010;

Çakir, Zemel, & Stahl, 2009) [Investigation 12]. Here, we want to bring out the importance of literally looking at some mathematical object together in order to share the visual experience and to relate to—intend or "be at"—the object together. People often use the expression "I do not see what you mean" in the metaphorical sense of not understanding what someone else is saying. In this case study, we often encounter the expression used literally for not being able to visually perceive a graphical object, at least not being able to see it in the way that the speaker apparently sees it.

While empiricist philosophy refers to people taking in uninterpreted sense data much like arrays of computer pixels, post-cognitive philosophy emphasizes the phenomenon of "seeing as." Wittgenstein notes that one sees a wire-frame drawing of a cube not as a set of lines, but as a cube oriented either one way or another (Wittgenstein, 1953, sec. 177). For Heidegger, seeing things as already meaningful is not the result of cognitive interpretation, but the precondition of being able to explicate that meaning further in interpretation (Heidegger, 1927/1996, pp. 139f). For collaborative interpretation and mathematical deduction, it is clearly important that the participants see the visual mathematical objects as the same, in the same way. This seems to be an issue repeatedly in the online session we are analyzing as well.

In line 705 of Log 17.4, student 137 proposes a mathematical task for the group. This is the first time that the term "hexagonal array" is used. Coined for the first time in this posting, the term will become a mathematical object for the group as the discourse continues. However, at this point, it is problematic for both Qwertyuiop and Jason because it is new to them. In line 706, Qwertyuiop poses a question for clarification and receives an affirmative, but minimal response. Jason, unsatisfied with the response, escalates the clarification request by asking for help in seeing the diagram in the whiteboard *as* a "hexagonal array," so he can see it *as* 137 sees it. Between Jason's request in line 709 and acceptance in line 710, Qwertyuiop and 137 work together to add lines outlining a large hexagon in the triangular array. Demonstrating his ability to now see hexagons, Jason thereupon proceeds with the mathematical work, which he had halted in the beginning of line 709 in order to keep the group aligned. Jason tentatively proposes that every hexagon "has at least 6 triangles" and he makes this visible to everyone by pointing to an illustrative small hexagon from the chat posting, using the VMT graphical pointing tool.

In Log 17.5, 137 asks the team to share its knowledge about how to color lines in the VMT whiteboard. Jason gives instructions for 137 to visually locate the appropriate icon in the VMT interface. Demonstrating this new knowledge, 137 changes the colors of the six lines outlining the large hexagon, from black to blue, making the outline stand out visually (see Fig. 17.1). 137 thereby finally clarifies how to look at the array of lines *as* a large hexagon, a task that is more difficult than looking at the small hexagon that Jason pointed to. In this excerpt, the group shares their working knowledge of their virtual world (including the software functionality embedded in it), incidentally to carrying out their task-oriented discourse within that world.

Log 17.6 Proposal by Jason

720	19:20:02	Jason	So… should we try to find a formula I guess
721	19:20:22	Jason	Input: side length; output: # triangles
722	19:20:39	Qwertyuiop	It might be easier to see it as the 6 smaller triangles
723	19:20:48	137	Like this?
724	19:21:02	Qwertyuiop	Yes
725	19:21:03	Jason	Yup
726	19:21:29	Qwertyuiop	Side length is the same…
727	19:22:06	Jason	Yeah
728	19:22:13	Jason	So it'll just be x6 for # triangles in the hexagon
729	19:22:19	137	Each one has 1 + 3 + 5 triangles

In Log 17.6, Jason proposes a specific mathematical task for the group to undertake, producing a formula for the number of triangles in a hexagonal array of any given side length. (As we shall see below, the group uses the term “side length” as the measure of a geometric pattern at stage n.) Qwertyuiop responds to this proposal with the suggestion to “see” the hexagon (of any size) as a configuration of six triangular areas. (To see what Qwertyuiop is suggesting, look at Fig. 17.1; one of the six triangular areas of the large hexagonal array has its “sticks” colored with thick lines. Looking at this one triangular area, you can see in rows successively further from the center of the hexagon a sequence of 1 small triangle, then 3 small triangles, and then 5 small triangles.)

In line 723, 137 seeks confirmation that he is sharing Qwertyuiop’s understanding of the suggestion. After posting, “Like this?” with a reference back to Qwertyuiop’s line 722, 137 draws three red lines through the center of the large hexagon, dividing it visually into six triangular areas. Upon seeing the hexagon divided up by 137’s lines, Qwertyuiop and Jason both confirm the shared understanding. Now that they are confident that they are all seeing the mathematical situation the same, namely, *as* a set of six triangular sub-objects, the group can continue its mathematical work. Jason draws the consequence from Qwertyuiop’s suggestion that the formula for the number of small triangles in a hexagon will simply be six times the number in one of the triangular areas of that hexagon, thereby subdividing the problem. 137 then notes that each of those triangular areas has 1 + 3 + 5 small triangles, at least for the example hexagonal array that they are looking at. The fact that the three members of the group take turns making the consecutive steps of the mathematical deduction is significant; it demonstrates that they share a common understanding of the path of deduction and are building their shared knowledge collaboratively.

The observation, “Each one has 1 + 3 + 5 triangles,” is a key move in deducing the sought equation. Note that 137 did not simply say that each triangular area had nine small triangles. The posting used the symbolic visual representation, “1 + 3 + 5.” This shows a pattern of the addition of consecutive odd numbers, starting with 1. This pattern is visible in the posting. It indicates that 137 is seeing the nine triangles *as* a pattern of consecutive odd numbers—and thereby suggests that the reader also see the nine triangles *as* such a pattern. This is largely a visual accomplishment of the human visual system. People automatically see collections of small numbers of objects as sets of their specific size (Lakoff & Núñez, 2000). For somewhat larger sets, young children readily learn to count the number of objects. The team has constructed a graphical representation in which all the members of the team can immediately see features of their mathematical object that are helpful to their mathematical task. The team is collaborating within a shared virtual world in which they have co-constructed visual, narrative, and symbolic objects in the chat and whiteboard areas. The team has achieved this shared vision by enacting (within and for their group) practices specific to mathematics as a profession for shaping witnessed events, such as invoking related math terms and drawing each other’s attention to relevant objects in the scene (Goodwin, 1994). They have learned and taught each other how to work, discuss, and perceive as a group in this shared virtual world, via the adoption of group practices [Investigation 16].

Log 17.7 Bridging by Qwertyuiop

731	19:22:29	Qwertyuiop	the “each polygon corresponds to 2 sides” thing we did last time doesn’t work for triangles
732	19:23:17	137	It equals 1 + 3 + … + (n + n−1) because of the “rows”?
733	19:24:00	Qwertyuiop	yes—1st row is 1, 2nd row is 3…
734	19:24:49	137	And there are n terms so… n(2n/2)
735	19:25:07	137	Or n^2
736	19:25:17	Jason	Yeah
737	19:25:21	Jason	Then multiply by 6
738	19:25:31	137	To get 6n^2

Log 17.8 Proposal by Qwertyuiop

742	19:25:48	Qwertyuiop	An idea: Find the number of a certain set of colinear sides (there are 3 sets), and multiply the result by 3
746	19:26:36	137	As in those?
747	19:27:05	Qwertyuiop	No—in one triangle. I'll draw it…
748	19:28:10	Qwertyuiop	Those
749	19:28:28	Qwertyuiop	Find those, and then multiply by 3
750	19:28:50	137	The rows?
751	19:30:01	Qwertyuiop	The green lines are all colinear. There are 3 identical sets of colinear lines in that triangle. Find the number of sides in one set, and then multiply by 3 for all the other sets
752	19:30:23	137	Ah. I see

Dimensions of a Virtual World

There has not been much written about the constitution of the intersubjective world as the background of shared understanding, particularly in the CSCL online context. This is largely the result of the dominance of the cognitive perspective, which is primarily concerned with mental models and representations of the world; this rationalist view reduces the shared world to possible similarities of individual mental representations. Within the VMT Project, we have analyzed the dimensions of domain content, social interaction, and temporal sequencing in the co-construction of a virtual math team's world or joint problem space (Sarmiento & Stahl, 2008; Sarmiento-Klapper, 2009a, 2009b). In this work, we have found the following conceptualizations to be suggestive and helpful: the "joint problem space" (Teasley & Roschelle, 1993) and the "indexical ground of reference" of domain content (Hanks, 1992); the social "positioning" of team members in discourse (Harré & Gillet, 1999) and their self-coordination (Barron, 2000); and the temporal sequentiality of discourse (Schegloff, 1977) and the bridging of temporal discontinuities.

In its previous sessions, Team C had tried to derive formulae for the number of two-dimensional objects (small squares or small triangles) in a growing pattern of these objects, as well as the number of one-dimensional sides, edges, or "sticks" needed to construct these objects. A major concern in counting the number of sides is the issue of "overlap." In a stair-step two-dimensional pattern (like the 2-D version of the stair-step pyramid in the lower right section of Fig. 17.1), one cannot simply multiply the number of squares by 4 to get the number of sides because many of the sides are common to two squares. In Session 1, Team C had seen that in moving from one stage to the next stage of the stair-step pattern, most new squares only required two new sides.

In Log 17.7, Qwertyuiop moves on from the derivation of the number of triangles to that of the number of sides. He "bridges" back to the group's earlier insight that the addition of "each polygon corresponds to [an additional] 2 sides." In bridging to past sessions, we found, it is necessary for a group to re-situate a previous idea in the current context. In line 731, Qwertyuiop is reporting that for their hexagon formula, such situating does not work—i.e., that the current problem cannot be solved with the same method as the previous problems. The team then returns to the formula for the number of triangles and efficiently solves it by summing the sequence of consecutive odd numbers using Gauss' technique—the sum of n consecutive odd integers is n(2n/2)—which they had used in previous sessions.

In Log 17.8, Qwertyuiop makes a particularly complicated proposal, based on a way of viewing the sides in the large hexagon drawing. He tries to describe his view in chat, talking about sets of collinear sides. Jason does not respond to this proposal, and 137 draws some lines to see if he is visualizing what Qwertyuiop has proposed, but he has not. Qwertyuiop has to spend a lot of time drawing a color-coded analysis of the sides as he sees them.

Log 17.9 Bridging by Nan

804	19:48:49	Nan	(We got a question for you from another team, which was posted in the lobby
805	19:48:53	Nan	Quicksilver 7:44:50 PM EDT: Hey anyone from Team C, our team needs to know what n was in your equations last week
806	19:49:04	Jason	Oh
807	19:49:15	137	The length of a side
808	19:49:16	Qwertyuiop	Was n side length?
809	19:49:33	Jason	Are you talking about the original problem with the squares
810	19:49:48	137	I think nan is
811	19:49:58	Qwertyuiop	I think it's squares and diamonds
812	19:49:58	Jason	Oh
813	19:50:12	Jason	Then if you look in the topic description, there's a column for n;
814	19:50:14	Jason	That's what it is
815	19:50:17	Nan	OK, quicksilver said they got it
816	19:50:25	Jason	So yes it is # sides
817	19:50:26	Nan	Thanks guys

Log 17.10 Generalization by Qwertyuiop

20:12:22	Qwertyuiop	What about the hypercube?
20:12:33	137	Er…
20:12:39	137	That thing confuses me
20:13:00	137	The blue diagram, right?
20:13:13	Qwertyuiop	Can you imagine extending it is 4 dimensions, and a square extends into a grid?
20:13:17	Qwertyuiop	Yes
20:13:30	137	I didn't get that?
20:13:32	Qwertyuiop	I'm having trouble doing that
20:13:45	Qwertyuiop	Didn't get this?
20:13:50	137	Ya
20:15:02	Qwertyuiop	If you have a square, it extends to make a grid that fills a plane. A cube fills a space. A similar pattern of hypercubes fills a "hyperspace"
20:15:19	137	The heck?
20:15:29	137	That's kinda confusing
20:15:43	Qwertyuiop	So, how many planes in a hypercube lattice of space n?
20:16:05	137	Er…
20:16:07	Qwertyuiop	Instead of "how many lines in a grid of length n"
20:16:17	Qwertyuiop	Does that make any sense?
20:16:30	137	No. No offense, of course

He has decomposed the set of sides of one triangular area into three subsets, going in the three directions of the array's original parallel lines. He can then see that each of these subsets consists of 1 + 2 + 3 sides. There are three subsets in each of the six triangular areas. Based on this and generalizing to a growing hexagonal array, which will have sums of consecutive integers in each subset, the team can derive a formula using past techniques.

At some point, they will have to subtract a small number of sides that overlap between adjacent triangular areas. Qwertyuiop has proposed a decomposition of the hexagonal array into symmetric sets, whose constituent parts are easily visible. Thus, his approach bridges back to previous group practices, which are part of the shared world of the group—see the analysis of a similar accomplishment by Group B in (Medina, Suthers, & Vatrapu, 2009). The hexagonal pattern, which Team C came up with on its own, turns out to be considerably more difficult to decompose into simple patterns that the original problem given in Session 1. It strained the shared understanding of the group, requiring the use of all the major analytic tools they had co-constructed (decomposing, color-coding, visually identifying sub-patterns, summing series, eliminating overlaps, etc.).

In Log 17.9, the group work is interrupted by an interesting case of bridging across teams. At the end of each session, the teams had posted their findings to a wiki shared by all the participants in the VMT Spring Fest 2006. During their Session 3, Team B had looked at Team C's work on a pattern they had invented: a diamond variation on the stair-step pattern. In their wiki posting, Team C had used their term, "side length." Because members of Team B did not share Teams C's understanding of this term, they were confused by the equation and discussion that Team C posted to the wiki. Team B's question sought to establish shared understanding across the teams, to build a community-wide shared world. As it turned out, Team C had never completed work on the formula for the number of sides in a diamond pattern, and Team B eventually discovered and reported the error in Team C's wiki posting, demonstrating the importance of community-wide shared understanding.

Grounding Group Cognition

CSCL is about meaning making by groups (Stahl, Koschmann, & Suthers, 2006). At its theoretical core are questions about how groups of students collaborating online co-construct and understand meaning. In this essay, we conceptualize this issue in terms of online groups, such as virtual math teams, building a shared meaningful world in which to view and work on mathematical objects.

Log 17.10 illustrates a limit of shared understanding, closely related to the notion of a "zone of proximal development" (Vygotsky, 1930/1978, pp. 84–91). The original stair-step pattern consisted of one-dimensional sides and two-dimensional squares. In their Session 2, Team C had generalized this pattern into a three-dimensional pyramid consisting of cubes. Now Qwertyuiop proposes to further generalize into a mathematical fourth dimension and derive formulae for patterns of one-, two-, three-, and four-dimensional objects. He had previously imported a representation of a four-dimensional hypercube (see the upper area of Fig. 17.1) into the whiteboard for everyone to see.

At this point late in Session 3, Jason had left the VMT environment. Qwertyuiop was unable to guide 137 to see the drawing in the whiteboard as a four-dimensional object. Apparently, Qwertyuiop had been exposed to the mathematical idea of a fourth dimension and was eager to explore it. However, 137 had not been so exposed. They did not share the necessary background for working on Qwertyuiop's proposal. The only resource available for scaffolding joint meaning making on this topic was the graphic that Qwertyuiop imported—and that was apparently not enough by itself.

This shows that tasks for student groups, even tasks they set for themselves, need to be within a shared group zone of proximal development or be adequately supported by the collaboration environment. The stair-step problem was in their zone—whether or not they could solve it themselves individually, they were able to solve it collectively, with enough shared understanding and background knowledge that they could successfully work together. Their three-dimensional pyramid turned out to be quite difficult for them to visualize in a shared way. Their diamond pattern seemed to be easy for them, although they forgot to work on some of it and posted an erroneous formula. The hexagonal array required them to develop their skills in a number of areas, but they eventually solved it nicely. However, the hypercube exceeded at least 137's ability (or desire) to participate in investigating it.

Rationalist philosophy reduces the complexity of social human existence to a logical, immaterial mind that thinks about things by representing them internally. It confuses the mind with the brain and conflates the two. It assumes that someone thinking about a hexagon or working on a math problem involving a hexagon must primarily be representing the hexagon in some kind of mental model. But one of the major discoveries of phenomenology (Husserl, 1936/1989) was that (mental) intentionality is always the intentionality of some (nonmental) object and that cognition takes place as a "being-with" that object, not as a mental act of some transcendental ego [see Investigation 18].

As an example, we have seen that the members of Team C are focused on the graphical image of the hexagon in their virtual world on their computer screens. They reference this image and transform it with additional lines, colors, and pointers. They chat about this image, not about some personal mental representations. They work to get each other to see that image in the same way that they see it. This "seeing" is to be taken quite literally. Their eyes directly perceive the image. They perceive the image in a particular way (which may change and which they may have to learn to see).

"Seeing" is not a metaphor to describe some kind of subjective mental process that is inaccessible to others, but a form of contact with the object in the world. Accordingly, we may say that shared understanding is a matter of the group members being-there-together at the graphical image in the whiteboard.

Being-there-together is a possible mode of existence of the online group. The “there” where they are is a multidimensional virtual world. This world was partially already there when they first logged in. It included the computer hardware and software. It included the VMT Spring Fest as an organized social institution. As they started to interact, the students fleshed out the world, building social relationships, enacting the available technology, interpreting the task instructions, and proposing steps to take together. Over time, they constructed a rich world, furnished with mathematical objects largely of their own making and supporting group practices that they had introduced individually but which they had experienced and adopted as a group [Investigation 16].

Being-there-together in their virtual world with their shared understanding of many of this world’s features, the group was able to accomplish mathematical feats that none of them could have done alone.

Each individual in the group shared an understanding of their group work at least enough to make productive contributions that reflected a grasp of what the group was doing. Their group accomplishments were achieved through group processes of visualization, discourse, and deduction. They were accomplishments of group cognition, which does not refer to anything mystical, but to the achievements of group interaction. The group cognition was possible because of, and only based upon, the shared understanding of the common virtual world. Shared understanding is not a matter of similar mental models, but of experiencing a shared world.

Of course, there are limits to group cognition, just as there are limits to individual cognition. We saw that Team C could not understand Qwertyuiop’s ideas about the fourth dimension. Without shared understanding about this, the group could not engage in discourse on that topic. Group cognition can exceed the limits of the individual cognition of the group members but only by a certain amount. The individuals must be able to stretch their own existing understanding under the guidance of their peers, with the aid of physical representations, tools, concepts, scaffolds, and similar artifacts, whose use is within their grasp—within their zone of proximal development (Vygotsky, 1930/1978). We have seen that Team C was able to solve a complex mathematical problem that they set for themselves involving a hexagonal array by building up gradually, systematically and in close coordination a meaningful virtual world.

An analysis of the log of the interaction in our case study has demonstrated much about the team’s group cognition. Their group work proceeded by contributions from different individuals, with everyone contributing in important ways. Their questions showed that their individual cognition was initially inadequate to many steps in the work; but their questions also served to expand the shared understanding and to ensure that each member shared an understanding of each step. Because the students demonstrated an understanding of the group work through their successive contributions, we can see not only that individual learning took place, but we can analyze the interactional processes of group learning or group cognition through which it took place by detailed analysis of the chat and drawing actions.

As Vygotsky argued, not only does group cognition lead individual cognition by several years, but individual cognition itself develops originally as a spin-off of group cognition. Individuals can learn on their own, but the cognitive and practical skills that they use to do so are generally learned through interaction with others and in small groups.

This is a powerful argument for the use of CSCL in education. It is incumbent upon CSCL research to further analyze the processes by which this takes place in the co-construction of shared understanding within co-experienced virtual worlds. As we have seen, participants in CSCL virtual environments co-construct worlds to ground their interactions. These virtual worlds exploit intersubjective meaning-making, perceptual joint attention, and referential practices learned in the physical social world and adapted to the co-experienced online world.

Appendix

Following is the complete chat log of Session 3 of Group C of VMT Spring Fest 2006. A Replayer file of the entire Group C interaction, including whiteboard and chat, is available on request from the author.

663		17:20:42	Nan	Joins the room
665		19:01:25	Jason	Joins the room
666		19:02:22	137	Joins the room
667	19:02:30	19:02:37	Nan	Hi Jason and 137, welcome back
668	19:02:49	19:02:49	Jason	Hi
669	19:03:05	19:03:06	137	Hi
670	19:02:56	19:03:09	Nan	I'll be your facilitator tonight
671	19:02:51	19:03:13	Jason	It looks like ssjnish is having connection problems again, even after I pointed him to an email on how to clear his Java cache
672		19:03:45	Qwertyuiop	Joins the room
673	19:04:07	19:04:13	Nan	Hi Qwertyuiop
674	19:04:23	19:04:23	Qwertyuiop	Hi
675	19:04:24	19:04:36	Nan	Do any of you know if David is coming?
676	19:04:33	19:04:41	137	So we do what we did last time again?
677	19:04:46	19:04:47	Nan	Yes
678	19:04:42	19:04:52	137	I forgot to ask David at school
679	19:04:59	19:05:04	137	I don't think he'd remember
680	19:04:48	19:05:11	Nan	First take a few minutes to read the feedback posted on the whiteboard
681	19:05:19	19:05:21	Nan	No problem
682	19:05:23	19:05:27	Nan	I guess we can start
683	19:05:38	19:05:48	Nan	David can join later when he comes
684	19:05:53	19:05:54	137	Right
685	19:06:19	19:06:34	Qwertyuiop	Has everyone read the green text box?
686	19:06:43	19:06:44	Jason	1 sec
687	19:06:43	19:06:45	137	Yes…
688	19:07:00	19:07:01	Jason	Alright I'm done
689	19:06:27	19:07:02	Nan	Did you see some little squares after message? I haven't seen those before, interesting
690	19:07:10	19:07:11	Qwertyuiop	Yes
691	19:07:07	19:07:12	Jason	Yeah, they just indicate whiteboard activity
692	19:07:31	19:07:32	137	Oh
693	19:07:22	19:07:40	Nan	I see. I was on a leave for 2 weeks and this version is the latest
694	19:11:02	19:11:16	137	Great. Can anyone make a diagram of a bunch of triangles?
695	19:11:47	19:11:51	Qwertyuiop	Just a grid?
696	19:12:04	19:12:07	137	Yeah…
697	19:12:14	19:12:17	Qwertyuiop	OK…
698	19:13:40	19:14:09	Nan	So what's up now? Does everyone know what other people are doing?
699	19:14:23	19:14:25	137	Yes?
700	19:14:18	19:14:25	Qwertyuiop	No—just making triangles
701	19:14:31	19:14:33	137	I think…
702	19:14:32	19:14:34	Jason	Yeah
703	19:14:44	19:14:46	Nan	Good:-)
704	19:14:45	19:14:51	Qwertyuiop	Triangles are done
705	19:14:46	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:22	19:15:45	Qwertyuiop	What's the shape of the array? A hexagon?
707	19:16:00	19:16:02	137	Ya
708	19:16:13	19:16:15	Qwertyuiop	OK…

709	19:16:20	19:16:41	Jason	Wait—can someone highlight the hexagonal array on the diagram? I don't really see what you mean…
710	19:17:28	19:17:30	Jason	Hmm.. okay
711	19:17:42	19:17:43	Qwertyuiop	Oops
712	19:17:35	19:17:44	Jason	So it has at least 6 triangles?
713	19:17:55	19:17:58	Jason	In this, for instance
714	19:18:48	19:18:53	137	How do you color lines?
715	19:18:58	19:19:06	Jason	There's a little paintbrush icon up at the top
716	19:19:06	19:19:12	Jason	It's the fifth one from the right
717	19:19:19	19:19:20	137	Thanks
718	19:19:18	19:19:21	Jason	There ya go :-)
719	19:19:44	19:19:48	137	Er… That hexagon
720	19:19:52	19:20:02	Jason	So… should we try to find a formula I guess
721	19:20:13	19:20:22	Jason	Input: side length; output: # triangles
722	19:20:12	19:20:39	Qwertyuiop	It might be easier to see it as the 6 smaller triangles
723	19:20:44	19:20:48	137	Like this?
724	19:21:01	19:21:02	Qwertyuiop	Yes
725	19:21:00	19:21:03	Jason	Yup
726	19:21:23	19:21:29	Qwertyuiop	Side length is the same…
727	19:22:05	19:22:06	Jason	Yeah
728	19:22:06	19:22:13	Jason	So it'll just be x6 for # triangles in the hexagon
729	19:22:04	19:22:19	137	Each one has 1 + 3 + 5 triangles
730	19:22:17	19:22:23	Jason	But then we're assuming just regular hexagons
731	19:21:53	19:22:29	Qwertyuiop	the "each polygon corresponds to 2 sides" thing we did last time doesn't work for triangles
732	19:22:43	19:23:17	137	It equals 1 + 3 + … + (n + n-1) because of the "rows"?
733	19:23:43	19:24:00	Qwertyuiop	yes—1st row is 1, 2nd row is 3…
734	19:24:22	19:24:49	137	And there are n terms so… n(2n/2)
735	19:25:01	19:25:07	137	Or n^2
736	19:25:17	19:25:17	Jason	Yeah
737	19:25:18	19:25:21	Jason	Then multiply by 6
738	19:25:26	19:25:31	137	To get 6n^2
739	19:25:21	19:25:39	Jason	But this is only with regular hexagons… is it possible to have one definite formula for irregular hexagons as well
740	19:24:19	19:25:46	Nan	(Sorry to interrupt) Jason, do you think you can ask ssjnish to check the email to see the instructions sent by VMT team, which might help?
741	19:25:42	19:25:48	Jason	I'm not sure if it's possible tho
742	19:24:39	19:25:48	Qwertyuiop	An idea: Find the number of a certain set of colinear sides (there are 3 sets) and multiply the result by 3
743	19:25:57	19:26:03	Jason	I did—apparently it didn't work for him
744	19:26:05	19:26:13	Jason	Or his Internet could be down, as he's not even on IM right now
745	19:26:10	19:26:13	Nan	I see. Thanks!
746	19:26:20	19:26:36	137	As in those?
747	19:26:46	19:27:05	Qwertyuiop	No—in one triangle. I'll draw it…
748	19:28:09	19:28:10	Qwertyuiop	Those
749	19:28:18	19:28:28	Qwertyuiop	Find those, and then multiply by 3
750	19:28:48	19:28:50	137	The rows?
751	19:29:01	19:30:01	Qwertyuiop	The green lines are all colinear. There are 3 identical sets of colinear lines in that triangle. Find the number of sides in one set, and then multiply by 3 for all the other sets
752	19:30:20	19:30:23	137	Ah. I see
753	19:31:00	19:31:07	137	Wait. Wouldn't that not work for that one?
754	19:31:11	19:31:12	Jason	Yeah
755	19:31:12	19:31:15	Jason	Beacuse that's irregular
756	19:31:09	19:31:17	137	Or are we still only talking regular ones?

757	19:31:20	19:31:22	137	About
758	19:30:38	19:31:24	Qwertyuiop	Side length 1 = 1, side length 2 = 3, side length 3 = 6…
759	19:32:32	19:32:50	137	Shouldn't side length 2 before?
760	19:32:52	19:32:53	137	*Four
761	19:33:06	19:33:10	Qwertyuiop	I count 3
762	19:33:20	19:33:25	137	Oh. Sry
763	19:33:24	19:33:30	Qwertyuiop	It's this triangle
764	19:33:44	19:33:45	137	We
765	19:33:47	19:33:54	Qwertyuiop	I don't see the pattern yet…
766	19:33:50	19:34:01	137	We're ignoring the bottom one?
767	19:34:11	19:34:29	Qwertyuiop	No, 3 is only for side length 2
768	19:34:36	19:34:52	137	And I think they're all triangular numbers
769	19:35:06	19:35:17	Qwertyuiop	"Triangular numbers"?
770	19:35:28	19:35:37	Jason	You mean like 1, 3, 7, …
771	19:35:39	19:35:39	Jason	?
772	19:35:48	19:35:59	137	Like 1, 3, 6, 10, 15, 21, 28
773	19:35:51	19:36:02	Qwertyuiop	The sequence is 1, 3, 6…
774	19:36:02	19:36:30	137	Numbers that can be expressed as n(n + 1)/2, where n is an integer
775	19:36:44	19:36:45	Qwertyuiop	Ah
776	19:37:09	19:37:18	137	So are we ignoring the bottom orange line for now?
777	19:37:32	19:37:36	Qwertyuiop	"Green"?
778	19:37:44	19:37:48	137	The short orange segment
779	19:37:49	19:38:05	137	Parallel to the blue lines
780	19:37:58	19:38:05	Qwertyuiop	I don't think so…
781	19:38:20	19:38:26	137	Wait, we are counting sticks right now, right?
782	19:38:35	19:38:48	Qwertyuiop	Yes—one of the colinear ets of sticks
783	19:38:55	19:39:08	Qwertyuiop	Oops—"sets" not "ets"
784	19:39:22	19:39:42	137	So we are trying to find the total number of sticks in a given regular hexagon?
785	19:39:50	19:40:18	Qwertyuiop	Not yet—we are finding one of the three sets, then multiplying by 3
786	19:40:25	19:40:40	Qwertyuiop	That will give the number in the whole triangle
787	19:40:34	19:40:51	137	Then shouldn't we also count the bottom line?
788	19:40:52	19:41:01	Jason	Are you taking into account the fact that some of the sticks will overlap
789	19:41:25	19:41:41	137	Then number of sticks needed for the hexagon, right?
790	19:41:16	19:42:22	Qwertyuiop	Yes. The blue and green/orange lines make up one of the three colinear sets of sides in the triangle. Each set is identical and doesn't overlap with the other sets
791	19:42:50	19:42:50	Jason	OK
792	19:43:03	19:43:11	Jason	This would be true for hexagons of any size right>
793	19:43:09	19:43:13	Qwertyuiop	Triangle, so far
794	19:43:25	19:43:25	137	Oh
795	19:43:25	19:43:26	Qwertyuiop	This one
796	19:43:42	19:43:52	137	Yes, but they will overlap…
797	19:43:59	19:44:13	137	Eventually when you multiply by 6 to get it for the whole figure
798	19:44:01	19:44:30	Qwertyuiop	No, the sets are not colinear with each other. I'll draw it…
799		19:44:59	137	
800	19:46:22	19:46:34	137	Oh. I see
801	19:46:22	19:46:52	Qwertyuiop	Those are the 3 sets. One is red, one is green, one is purple
802	19:47:04	19:47:12	Jason	Wait—I don't see the green/purple ones
803	19:47:18	19:47:40	Qwertyuiop	So we find a function for that sequence and multiply by 3
804	19:48:25	19:48:49	Nan	(We got a question for you from another team, which was posted in the lobby:
805	19:48:52	19:48:53	Nan	Quicksilver 7:44:50 PM EDT: Hey anyone from Team C, our team needs to know what n was in your equations last week

806	19:49:04	19:49:04	Jason	Oh
807	19:49:12	19:49:15	137	The length of a side
808	19:49:10	19:49:16	Qwertyuiop	Was n side length?
809	19:49:26	19:49:33	Jason	Are you talking about the original problem with the squares
810	19:49:44	19:49:48	137	I think nan is
811	19:49:43	19:49:58	Qwertyuiop	I think it's squares and diamonds
812	19:49:58	19:49:58	Jason	Oh
813	19:49:59	19:50:12	Jason	Then if you look in the topic description, there's a column for n
814	19:50:12	19:50:14	Jason	That's what it is
815	19:50:09	19:50:17	Nan	OK, quicksilver said they got it
816	19:50:22	19:50:25	Jason	So yes it is # sides
817	19:50:21	19:50:26	Nan	Thanks guys
818	19:51:11	19:52:19	Qwertyuiop	What about: f(n) = 2n−1 where n is side length
819	19:52:55	19:53:03	137	I don't think that works
820	19:53:07	19:53:18	137	Howbout just n(n + 1)/2
821	19:53:37	19:53:41	Jason	For # sticks?
822	19:53:38	19:53:48	Qwertyuiop	That's number of sides for one set
823	19:53:50	19:53:51	Qwertyuiop	?
824	19:53:57	19:53:59	Jason	Oh OK nvm
825	19:54:26	19:54:29	137	Ya
826	19:54:36	19:54:58	Qwertyuiop	Then x3 is 3(n(n + 1)/2)
827	19:55:04	19:55:07	Qwertyuiop	Simplified to…
828	19:55:11	19:55:37	Qwertyuiop	(n(n + 1)1.5
829	19:55:34	19:55:44	137	On second thought, shouldn't we use n(n-1) for these
830	19:55:31	19:55:55	Nan	Just a kind reminder: Jason mentioned that he needs to leave at 7p central time sharp
831	19:56:05	19:56:19	Nan	Rest of you can continue if you like
832	19:56:19	19:56:25	137	Is that 5 pm PST?
833	19:56:27	19:56:31	137	Or 4 pm?
834	19:56:32	19:56:32	Nan	Yes
835	19:56:41	19:56:42	137	Ah
836	19:56:42	19:56:56	Nan	Which is a couple of min from now, right, Jason?
837	19:57:15	19:57:16	Qwertyuiop	Jason?
838	19:57:30	19:57:33	137	I think he left?
839	19:57:43	19:57:52	Jason	Sorry I was away for a couple minutes
840	19:57:58	19:58:02	Jason	Yeah I'll need to go pretty soon
841	19:58:23	19:58:25	Qwertyuiop	Back to this?
842	19:58:32	19:58:34	137	Ya
843	19:58:39	19:58:49	Qwertyuiop	Why not n(n−1)?
844	19:58:39	19:58:50	Jason	You guys pretty much have the formula for this hexagon problem…
845	19:58:57	19:59:28	Qwertyuiop	We almost have it for the triangle. I don't know about the hexagon
846	19:59:35	19:59:50	Jason	Well that's just multiplied by a certain number for a hexagon, provided that it is regular
847	19:59:58	20:00:14	Qwertyuiop	But the sides of the triangles making up the hexagon overlap
848	19:59:52	20:00:18	Jason	Well I have to leave now; sorry for not participating as much as I wanted to, it's a pretty busy night for me with school and extracurricular stuff
849	20:00:31	20:00:35	Jason	See you guys Thursday!
850	20:00:44	20:00:48	Nan	Thanks for participating
851	20:00:53	20:00:57	Nan	See you Thursday
852	20:00:57	20:01:00	137	Cya/
853		20:01:07	Jason	Leaves the room
854	20:01:19	20:01:31	137	Anyways, if we multiply the orange by 3, we get the
855	20:01:14	20:01:34	Nan	Do two of you want to continue working for a bit or stop here?

856	20:01:40	20:01:44	Nan	I guess that's the answer
857	20:01:47	20:01:48	Nan	Go ahead
858	20:01:57	20:02:14	137	So then we add 12n for
859	20:01:28	20:02:15	Qwertyuiop	Actually, this doesn't complicate it that much. The overlaps can be accounted for with "−6n"
860	20:02:54	20:02:55	137	Oh
861	20:02:56	20:03:07	137	I like addition more than subtraction
862	20:03:11	20:03:16	Qwertyuiop	Do you see why that works
863	20:03:18	20:03:18	Qwertyuiop	?
864	20:03:12	20:03:29	137	So: 9n(n + 1)−6n
865	20:03:41	20:03:45	Qwertyuiop	9, not 3?
866	20:04:13	20:04:14	137	?
867	20:04:18	20:04:35	Qwertyuiop	You have "9n(n…)"
868	20:04:37	20:04:47	Qwertyuiop	Not "3n(n…)"?
869	20:04:51	20:05:00	137	But we need to multiply by 6 then divide by 2
870	20:05:10	20:05:22	Qwertyuiop	x6 and /2 for what?
871	20:05:44	20:05:47	137	For each triangle
872	20:05:48	20:06:02	137	And /2 because it's part of the equation
873	20:06:03	20:06:06	137	Of n(n + 1)/2
874	20:05:36	20:06:20	Qwertyuiop	It's x3 for the 3 colinear sets, then x6 for 6 triangles in a hexagon… where's the 9 and 2?
875	20:06:28	20:06:28	Qwertyuiop	Oh
876	20:06:35	20:06:38	137	So 18/2
877	20:06:42	20:06:50	137	A.K.A. 9
878	20:06:48	20:07:08	Qwertyuiop	(n(n + 1)/2) x 3 x 6
879	20:07:14	20:07:15	137	Yeah
880	20:07:20	20:07:27	Qwertyuiop	Which can be simplified…
881	20:07:42	20:07:46	137	To 9n(n + 1)
882	20:08:01	20:08:04	Qwertyuiop	That's it?
883	20:08:10	20:08:12	137	-6n
884	20:08:17	20:08:24	137	So 9n(n + 1)−6n
885	20:08:20	20:08:34	Qwertyuiop	I'll put it with the other formulas…
886	20:09:39	20:09:47	Qwertyuiop	Number of triangles is…
887	20:10:27	20:10:28	137	That
888	20:10:37	20:10:43	137	6n^2
889	20:11:25	20:11:26	Qwertyuiop	Oops
890	20:12:12	20:12:22	Qwertyuiop	What about the hypercube?
891	20:12:29	20:12:33	137	Er…
892	20:12:36	20:12:39	137	That thing confuses me
893	20:12:56	20:13:00	137	The blue diagram, right?
894	20:12:37	20:13:13	Qwertyuiop	Can you imagine extending it is 4 dimensions, and a square extends into a grid?
895	20:13:16	20:13:17	Qwertyuiop	Yes
896	20:13:26	20:13:30	137	I didn't get that?
897	20:13:21	20:13:32	Qwertyuiop	I'm having trouble doing that
898	20:13:41	20:13:45	Qwertyuiop	Didn't get this?
899	20:13:49	20:13:50	137	Ya
900	20:13:57	20:15:02	Qwertyuiop	If you have a square, it extends to make a grid that fills a plane. A cube fills a space. A similar pattern of hypercubes fills a "hyperspace"
901	20:15:17	20:15:19	137	The heck?
902	20:15:25	20:15:29	137	That's kinda confusing
903	20:15:16	20:15:43	Qwertyuiop	So, how many planes in a hypercube lattice of space n?
904	20:16:04	20:16:05	137	Er…
905	20:15:48	20:16:07	Qwertyuiop	Instead of "how many lines in a grid of length n"

906	20:16:11	20:16:17	Qwertyuiop	Does that make any sense?
907	20:16:23	20:16:30	137	No. No offense, of course
908	20:16:35	20:16:43	Qwertyuiop	OK… let me think…
909	20:16:58	20:17:19	Qwertyuiop	Imagine our first problem with a grid of squares
910	20:17:29	20:17:31	137	Right
911	20:17:23	20:18:07	Qwertyuiop	The squares are 2 dimensional and they can be arranged in a grid to tessalate over a plane. The plane is also 2 dimensional
912	20:18:39	20:18:41	137	Right
913	20:18:12	20:18:54	Qwertyuiop	If you use 3 dimensional cubes, they can be arranged to fill a 3 dimensional space
914	20:19:08	20:19:17	137	And that structure's 4 dimensional?
915	20:18:56	20:19:25	Qwertyuiop	If you have hypercubes, they can be arranged to fill a 4 dimensional "hyperspace"
916	20:19:32	20:19:36	Qwertyuiop	What's 4D?
917	20:19:45	20:19:46	137	?
918	20:19:43	20:20:04	Nan	You may want to make your ideas available on the wiki before you go
919	20:20:06	20:20:09	Nan	Which may take some time
920	20:20:15	20:20:24	137	Actually, I only have around 10 minutes left
921	20:19:51	20:20:29	Qwertyuiop	You say "and that structure's 4 dimensional?"—what's "that"
922	20:20:33	20:20:34	Nan	Oh
923		20:20:35	137	
924	20:20:36	20:20:43	137	The hypercube
925	20:20:50	20:20:50	Qwertyuiop	Yes
926	20:21:00	20:21:02	137	Um…
927	20:20:58	20:21:09	Qwertyuiop	I have homework to do, too…
928	20:21:03	20:21:33	137	So how the heck are we supposed to calculate the number of four-dimensional figures?
929	20:21:32	20:21:42	Nan	Do you want to stop here and start putting ideas on wiki?
930	20:21:47	20:21:47	Qwertyuiop	OK
931	20:21:51	20:21:52	137	Sure
932	20:22:02	20:22:09	Qwertyuiop	Resume from here next time?
933	20:22:16	20:22:17	Nan	Sure
934	20:22:18	20:22:19	137	Ya
935	20:22:32	20:22:48	Qwertyuiop	We have the 2 hexagon equations to put on the wiki
936	20:23:04	20:23:04	137	Right
937	20:23:11	20:23:18	Qwertyuiop	Where's the wiki again?
938	20:23:27	20:23:30	Nan	Open "view topic"
939	20:23:23	20:23:31	137	Somewhere in the view topic button
940	20:23:39	20:23:41	Nan	There's link
941	20:23:53	20:23:54	Qwertyuiop	I see it
942		20:24:28	137	Leaves the room
943	20:24:57	20:25:02	Qwertyuiop	I'll write it
944		20:25:05	Qwertyuiop	Leaves the room
945		20:25:19	Nan	Leaves the room

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Investigation 18. From Intersubjectivity to Group Cognition

Gerry Stahl

Abstract
The term "intersubjectivity" is ambiguous. It can refer to the problem of how two or more minds can interrelate: understand each other and work together from their individual cognitive positions. It can also refer to a form of joint cognition that is shared by a group and transcends, unifies, or even founds the cognition of the participating individuals. This Investigation traces a historical evolution in philosophy from the former view to the later, considering in turn Plato, Descartes, Kant, Husserl, Schutz, Heidegger, Merleau-Ponty, Tomasello, and Vygotsky. It proposes a view of intersubjectivity as group cognition, appropriate to CSCW and CSCL, illustrated with a CSCW example of paired programming and a CSCL example from online collaborative geometry.

Keywords
Intersubjectivity · Shared understanding · Joint intentionality · We-awareness · Group cognition · Group agency · Joint participation · Perspectival individuality · Joint attention · Shared meaning making · Being-there-with-others · Shared world

The Issue of Intersubjectivity

The question of how it is possible for people to understand each other has been a controversial theme throughout the history of philosophy. It is a foundational issue for the social sciences, in which researchers try to understand the behaviors and statements of other people. It is of particular relevance to Computer-Supported Cooperative Work (CSCW) and Computer-Supported Collaborative Learning (CSCL), where participants have to understand, work with, and learn with each other. Philosophers have posed the issue of how an individual can understand another and how a small group or community can have a joint understanding, shared intentionality, or we-awareness. Studies of CSCW not only adopt insights from the philosophy of intersubjectivity to ground their methodology; they also

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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contribute to the analysis of how intersubjectivity is established in concrete settings, including in virtual environments. Similarly, CSCL research can investigate how groups of people learn to construct intersubjective understandings in both traditional and technologically enhanced interactions. While classical phenomenology of intersubjectivity started from the cognitions of a solitary mind, the notion of intersubjectivity has subsequently shifted to a more social view. Recent studies of intersubjectivity suggest a structure of group cognition, which can provide a foundation for collaboration in work and learning that incorporates but transcends individual cognition.

While “intersubjectivity” is a modern term, it points to an issue that is both as old as philosophy and as current as the lead article in a CSCW journal special issue on the topic (Tenenberg, Roth, & Socha, 2015). Intersubjectivity is what makes we-awareness possible. By referencing a realm between or encompassing multiple people, intersubjectivity raises the question of whether knowing, thinking, and being aware are at base matters of individual consciousnesses or of collectivities. The following historical review of the philosophy of intersubjectivity will trace a shift from a foundation in solitary minds to one in human groups or communities. It will consider the central statements concerning intersubjectivity from Husserl, Schutz, Heidegger, Merleau-Ponty, Hegel, Marx, Vygotsky, and Tomasello. Implications of the philosophic conception of intersubjectivity for CSCW and CSCL methodology—in which the analytic foundation in individual or group cognition is currently highly contentious—will then be suggested and be related to research in these fields.

The issue of intersubjectivity is paramount to our times. The major geopolitical issues of the day concern how people around the shrinking globe can understand each other and relate in unity to their shared world. How can the rich and the poor see eye to eye on global ecology; how can former colonial powers and former colonies work together for peace and mutual benefit; and how can populations with incompatible politics, ideology, religion, and economic interests coexist? We do not adequately grasp how people understand each other even in dyads, let alone in international communities. Researchers in CSCW and CSCL could contribute to such a comprehension, but they tend to get distracted with methodological concerns based on outmoded philosophies and approaches misappropriated from the natural sciences.

The problematic of intersubjectivity emerged in response to the growth of the social sciences a century ago. The first explicit systematic discussion was in the phenomenology of Husserl, grappling with issues in traditional philosophy. Although the historical movement from intersubjectivity to group cognition followed multiple intertwined paths, this Investigation will present a single conceptual thread. It will review the core discussions of intersubjectivity in the primary philosophic texts that defined the concept. As we will see, the term “intersubjectivity” is ambiguous. It can refer to the problem of how two or more minds can interrelate: understand each other and work together from their individual cognitive positions. It can also refer to a form of joint cognition that is shared by a group and transcends, unifies, or even founds the cognition of the participating individuals. This Investigation will trace an evolution in philosophy from the former view to the later and will propose a view of intersubjectivity as group cognition, appropriate to CSCW and CSCL.

The Philosophy of Subjectivity: Plato, Descartes, and Kant

Socrates was the poster child for the self-reflective individual, who radically examined his own life and thought. However, in the end he submitted to Athenian society as the collectivity to which he fundamentally belonged. Perhaps horrified by the consequence of Socrates’ refusal to break with his corrupt, irrational, and unheeding community, Plato (340 BCE) metaphorically left his fellow citizens behind in the dark cave of their traditions and illusions to emerge into true knowledge as an isolated individual. Thenceforth, truth, knowledge, and learning were no longer matters founded in traditional society, but concerned eternal ideas discoverable through individual critical reflection.

The focus on individual thought found its ultimate formulation in Descartes (1633). In his argument—popularly formulated as "I think, therefore I am"—Descartes claimed that as much as he tried to doubt the reality of everything, he could not doubt that he was thinking, because his doubt was itself an instance of him thinking. If he was thinking, then there must be a subject (namely, him) who was doing the thinking. Descartes thereby established as a foundation for philosophy and all knowing that an individual thinking subject existed. This raised subsequent problems, which were much harder for Descartes and his successors to address: How can this radically doubting individual subject be certain about knowledge of any object in the physical world (the problem of epistemology) and how can this isolated individual subject be certain about knowledge of other people's minds (the problem of intersubjectivity). How can one even know that a world or that other people exist external to the individual thinking subject (the problem of solipsism)?

There were many attempts to address the problems left in Descartes' wake. These produced philosophies of empiricism, rationalism, materialism, idealism, etc. Some principles from these classical philosophies were adopted as foundations of scientific method and are still assumed in many contemporary research methodologies. Kant (1787) came up with a synthesis of the major philosophic approaches of his time, still focusing on the individual human mind as the seat of pure reason. He argued that the only access we have to the world is to versions of objects that we have constructed ourselves from our sense perceptions. We structure what we sense from the world that is external to our individual minds. We do so in terms of categories of time, space, and causality, which we impose in constructing the world as meaningful and knowable. That provides us with a view of the world that makes sense to us, with persistent, meaningful objects. Kant's solution to the problem of epistemology provides a form of constructivism that makes impossible "objective" knowledge (other than logical deductions) in a naïve sense. Kant demonstrated that there are many questions that are meaningless to pose—often because they presume to peek behind the constructions that our understanding of the world unavoidably erects.

The Phenomenology of Intersubjectivity: Husserl

While philosophy has always been concerned with the nature of subjectivity, the first major discussion of intersubjectivity was by Husserl. He devoted his popular introduction to phenomenology to the problem of intersubjectivity. His *Cartesian Meditations* (Husserl, 1929) was presented at the Sorbonne in 1929. (Merleau-Ponty was in the audience as a student.) This was a couple years after Husserl's student and assistant, Heidegger, had published *Being and Time*, but Husserl's presentation was as yet unaffected by that. Husserl was concerned with the crisis of the philosophical foundations of the sciences. Dilthey and others had differentiated the human sciences from the natural sciences. Einstein and quantum theory were shaking the physical sciences with the idea that observation was relative to the observer. The foundations of logic and mathematics were in dispute. Weber and others were formulating social sciences (linguistics, anthropology, as well as sociology) in terms of meaning and interpretation, hard to objectify.

Husserl began from Descartes' argument. It starts with the solitary subject ("I") doubting everything except its own existence. In five chapters or "meditations," Husserl builds toward the central problem, intersubjectivity: How can I know another person—that he[1] exists or what he means when he speaks? For a social science today, such as CSCW or CSCL, this asks: How does one person relate to co-workers or fellow students as equally human? How does one understand the meaningful actions and statements of others? And also how does a researcher analyze the meaning created in the discourse and in the work products of cooperating workers or collaborating students?

[1] The masculine pronoun is used here to refer to people of all genders, in keeping with traditional English grammar and philosophic usage.

After introducing Descartes' position in his first meditation, Husserl shows how minds construct meaningful objects. At first, cognition is intentional, that is, directed toward some phenomenon.[2] For instance, if my consciousness is directed toward a six-sided die, I perceive at any instant only evidence of certain sides. However, over time my consciousness can synthesize the die as having six sides, perceptible from different perspectives. Then the die is intended by my consciousness as "given" with more than the immediate evidence. The meaningful die is temporally constituted by a series of perceptions and synthesizing acts in my stream of consciousness. I understand the perceived view of the die as having a horizon of possibilities, anticipations, or potential remembrances that is given with the immediate perception as belonging to the meaning of the phenomenon of the observed view of the die. Husserl's third and fourth meditations outline his extensive phenomenological analyses of how the solitary subject constitutes his world and his lived temporality, starting from elementary cognitive experiences.

For Husserl, we construct or constitute our experiences of things, including other people, through sequences of cognitive acts, which are generally not conscious, but pre-reflective. Our knowledge of another person is constituted through our own processes of constructing our experience of them. We can, for instance, construct an understanding of someone else's behavior as the behavior of a person who is human like us, has a stream of consciousness like ours, and has understandings like ours. We can assemble evidence for our understanding of the other person from experiences we have had—both our experiences of the other person and our own experiences that are similar or relevant. For instance, we observe our own bodies and those of others—and we see that the other is like us.

In his concluding fifth meditation, Husserl reaches the goal of his presentation and gives us a summary of the first major extended analysis of intersubjectivity. He departs from Descartes and argues that we can experience other people as also sentient beings who experience the world as we do. In fact, this makes the world a shared, intersubjective one. We experience the socially shared world from our own perspective, and we see other people as also experiencing this same world from their positions:

> I experience others in shifting experiential manifolds. On the one hand, as objects in the world. Not just as mere natural things, but also experienced as psychically active in the natural bodies to which they each belong. On the other hand, I experience them simultaneously as subjects of this world, as experiencing this world—this same world that I experience myself. They are experiencing it with me, as I experience it and as within it I experience them.
> Even within my purely cognitive life, I experience the world including other people and the associated meaning not as a so-to-say private construction of synthesis, but as other than mine, as *intersubjective*, as existing for everyone, as having its objects accessible to everyone….
>
> To the character of the world and particularly of nature as objective, there belongs its being there for everyone, as constituted by us whenever we speak of objective reality. To this belongs the objects of the experienced world having mental characteristics, which refer to human subjects by their origins and meaning—and in general refer to other subjects and their actively constituting intentionality. This includes all cultural objects (books, tools and all kinds of works, etc.), which also carry with them the experiential meaning of being there for everyone. That is, for everyone of the corresponding cultural community, such as the European or more specifically the French. (Husserl, 1929, §43, my translation)

Husserl overcomes the solipsism of Descartes by showing that I experience others as fellow subjects in a shared world. However, this all takes place in my own consciousness and experiences. So it is not meaningful to ask if my understanding of the other person's behavior is identical to the other person's understanding of their own behavior. The gulf of intersubjectivity is spanned by Husserl in that we can construct an understanding of the other person as a person having their own understandings. Nevertheless, we cannot erase the gulf and obtain direct knowledge of their understanding. Any two people construct their own understanding of the shared world (including themselves and each

[2]The notion of intentionality was first developed by Husserl's teacher, Brentano (1874). Intentionality means that consciousness is always consciousness *of* something, always directed at something. Consciousness is not a purely mental phenomenon but extends into the "external" world.

other) from the perspective of their own subjectivity (stream of consciousness, personality, personal history, body position, etc.).

The Social Science of Intersubjectivity: Schutz

Schutz explicitly applied Husserl's approach to the social sciences, specifically to Weber's sociology. In 1932, he published a detailed and relatively clear book on the meaning-full construction of the social world (Schutz, 1932a), centered around a chapter on "Foundations of a theory of intersubjective understanding." While occasionally referencing Heidegger, Schutz remained true to Husserl's phenomenology, starting from the cognitions of an individual consciousness and constructing the intersubjective world upon that basis. This was also consistent with the methodological individualism of Simmel and Weber, which held that "all concrete social phenomena should be traced back to the modes of individual behavior" (Schutz, 1932b/1967, p. 4).

Schutz starts from Husserl's conclusion of the intersubjectivity of the world, namely, that people take for granted the existence of other people as having the same kinds of temporal streams of consciousness and as sharing the same social world. However, since people constitute the world from their own perspective (in terms of their own bodily location, personal history, ingrained habits, action goals, and subjective experiences), "the concept of the other person's intended meaning remains at best a limiting concept" (p. 98). We can only approach an understanding of another's cognition to a degree and without certainty.

To understand another person takes a reflective act. The other person typically does not understand his own action in this way: he is simply acting, not reflecting on his action. Thus, it does not even make sense to ask if a researcher's understanding of a subject's action corresponds to the subject's own understanding, since the subject probably does not have that kind of reflective understanding. If a researcher tries to triangulate his interpretation by asking a subject questions (in a test, a questionnaire, an interview, a focus group), then the subject may start to reflect on the relevant prior actions, but his newly constructed understanding or response was not something present at the time of the action, let alone motivating it in advance or causing it. Nor is the subject's retroactive self-understanding qualitatively superior to an observer's understanding of the subject, except that the subject may have access to a richer array of information about himself and his past. Like the researcher's analysis, the subject's self-understanding is also a speculative reconstruction from a series of perceived experiences.

Schutz provides analyses of meaning making, sign systems, and artifacts, as they enter into our understanding of other people and of their communications, actions, and interactions. He also describes concepts of "in-order-to motives" and "because motives," which can be used for understanding statements and actions, without attributing explicit knowledge to the actor. These feed into Schutz' interesting discussions of (a) the thou-orientation, (b) the we-relationship, (c) face-to-face situations, and (d) direct social observation.

(a) The *thou-orientation* is a pre-reflective awareness of another person as a fellow human, who has consciousness and experiences similar in kind to my own. It thus embodies the intersubjectivity in which others are recognized as indubitable, aware, thoughtful, and human. To understand another in this way is to attribute meanings, desires, and plans to him. It is the first stage of intersubjectivity as a relationship between two individual subjects.
(b) When the thou-orientation becomes reciprocal, it forms a *we-relationship*, in which another and I experience the world together as a shared world. Schutz provides this example: "Perhaps while I was following the bird's flight I noticed out of the corner of my eye that your head was moving in the same direction as mine. I could then say that the two of us, that *we*, had watched the bird's

flight" (p. 165). Although we have experienced something together, that does not mean that we had the same subjective experience. For me to think about your experience, I have to step back from our we-relationship and reflect on evidences about your experience that are available to me. This is a second stage of intersubjectivity including reciprocity: I am aware that you are experiencing the same world as I am and we are doing it together.

(c) When two people are engaged *face to face*, they participate together in an ongoing series of acts of meaning-establishment and meaning-interpretation (such as elicitation/response pairs of discourse utterances, in which I say something and you respond, thereby establishing the meaning of my utterance through its implicit interpretation by your response). In orienting to objects of joint attention, the participants experience the objects as common to both their experiences. They are simultaneously aware of what each other experiences as being experienced together. The shared intersubjective world is constituted by this experience in the face-to-face situation. Over time, I understand my partner in terms of his motives (personality, habits). Furthermore, I can check my understanding of the other by asking him questions (e.g., to jointly create meaning and to avoid or repair potential misunderstandings). This all takes place within the merged experiential streams of the face-to-face situation. Although Schutz does not discuss the face-to-face mode of intersubjectivity in any detail, he hints here at an intersubjectivity that is more than the sum of its parts, the two individual subjectivities. Meanings are created through the interaction between the participants; there are group processes like repair of understandings; and the experience of the world is partially shared, not completely subjective. Schutz' face-to-face intersubjectivity provides a brief foretaste of group cognition.

(d) Schutz then contrasts the face-to-face situation (e.g., of participants collaborating) with *direct social observation* (e.g., by a social science researcher). Direct social observation is very different from the face-to-face situation. The observer is not engaged in the same undertaking as his subject, nor is he engaged with the subject in a shared context of action. Furthermore, the observer does not have the same kinds of access through interaction to check on and repair his understandings of the subject's subjective experiences, motivations, or attempts. The close mutuality and reciprocal mirroring of the face-to-face situation is missing in a context of objective observation. Schutz specifies three possible indirect approaches for scientific observation of a subject's motives: An observer can interpret the subject's behavior in terms of what he imagines he himself might have done under the circumstances. Alternatively, he can take into account the customary behavior of that kind of person (e.g., applying Weber's ideal types). Finally, he can interpret the observed behavior "in terms of the effect which it actually has and assume that the effect is what was intended" (p. 175). These modes of understanding other people and of intersubjectivity appear in various methodologies of CSCW and CSCL research.

The Being of Intersubjectivity: Heidegger

By the time Husserl's and Schutz' analyses of intersubjectivity were published, Heidegger's implicit repudiation of these theories was already widely read. Although Heidegger emerged from the Husserlian school of phenomenology and was deeply steeped in traditional philosophy, his *Being and Time* presented a radical rejection of the starting point of individual consciousness. In this sense, he left behind not only the constructivism of Kantian pure reason but also the cognitivism of any methodological individualism. Heidegger's analysis of human existence began with the unity of being-in-the-world, where people exist through their essential involvement in the world. This involvement includes being-there-together in the shared world with other people.

Heidegger's analysis of being-there-with-others (Heidegger, 1927, §§25–27) is laced with barbs against the positions of Husserl and Schutz. Heidegger refers to the enterprise of seeking a transition from the isolated individual to the other as a "mis-understanding" and explicitly rejects the conception of the unity of the self "as the identity of the I maintaining itself in the multiplicity of its 'experiences'" (p. 122).

Human being—as our openness to the world—is defined according to Heidegger, first and foremost, by the collectivity of other people, with whom we are concerned and with whom we share a joint world, filled with meaningful artifacts and natural objects that we deal with together. However, this collectivity is described abstractly by Heidegger—not in terms of our family, friends, colleagues, neighbors, community, or society. In fact, it is portrayed in rather dark tones, as an oppressive or at least obscuring view of the world through the outlook of an unenlightened mass culture.

Heidegger argues that because we are caught up in this distracting and obscuring culture and are constantly busily distracted by other people, with the objects in the world of our concern, and in our projects involving them, we cannot see our own true nature as being-there-with-others. Rather, we see things—including other people and even ourselves—in terms of an ontology of physical objects and mental ideas (*à la* Plato, Descartes, and the common sense of the collective). Unfortunately, after his brief but central and pivotal analysis of being-there-with-others, Heidegger shifts from the social basis of human existence, which he had finally uncovered, to a focus on the individual self as a secondary ontological mode, which supposedly provides greater understanding of human being than the collective view. He values this derived mode as more "authentic," although ironically it is close to the individualistic reflective mode of Husserl. Heidegger, thus, retreats from the social foundation he briefly established. By not elaborating this more concretely through contact with the other mainstream of German philosophy developed by Hegel and Marx, Heidegger remains at the level of politically conservative cultural criticism (Adorno, 1964/1973) and heads toward his fateful political error (Stahl, 1975).

The Corporeality of Intersubjectivity: Merleau-Ponty

Merleau-Ponty studied both Husserl and Heidegger carefully, including especially their responses to Descartes' problem of intersubjectivity.[3] Merleau-Ponty (1945/2002) fleshed out their analyses with an in-depth analysis of the role of the body and of embodied perception in human being and thinking. His chapter on other people and the human world comes as the culmination of his phenomenological description of human existence. He argues that the experience of another person—such as my sense of the other's grief or anger—is given immediately in my perception of his bodily contact and expression, not mediated through some form of my reflection on what his inner experiences must be like based on remembrances of similar experiences of my own (p. 356). We thus strive to project a shared world, in which we can communicate, for instance, about our grief or anger. We each do so from our own bodies, as corporeal actors.

Intersubjectivity is given with our being embodied in a shared world and forms a basis for our subjectivity. Intersubjectivity could not be "constituted" subsequently by isolated individual consciousnesses. As Merleau-Ponty says, "My greatest attempt at impartiality would never enable me to prevail over my subjectivity (as Descartes so well expresses it by the hypothesis of the malignant demon), if I had not, underlying my judgments, the primordial certainty of being in contact with being itself, if, before any voluntary adoption of a position, I were not already situated in an intersubjective

[3] When Merleau-Ponty died, he was found with his head literally in a book by Descartes, perhaps struggling to the end with the question of intersubjectivity.

world” (p. 355). Merleau-Ponty adopts Heidegger’s view of being-there-with-others as fundamental to the human condition. However, he does so more concretely and persistently. He refers to the perception of the other’s body as material, meaningful, and expressive. He cites evidence from child development that infants exist in a shared world without even differentiating themselves from others—so that subjectivity is seen to be a derived and learned phenomenon, not an absolute Cartesian starting point.

In addition, Merleau-Ponty looks at the role of language in the perception of other people. Language is essentially social; it transcends the individual and it merges the perspectives of multiple speakers. He describes eloquently how dialogue can establish a shared thinking in the verbal interaction of two people:

> My thought and his are interwoven into a single fabric, my words and those of my interlocutor are called forth by the state of the discussion, and they are inserted into a shared operation of which neither of us is the creator. We have here a dual being, where the other is for me no longer a mere bit of behavior in my transcendental field, nor I in his; we are collaborators for each other in consummate reciprocity. Our perspectives merge into each other, and we coexist through a common world. In the present dialogue, I am freed from myself, for the other person’s thoughts are certainly his; they are not of my making, though I do grasp them the moment they come into being, or even anticipate them. And indeed, the objection which my interlocutor raises to what I say draws from me thoughts which I had no idea I possessed, so that at the same time that I lend him thoughts, he reciprocates by making me think too. It is only retrospectively, when I have withdrawn from the dialogue and am recalling it that I am able to reintegrate it into my life and make of it an episode in my private history. (p. 354)

Through elicitation and response, the utterances of people in dialogue produce a cognitive stream that is not attributable to either speaker individually, but is a group process that only makes sense as such. This is a description of collaboration as an intersubjective form of cognition. There is a common world, in which the two personal perspectives are integrated in a single process of intersubjective meaning making—a “shared fabric.” The view of an individual’s contribution to the dialogue is a retroactive view, the result of subsequent reflection and appropriation into one’s (linguistic) self-narrative.

Merleau-Ponty’s description of the intersubjective source of my own creativity is particularly striking. The other draws from me thoughts “which I had no idea I possessed.” Of course, I did not “possess” such thoughts ahead of time—they emerged from the discourse. Nevertheless, they were understood by everyone as being my thoughts, from my perspective, and due to my agency. Here we get a glimpse of the power of intersubjective collaboration—and of how it is systematically covered over by commonsense views, interpretations, and retrospective accounts.

This model of intersubjectivity goes beyond Husserl’s and Schutz’ analyses of the individual’s “transcendental field.” It also escapes Heidegger’s version of intersubjectivity as an obfuscating mass culture. Merleau-Ponty agrees that one can step back from intersubjective engagement to reflect on one’s personal life, but now with positive insights about one’s own thinking that would not otherwise have occurred. Finally, we have a conception of intersubjectivity that values the potential of collaboration and of our concrete joint life in a shared world. Here, intersubjectivity can be a primordial experience, which provides a foundation for individual consciousness as derivative.

In recent decades, followers of phenomenology have adopted the shift of starting point from the individual to the shared world, pioneered in Heidegger’s being-there-with-others, the later Husserl’s life-world, and Merleau-Ponty’s intersubjectivity. For instance, Schegloff (1991, p. 168) writes, “In Western tradition, it is the single, embodied, minded individual who constitutes the autonomous reality.” He then contrasts the view of phenomenologically inspired ethnomethodology and conversation analysis to this earlier dominant cognitivist tradition: “Interaction and talk-in-interaction are structured environments for action and cognition, and they shape both the constitution of the actions and utterances needing to be ‘cognized’ and the contingencies for solving them.” As their names suggest, ethnomethodology describes the pervasive methods that people (ethno) use for creating social order during their interactions, and conversation analysis describes the patterns of talk that people use to support intersubjective understanding of the public meaning that is thereby created in the shared world. This approach details the rich and orderly variety of mechanisms that are used in human interaction to constitute and maintain intersubjectivity.

In addition to his phenomenological roots, Merleau-Ponty appreciated the other major philosophic tradition in twentieth-century European thought, that of Hegel and Marx, to which we turn next.

The Dialectic of Intersubjectivity: Hegel and Marx

When the movement of social history became conspicuous with the American and French revolutions, the march of Napoleon, and the early stirrings of the industrial working class, Hegel captured the nature of his dynamic times in his philosophy. His early lectures in particular defined a break with Kantian methodological individualism and described the social nature of man (Habermas, 1967; Hegel, 1806). This led to a philosophic approach to subjectivity contrasting to that of Husserlian phenomenology, which had remained neo-Kantian.

Until Hegel, human nature and human cognition were conceived as based on the individual person, as fully determined from birth ahistorically or universally—not dependent on one's biography or social context. The theories that minds develop, that social relations transform, or that humanity evolves all came after Hegel—in process-oriented sciences inspired by his philosophy. For Freud, Marx, and Darwin, to understand a psyche, a social formation, or a species requires understanding the history of its development, complete with conflicts and resolutions.

Hegel elaborated a dynamic view, in which mind develops all the way from primitive sense perception to sophisticated self-consciousness and cultural worldview. In the methodological Preface to his most influential presentation of the development of mind, Hegel (1807) wrote that one must analyze a phenomenon by looking at its unity as the result of its clashing temporal appearances:

> The bud, the blossom and the fruit's fluid nature make them into moments of an organic unity within which … one is equally as necessary as the other…. The subject matter is not exhausted in its ends; rather, it is exhaustively treated while it is worked out. Nor is the result that is reached the actual whole itself; rather, *the whole is the result together with the way the result comes to be*…. What is the most difficult of all is to grasp both what unites the process and the result, and to give a full exposition of what that is. (§2 & 3, my translation and italics)

Let us see how Hegel treated interaction between two people in his famous master/slave dialectic. A person first becomes aware of himself as a particular individual at this developmental stage within Hegel's system. The analysis focuses on the interaction of people and involves them working with objects in the world. The cognitive effect (self-consciousness) is a result of the whole dynamic of the interaction, not a pre-existing causal agent within the interaction. The prototypical interaction is here that of a worker creating an artifact; the worker recognizes himself as reflected in the product that he created to meet the needs of another person:

> Work *gives form* to its object. The worker's transforming relationship toward the object is transformed into the object's form and becomes something *persisting*, because for the worker the object gains self-sufficiency. This transforming mediation—the *activity* of forming—is also the *individuality* of consciousness or the pure being-for-itself of consciousness, which in the work process now steps out of consciousness and takes on the character of persistence. The consciousness of the worker thereby arrives at a perception of the self-sufficient artifact as a perception *of his self*. (Hegel, 1807, p. 238, my translation)

Hegel shows how human consciousness emerges through productive activity in the intersubjective and physical world. The worker and the master (for whom the object is produced) are formed as such (i.e., as self-conscious individual actors) through the interaction with each other and with artifacts (tools and products of work) in the world. Hegel describes the emergence of self-consciousness from within the process of mutual recognition of self, world, and other. In particular, it is the worker, who produces an artifact in the physical world at the bidding of an other, who is then able to perceive his labor as externalized and made persistent in the artifact. The worker's self-consciousness emerges through his activity in the shared world, where he comes to see himself as objectified in his artifacts and through the eyes of others.

Marx (1867) builds on this analysis of social interaction. He situates Hegel's idealist analysis in the historical context of early capitalism. The artifact that is produced by the worker's labor and that externalizes his self within its social relations to other people is specified within settings of capitalist production into a commodity (an artifact produced for sale on the open market). The worker's self-consciousness is reified, alienated, and fetishized because the commodity that reflects his identity is no longer his (but the capitalist's, who sells it) and because his social relations to potential users of the artifact are transformed into the abstract monetary value of the commodity. The meaning of the labor that went into forming the product's use-value undergoes multiple complex social transformations: it is externalized into an artifact, the artifact enters commodity relations, and the commodity is reflected back to the worker as monetary exchange-value belonging to his boss. For Marx, individuals in capitalist society are analyzed as results of their interactions as wage laborers, owners of the means of production, or consumers of commodities. He critiques the traditional notion of the abstract individual consciousness as an ideology of individualism that obscures concrete, historically specific human reality.

In his methodological *Grundrisse*, Marx (1858) identifies the interaction in which the worker exchanges his labor time for the capitalist's wages as the "cell form" for analysis. His analysis in *Capital* (1867) starts out from the simple dyadic interaction of a worker exchanging the product of his labor with another person. As his inquiry into social production in the capitalist era develops, this elemental intersubjective relation of production is mediated by its dialectical relationship to technology as the social means of production (e.g., the factory system, machinery, and automation in their historical development).

Intersubjectivity in this approach of Hegel and Marx is a concrete social and historical product of human labor with material artifacts. The subjectivity of individuals is a subsequent by-product of their interactions within the shared social world. The Kantian view of the individual mind producing the world is stood on its head. Mind is seen to be a social product, and individualism is characterized as an ideology serving competitive capitalism.

In a contemporary extension of this tradition, Habermas (1971) has argued for viewing communicative action as the basis for intersubjectivity and social theory. He starts by explicitly rejecting the individualism of Kant and Husserl, which do not allow escaping from monadic subjectivity. Incorporating the linguistic turn of Wittgenstein (1953), Habermas reconstructs the possibility of moral behavior and social science from the interpersonal relationship between people engaged in communicative action. The dialectical tradition takes as its starting point the social interaction among people in place of Descartes' isolated subject. It focuses on the dynamic and conflictual mediations of this interaction within the concrete, historical world.

The Mediation of Intersubjectivity: Vygotsky

Vygotsky provides a psychology of human cognition appropriate to Marx's methodology of social science. He adopts Marx' analytic cell form: the interaction among people mediated by artifacts. For Vygotsky, the notion of artifact encompasses both tools and language. Artifacts are both physically present in the world and meaningful to people. Their meaning is not projected from individual minds, but is intersubjectively emergent from social interactions, as in the dialectical presentations of Hegel and Marx.

As discussed in the section of Investigation 15 on a post-cognitive educational paradigm, Vygotsky analyzed the genesis of the pointing gesture as an artifact whose form and meaning emerge from the interaction between multiple actors, such as an infant and its mother. The actors form an intersubjective group, whose joint attention is directed toward some intended object by the co-constructed pointing gesture. This view of intentionality as emergent in the shared world stands in sharp contrast to the rationalist assumption that individuals "have" personal mental aims which they then express in speech or action and which others may notice and interpret in their own minds. Marx, Wittgenstein, and Heidegger (the primary founders of the major approaches in twentieth-century theory)—and their followers—soundly reject the cognitive picture of agency (see, e.g., Dennett, 1991; Dourish, 2001; Dreyfus, 1992; Ehn, 1988; Suchman, 2007). The rationalist, mentalist view persisted in the theories of intersubjectivity of Husserl and even Schutz, as we have seen.

Although Vygotsky was a trained psychologist and even a behaviorist during part of his career, his research agenda points toward a vision of group cognition. For instance, Vygotsky's analysis of learners' "zones of proximal development" stresses the origin of higher forms of human cognition in developmental processes involving intersubjective meaning making. In a formulation evoking Hegel, he writes of the need to analyze such developmental processes, not just learning outcomes: "The zone of proximal development defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state. These functions could be termed the 'buds' or 'flowers' of development rather than the 'fruits' of development." He then cites a study in which children "could do only under guidance, in collaboration and in groups at the age of three-to-five years what they could do independently when they reached the age of five-to-seven years" (Vygotsky, 1930/1978, pp. 86–87). In Vygotsky's approach, cognitive development is founded on the intersubjectivity of collaborative learning. The results of collaborative learning may later appear as individual learning through subtle processes of "internalization."

In his less quoted section on "Problems of Method," Vygotsky (1930/1978, pp. 58–75) called for a new paradigm of educational research almost a century ago. Arguing that one cannot simply look at visible post-test results of an experiment, he approvingly quoted Marx: "if the essence of objects coincided with the form of their outer manifestations, then every science would be superfluous." He then emphasized the Hegelian approach: "*To study something historically means to study it in the process of change*; that is the dialectical method's basic demand. To encompass in research the process of a given thing's development in all its phases and changes—from birth to death—fundamentally means to discover its nature, its essence." In Vygotsky's analysis based on his experiments with young children, the skills and understanding of individuals are traced back to their long forgotten origins in intersubjective meaning making.

Vygotsky (1930/1978) outlines an intersubjective conception of the development of human cognition and collaborative learning, which treats the interaction, development, and learning of small groups with artifacts in the shared world as foundational. We shall see a concrete example of this approach toward the end of this Investigation. One's understanding of oneself, of artifacts (including representations, gestures, signs, symbols, language), and of the meaningful world is constructed primarily and originally intersubjectively, socially, and culturally. The individual is a result of subsequent processes of internalization, including the transformation by young children of speech as intersubjective communication into self-talk and then into silent verbal rehearsal or thinking.

The Evolution of Intersubjectivity: Tomasello

Tomasello (2014) complements Vygotsky's dialectical psychology with a corresponding evolutionary anthropology. He offers us a theory of intersubjective intentionality based on an analysis of human evolution and how human intentionality diverged from that of other primates throughout prehistory.

He complements Vygotsky's historical, developmental analysis of a child's learning with a similarly historical analysis of the development of human cognition by the species.

Under environmental pressures, humans developed increasingly complex forms of cooperative sociality (see also Seddon, 2014). Tomasello describes a two-step evolutionary sequence: *joint intentionality* followed by *collective intentionality*. At both of these transitions, a similar process took place. "A change of ecology led to some new forms of collaboration, which required for their coordination some new forms of cooperative communication, and then together these created the possibility that, during ontogeny, individuals could construct through their social interactions with others some new forms of cognitive representation, inference, and self-monitoring for use in their thinking" (p. 31).

Perhaps the first step took place in the context of collaborative foraging. Early human individuals— in response to a changing feeding ecology—began to join other individuals in pairs in pursuit of shared goals, and they jointly attended to situations relevant to their common goals.[4] "Each participant in the collaboration had her own individual role and her own individual perspective on the situation as part of the interactive unit" (p. 78). Tomasello highlights this dual-level structure—*simultaneous joint participation and perspectival individuality*—as a defining structure of what he calls joint intentionality. For him, it is foundational for all subsequent manifestations of human shared intentionality. Of course, early humans had always lived in family units and small tribes (like other primates), but now they began to carry out tasks like strategic hunting in small teams as an "interactive unit."

The second step took place more recently, as agriculture and domestication of animals led to the founding of the first great civilizations. Modern humans became predominantly cultural beings by identifying with their specific cultural group and collectively creating various kinds of cultural conventions, norms, and institutions (p. 80). They thus became thoroughly group-minded individuals. Tomasello argues that the development of joint and collective intentionality provided a necessary foundation for the development of human language and culture, which allowed for the escalating evolutionary emergence of modern human cognition and thinking (p. 128). This rapid form of evolution took place through historically transmitted culture (Donald, 1991, 2001), rather than as biological adaptation. Increasingly, our individual cognition became mediated by and derivative of group, collective, cultural, and now even global cognition.

Intersubjectivity—as the recognition of other people as having the same kinds of comprehension capabilities as we do (so-called theory of mind)—involves perspective taking, being able to view from the other person's position. For instance, to understand what someone says to me, I have to be able to understand the utterance as coming from the other person, as she might have understood it in articulating it. I also have to understand it as having been designed for me to understand it ("recipient design"). So I have to recognize the speaker as someone who understands meaning and can create it, as well as someone who knows how I might understand what she says. This mutual or reciprocal recognition is a precondition for distinctively human communication (e.g., as evolved beyond animal vocal signaling). Intersubjectivity is a foundation for—a condition for the possibility of—modern human interaction (Duranti, 2010).

Of course, our understanding of each other is only tentative and partial. There is no possibility of absolute knowledge of other minds or of identity of mental contents, as Husserl and Schutz argued. Shared understanding is, rather, taken for granted, not objective. Furthermore, the sharing is generally developed only to the point necessary to maintain communication (Linell, 2014). In general, under-

[4]Evolutionary development of mirror neurons and increased brain structure on the biological level may have accompanied and facilitated this increased sense of mutuality on the cultural level as a competitive advantage (Gallese & Lakoff, 2005), but see also (Hickok, 2014).

standing is always partial and pragmatic; I only understand even my own thoughts enough to continue engaging in the current activity that involves those thoughts.

As Heidegger put it, understanding is an aspect of our being-in-the-world, of situated activity rather than of abstractly mental cognition. We understand something *as* something to the extent necessary for our dealings with it. Accordingly, our shared understanding with other people should be seen as an aspect of our being-there-with-others in the same world [Investigation 17]. We share understandings because we share one world; and we do so to the extent necessary for our care for things in the world and our concern for other people as part of our existence in the social world (with our background, our plans, our situation).

The discussion of intersubjectivity in twentieth-century philosophy and social science theory has moved decisively away from the rationalism of Descartes and its focus on the reasoning of an individual mind. We are embodied in a shared world, and we understand ourselves, each other, and our world through social interaction, gradual cognitive development, and cultural transmission. Intersubjectivity can be more than just the confrontation of independent individuals. It can include the collaborative production of joint meaning in a shared world, where the interaction can result in a unity that is more than a simple aggregate of the inputs of the individuals.

The refined conceptions of shared understanding in our intersubjective world that emerge from the preceding review are suggestive for research in CSCW and CSCL. We turn now to examples of empirical studies from these fields.

Intersubjectivity in CSCW

The lead article in the CSCW journal special issue on intersubjectivity, by Tenenberg et al. (2015), documents an instance of intersubjectivity in which there is joint attention and mutual recognition. Many of the characterizations of forms of intersubjectivity summarized above can be related to the recorded actions of software programmers Hank and Danny in that case study and to the analysis of the data by the article authors.

All of the theory sources considered in this Investigation have discussed the importance of one person seeing the other and being able to observe that they were attending to the same objects. This was a central theme in the lead article as well. The pair-programming work environment being studied was carefully structured so that the participants could see each other and could track each other's general gaze. This environment was an interesting hybrid of face-to-face and computer-mediated. In fully online alternative systems mentioned in the article, the awareness of joint attention was either supported with specific functionalities or seen to be problematic.

The article explicitly focuses on the initial alignment phase of Hank and Danny working together. Consequently, we do not get to observe much of how they subsequently proceed in accomplishing their shared work in a fully intersubjective mode. The data presented gives a glimpse into a very narrow—but critical—slice of the intersubjective experience. As the authors note, Hank and Danny are very much at home in their specific work world and only need to align around the particular task at hand. These programmers are experienced at working together in this paired manner. The physical and technical environment has been carefully set up to support their closely coupled cooperative work, and they move around within it skillfully, without displaying explicitly much of the understanding or practices that contribute to such being-there-with-others.

Paired programming—like intersubjectivity itself—can be viewed in two ways. In one (like Husserl's), there is cooperation between two subjectivities, who coordinate their actions and reciprocal understandings of each other in two parallel streams of individual cognition. Excerpts 1 and 2 in the article include division of labor, for instance, where Danny will write a list on paper, while Hank

Log 18.1 Interaction by pair-programmers

3.1	Danny:	((Just before he starts talking, Danny moves his left hand that is holding a pen so that the pen points to a specific item on a dropdown menu on the left monitor)) I bet you if
3.2		((at apex of point, with pen tapped on screen))
3.3		((Hank selects item on list that is four items below Danny's point, which is highlighted on the display))
3.4	Danny:	you (go?) ((starts to withdraw hand))
3.5	Hank:	((Hank uses mouse to move cursor two elements higher on the list))
3.6	Danny:	bidoni
3.7	Hank:	((Hank moves up two additional elements on list, stays there))
3.8	Danny:	m-t-m black

operates the computer. In this view, one programmer may bring in resources (knowledge, skills, processes, artifacts) that the first does not have, or the second programmer can provide an immediate check on the work accomplished by the first.

In the alternative view (like Tomasello's), the pair collaborates in a single cognitive process of jointly accomplishing the programming task. For instance, the interaction presented in Log 18.1 can be seen as the pair narrowing in on a relevant object together through their joint attention to a list on the screen and their interactive construction of an increasingly narrow focus within that list.

The authors first describe the actions of the programmers: "Danny uses physical gestures and speech that complement and complete one another to direct Hank to a specific location. Hank uses the mouse for placing the cursor preparatory to acting with it, which, in its visibility to Danny takes a role in the 'conversation' that the two are having concerning the specific location of the next operation." Then the authors summarize the interaction as follows: "They thus combine a variety of semiotic resources to give this fragment its orderly, sequential character." What they call the programmers' "conversation" (including words, cursor movements, pointing gestures, and mutual bodily visibility) is in fact a single, well-ordered achievement. It is irrelevant which programmer introduced which resource. All the resources received their meaning from the unfolding joint process of locating the cursor on a particular font name so that the team could work on that object. The actions of the two programmers form a single orderly sequence.

In the analysis of this work as a collaboration, the two programmers are seen to be checking—or grounding (Clark & Brennan, 1991)—their understanding of each other through their utterances, repairs, gestures, and gazes. This reciprocal testing of interlocutors' understandings corresponds to the mutual reciprocity of knowledge in some of the theories of intersubjectivity reviewed above. Certainly, Husserl and Schutz, with their orientation to individual consciousnesses, relied heavily on one subject's knowledge that the other knows that the first knows that…. Even Tomasello focuses on the recursive recognition of other minds as sentient and perspectival. While Tomasello is persuasive that the evolution of this capability of recursive recognition to arbitrary levels was a necessary evolutionary precondition for modern human cognition and collaboration, that does not mean that we must always engage in some sort of mental recognition that you understand that I understand, etc. There may be occasions when this is indeed necessary, but only then does it actually have to be carried out. Furthermore, we have the ability to respond to questioning by making retroactive statements of mutual recognition to arbitrary levels of recursion. However, this need not enter into most activities of joint understanding. Such mutual recognition is already implicit in the fact of joint understanding. It is taken for granted in Heidegger's being-there-with-others, in which we care for each other as human, or in Merleau-Ponty's gaze, in which we see the body of the other as another human perspective on our shared world.

In his recommendations for social science analysis, Garfinkel (1967) noted that common ground is established by the methodical ways in which things are said, not by a process of verifying agreement of the sets of presumed mental contents stored in the heads of the speaker and of the hearer:

> For the conduct of their everyday affairs, persons take for granted that what is said will be made out according to methods that the parties use to make out what they are saying for its clear, consistent, coherent, understandable, or planful character, i.e., as subject to some rule's jurisdiction—in a word as rational. To see the "sense" of what is said is to accord to what was said its character "as a rule." "Shared agreement" refers to various social methods for accomplishing the member's recognition that something was said-according-to-a-rule and not the demonstrable matching of substantive matters. The appropriate image of a common understanding is therefore an operation rather than a common intersection of overlapping sets. (p. 30)

The authors of the lead article have gone to pains to avoid mentalist explanations. They formulate their discussion of aligning visual fields in terms of the methodical ways of establishing joint attention to a shared object rather than as checking that one subject knows that the other is looking at the object, and the other knows that the first knows that, and so on. The establishment of joint attention—so necessary for collaboration—entails that the people involved are looking at the same object *together*. They do not just happen to be both individually oriented to the object, but are oriented toward it in a coordinated way. They do not have to be separately aware of the assumed recursive mutuality of this relationship—unless there is some kind of breakdown that needs to be repaired by checking verbally on the mutuality of gaze to some recursive depth. A contribution of the lead article analysis is to explicate the need to support the participants' operations of maintaining awareness of the mutuality of their joint attention and to describe their methods of doing so in their hybrid environment.

Just as there is an ambiguity to the method of paired programming between cooperation (with division of labor) and collaboration (working together on each step, although possibly from different perspectives or with different resources), so there is an ambiguity to the transcript in Log 18.1. While we have viewed the interaction there as a single, coherent, meaningful achievement, it could also be viewed in terms of the distinct actions of two individual subjects. One could speculate that Danny had himself identified the item in the list on the computer screen from the start by tapping on it with his pen. Then Hank followed Danny's guiding gestures to eventually recognize the same item by highlighting it with his cursor. This is a pervasive ambiguity in the analysis of CSCW data. To decide in favor of an analysis that treats the group as the primary agent or one that focuses on the contributions of individuals generally requires detailed interactional data, which is rarely available to researchers. For instance, if the transcript did not include Danny's bodily gestures and Hank's computer actions in addition to the spoken discourse, it would be impossible to analyze the identification of the font as a joint achievement.

The alignment phase involves a transition from individual cognition to intersubjective cognition. It therefore contains elements of each and can be analyzed at either the individual or group unit of analysis. At the individual level, it appears that subjects are monitoring each other's gaze or focus of attention. Here is where the reciprocal and recursive recognition come in and the conception of communicative signals being exchanged. Especially in the case of dyads, it is tempting to analyze individual intentionality and agency in a traditional, individualistic way; in somewhat larger groups, the interaction is often harder to attribute to individuals as the discussion builds on individual utterances in complex ways and takes twists that no one participant could have planned. At the group level of description, the group is beginning to act as a unity, creating social order and joint meaning in a shared world—not through independent acts of the individual participants, but through the interaction of the group.

The ambiguity is important. The point is not so much to always opt for an individual or a group focus, but to recognize their intertwining: that the individual is a social product but also that the intersubjective has the individual at its poles. Sometimes one unit of analysis is more useful than the other. Efforts at alignment, in particular, involve a transition from multiple individual cognitions to unified group cognition. Philosophies of dialogicality have long tried to maintain this balance of what Tomasello calls joint intentionality with individual perspectives, which is not well supported by our inherited conceptualizations (Rommetveit, 2003; Wertsch, 1991). Interaction analysis—as carried out in the lead article—has shown us how to analyze the displayed utterances of individuals as part of intersubjective processes of group meaning making and social-order construction, without hypothesizing hidden mental phenomena (Schegloff, 1991).

To understand we-awareness or intersubjectivity once a team has come into alignment and is working smoothly together, it would be useful to analyze excerpts of interaction in later phases with the same kind of detail provided for the alignment phase in the lead article. Fuller examples of completely online group work would also be relevant to CSCW. The authors note a paucity of appropriate, detailed data about computer-mediated CSCW interactions on work like paired programming using different mediating technologies. In addition, we might add, there is little data reported about how people first learn to interact skillfully within such contexts. For a suggestion of how intersubjectivity might be analyzed and supported in more contexts, we turn to CSCL.

Intersubjectivity in CSCL

The relation of CSCW to CSCL has not been widely noted or clearly articulated. Both involve computer support for people interacting. While CSCW has the advantage of studying people who are expert at their work and experienced at working together, CSCL has the advantage of observing how such expertise and such interaction between people is originally constituted and learned. CSCL education can prepare students for careers in CSCW workplaces, and CSCW can display domain-related practices for adoption in CSCL curricula. The two fields share an interest in how individual and intersubjective cognition complement each other and how computer-support artifacts or environments can mediate between them.

We will now review a specific research agenda that explores the nature of intersubjectivity in a variety of small-group math education settings. We will present examples of intersubjective knowledge building under several diverse, but typical learning conditions, involving computer mediation.

Based on research in CSCW and CSCL, Stahl (2006) proposes a form of intersubjectivity called *group cognition*. Group cognition can be thought of as a form of intersubjectivity that goes beyond the mutual recognition of individual minds in Husserl and the recursive thou-relationship of Schutz to a being-there-with-others that Heidegger and Merleau-Ponty briefly hint at. Its analysis is based on the social-historical-cultural approach of Hegel, Marx, and Vygotsky. It is a developed form of Tomasello's joint intentionality with individual perspectives. Group cognition is a vision of intersubjectivity for CSCW and CSCL, which exceeds the accomplishments of individual cognition within group efforts, especially in online settings.

In group cognition, multiple people participate in coherent interactions that achieve cognitive accomplishments which are best analyzed at least in part at the group unit, rather than attributing contributions and agency entirely to individual minds. When a number of people are involved in group-cognitive processes or activities, their individual utterances or actions are taken as merged in a single cognitive system, which is distributed across the people and the artifacts that are involved (Hutchins, 1996). Ideas, practices, habits, and traditions from the larger culture are also brought in, so that the group cognition mediates between individual and community levels of description (Stahl, 2013, Ch. 8).

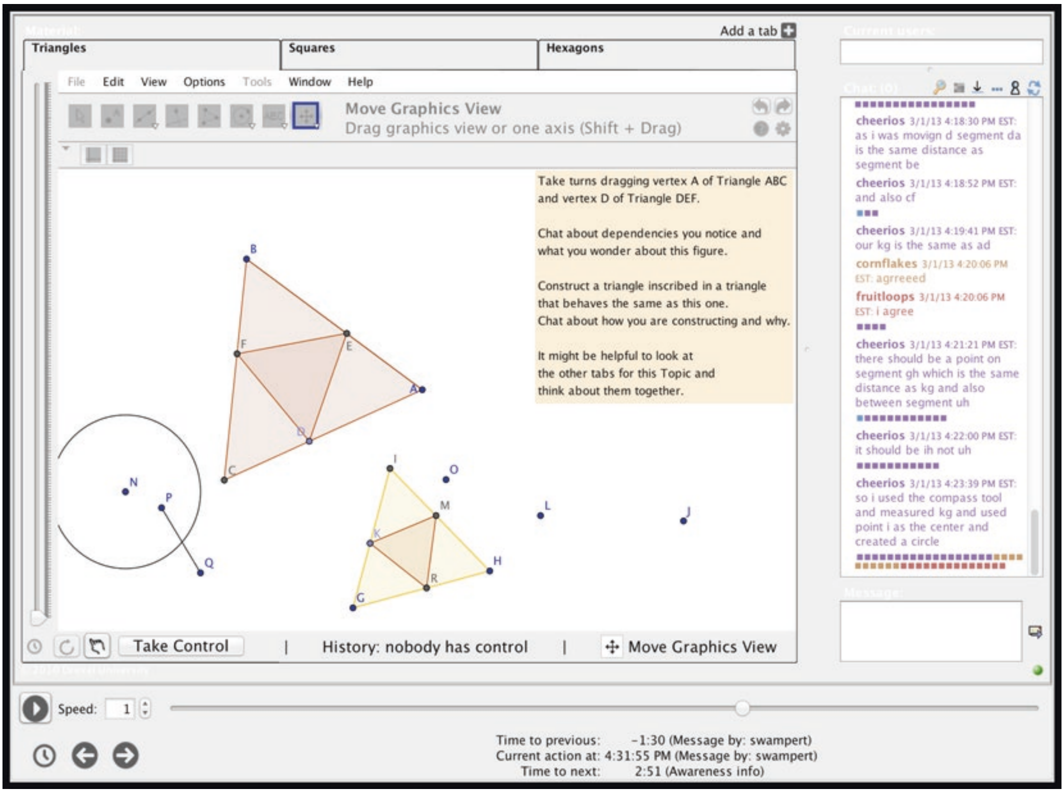

Fig. 18.1 The state of the inscribed-triangles construction after Fruitloops finished triangle KMR inscribed in GHI

The original elaboration of the notion of group cognition emerged from a series of studies of software environments to support perspectives, negotiation, and group formation in specific workplace and school settings (Stahl, 2006, e.g., Ch. 3, 6, 8). It provided, for instance, a detailed example of group cognition, in which a face-to-face student group co-constructed the applicability of a scientific representational artifact in an educational computer simulation in 1998 (Ch. 12 & 13). However, the collection of studies also acknowledged that the vision of group cognition as an effective form of collaborative learning is rarely achieved in practice. Furthermore, it noted the difficulty of finding or collecting data that is adequate for establishing and analyzing group cognition, let alone for observing the mediation across units of analysis.

Later (from 2002 to 2015), the Virtual Math Teams (VMT) system was developed as a test ground for studying group cognition. VMT is a collaboration environment for mathematical problem-solving by online small groups of students. Reports on pedagogical and methodological issues in VMT (Stahl, 2009) include analysis of a text chat in which several online students solved a challenging word problem collaboratively that none could solve individually (Ch. 5). The analysis argues that their chat could be viewed as a group-cognitive accomplishment, integrating a chain of interactive responses similar to a solution that could have been stated by one person, but here involving the whole group as the problem-solving agent. Another case study (Ch. 7) discusses how three students working online in VMT with a shared graphics whiteboard maintain joint attention to geometric details and organize their graphical, symbolic, and narrative interactions to solve an intricate problem in combinatorics collaboratively.

More recently, the VMT environment was extended with a custom multi-user version of GeoGebra, an application for dynamic geometry. A stimulating problem often given to people once they become comfortable with dynamic geometry is that of constructing inscribed triangles that behave like a given pair of inscribed triangles. (See the instructions and inscribed triangles ABC/DEF in Fig. 18.1.) This is a difficult task even for adults who enjoy mathematics. The VMT research team looked closely at the logs of a group of three 14-year-old girls who succeeded with this problem in less than an hour. None of the students had studied geometry before joining an after-school math club as part of the research project; they spent 4 h working together on collaborative dynamic geometry before this session.

The analysis of the team's work concludes that the students' success was an instance of group cognition (Stahl, 2013, Ch. 7.3). None of the students could construct the triangle configuration themselves, and the process of construction involved all three exploring, planning, and carrying out the construction. Each of the three girls displays a different characteristic behavior pattern throughout their work in the 8 h-long sessions of our study. Yet, the team is impressively collaborative. This illustrates nicely the notion of individual perspectives within intersubjective group interaction.

What is particularly striking in the team's successful construction of the inscribed triangles is that on first appearance it seems like the team's insightful and skilled work is actually done primarily by the student who until then had seemed the least insightful and skilled. If one just looks at the chat postings (see panel in the right side of Fig. 18.1), Cheerios does all the talking and Fruitloops (who is usually the most reflective and insightful) and Cornflakes (who explores the technology and often shows the others how to create geometric objects) simply register passive agreement. However, the actual GeoGebra construction actions tell a far more nuanced story. First, for most of the hour, each of the three students in the "Cereal Team" takes extended turns exploring the given example of inscribed triangles by dragging the vertices to discover dependencies in the construction that dynamically maintain the invariances of equilateral triangles. The dragging of figures is displayed simultaneously on each student's computer. Only one person at a time can create or drag geometric objects, in order to maintain joint attention by everyone to a single, shared sequence of actions.

Cheerios observes Fruitloops experimenting with the use of the GeoGebra compass tool just before Cheerios takes control and makes her discovery. Cheerios continues to manipulate Fruitloops' construction, involving a circle whose radius was constructed with the compass tool to be dependent on the

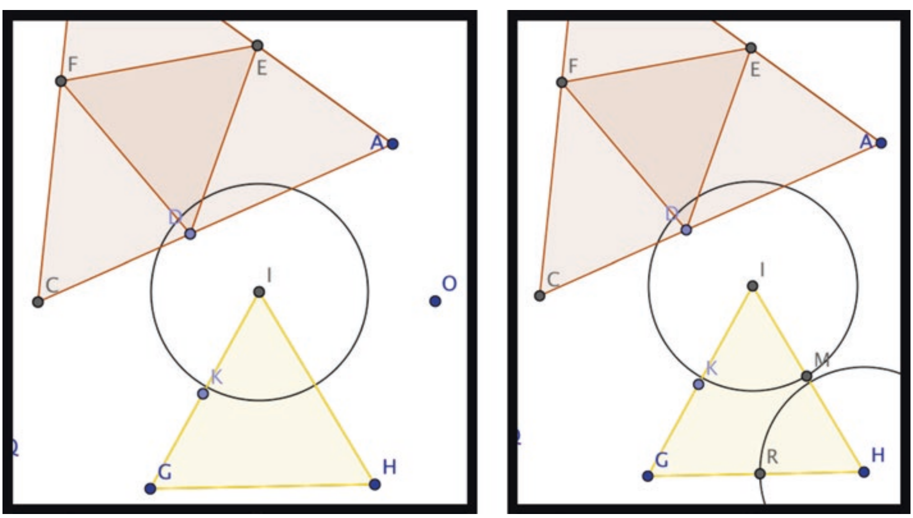

Fig. 18.2 The state of the construction after Cheerios finished (left) and after Cornflakes finished (right)

length of a line segment. Then Cheerios very carefully drags points on the original inscribed-triangle figure to discover how segments BE and CF are dependent upon the length of segment AD, refining prior movements by the other students. The dynamic relationship between the side lengths becomes visually salient as she increases the size of the triangles or their orientation and as she drags point D along side AC.

Cheerios has a sense that the compass tool should be used to measure segment KG, but she does not quite understand how to make use of that tool. Following Fruitloops' example, Cheerios uses the compass to draw a circle around point I, whose radius equals length GK (see Fig. 18.2, left). However, she is unable to further implement the plan she has already projected in chat.

Next, Cornflakes takes control of the construction, places a point, M, where Cheerios' circle intersects side HI and then repeats the process with the compass to construct another point, R, on the third side of the exterior triangle (see Fig. 18.2, right).

Fruitloops then takes control and uses the polygon tool to construct a shaded interior triangle, KMR, connecting Cornflakes' three points on the sides of the exterior triangle (see Fig. 18.2). She then conducts a drag test, dragging points on each of the new triangles to confirm that they remain equilateral and inscribed dynamically, just like the example figure. At that point, the students have been working in the room for over an hour and end their session, having succeeded as a team.

The VMT software is fully instrumented, so that researchers can obtain detailed logs and even replay the sessions (as shown in Fig. 18.2, a screen image from the replayer) to see precisely what the students all saw on their screens. Of course, as Schutz pointed out, researchers have a reflective relationship to the interaction, which is quite different from the engagement of the students. The intersubjectivity of the students, when things are functioning optimally, can be that of group cognition, where they act as one subject, constructing shared meaning through their interaction. The intersubjectivity of the researchers with the students involves systematic (methodical, self-conscious, research-driven, theory-laden) efforts to understand the meanings previously created by the students, based on a culture and world partially shared by the students and researchers.

Intersubjectivity as Group Cognition

The kind of data generated by teams of students using VMT can support detailed research into the nature of interaction and intersubjectivity in CSCW and CSCL situations. For instance, the VMT research team has now analyzed all 8 h of the Cereal Team's interaction (Stahl, 2016). In particular, the analysis tracks their enactment and acquisition of various member methods or group practices. It documents how the students form into an effective team and how they align and develop joint attention. By adopting specific sequences of group practices, the team learns how to collaborate, to manipulate technological affordances, to engage in collaborative dynamic geometry problem-solving, and to enter into mathematical discourse. One can see, displayed in the team interaction, group cognition in action as a specific form of intersubjectivity.

We see the potential productivity of collaboration in the way that the three students, participating from within their personal zones of proximal development, bring different resources to the interaction. Further, the interaction itself—including the reactions of the GeoGebra application to student attempts at geometric construction—elicits, as Merleau-Ponty put it, "thoughts which I had no idea I possessed." Ideas, skills, and approaches from different sources mix and spontaneously generate new, shared knowledge through the interaction itself and its internal logic or implicit connotations. Collaborative learning may be guided through reflection by the participants and through feedback from the problem-solving process itself. For instance, observation of the results of various people's efforts at geometric manipulations and constructions may lead to the discovery of solutions that cannot be attributed to any one of the participant's minds or even to a simple aggregation of their individual contributions. The dynamic, overdetermined behavior of their joint geometric-construction moves in their shared online world contributes to the unfolding of a solution path as well. The VMT environment incorporating its multi-user version of dynamic geometry provides visual feedback to construction or dragging actions, adding a computer-supported dimension to what Schön (1992) calls the back-talk of the materials of the (problem-solution) design situation.

In the Cereal Team's work, we see multiple instances of one student contributing a skill or insight from their individual perspective or developmental zone into the group work—usually in response to what another student did or tried to do. The other students learn from this—often from just one occurrence, where the contribution is discussed and consequently adopted by the team as a group practice. Subsequently, another student brings the newly learned skill into the group work, and it is accepted without comment. In this way, first, the group learns a skill or insight, and through that, each of the other individuals learns it. For instance, in the session just described, it took each of the three students doing some of the necessary actions to construct the inscribed triangles. However, in their next session, all three students very clearly knew how to carry out all those actions when the group worked on a related challenge of constructing inscribed squares.

In the longitudinal developmental trajectory of the Cereal Team (followed in detail in Stahl, 2016), as the team first learns to collaborate online and to engage in dynamic geometry, we can observe the reciprocal interpenetration of individual and collective understanding in the group-cognition form of intersubjectivity. We see what our review of theories of intersubjectivity characterized as simultaneous joint participation and perspectival individuality, as well as joint attention, shared meaning making, group agency, and being-there-with-others in a shared world.

The Cereal Team took up in their discourse mathematical terms like "constraint" and "dependency," which were introduced in their session instructions. The choice of classical geometry problems and the wording of their presentation to the students guided the student exploration and discourse, mediating the interaction with resources from the mathematical community. By responding to the cues in the instructions and incorporating these technical terms in their discourse with each other, the students gradually developed new conceptions. At first not understanding the terms at all, they passed through everyday uses of them to more rigorous mathematical statements—in a process recalling Vygotsky (1934/1986). The transitions in individual and group understanding of the role of dependencies in dynamic geometry can be tracked in the logs of their interaction (Stahl, 2016).

While all the reviewed theories of intersubjectivity noted the important role of language, Vygotsky is especially clear about the mediation of language—both spoken and silently thought—in how we understand each other and our shared world. Heidegger's later work (e.g., 1959/1971) also emphasizes how language can be seen as a source of meaning making—most visibly in poetry. For him, "speech speaks" (through us) and we live in language as the "house of being." As Tomasello (2014) notes, the cultural richness of spoken language incorporates eons of human shared experiences. In the mixing pot of group discourse, phrases evoke each other and thereby generate creative ideas.

Of course, competent language users are needed to speak and understand the phrases. However, the source of the creative generation and the deductive flow can be analyzed in terms of the meanings sedimented in the phrases, rather than being attributed to rational motives in the minds of individual participants. Group cognition and its associated intersubjectivity can be conceived in primarily linguistic, rather than mental, terms (as recommended by Habermas, 1971/2001). Its intentionality is not that of some kind of group mind or even primarily of the minds of the individual participants, but of the intersubjectively shared discourse and the historically mediated, referred intentionality of a culture, expressed in its passed-down meanings. That is why a goal of math education is to involve students in math discourse and collaborative exploration.

Group cognition is a form of intersubjectivity, in which the words and actions of group members are aligned in a coherent unity, which can be analyzed as a semantic (meaning-making) or cognitive (symbol-manipulating) system in its own right. This vision of a potentially powerful form of group intersubjectivity can inspire and guide the design of supportive technology and pedagogy in CSCW and CSCL, as it has done in the VMT project (Stahl, 2006, 2009, 2013, 2016).

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Investigation 19. The Constitution of Group Cognition

Gerry Stahl

Abstract

Cognition is no longer confined to the solitary musings of an armchair philosopher but takes place, for instance, in problem-solving efforts of teams of people distributed around the world and involving various artifacts. The study of such cognition can unfold at multiple units of analysis. In this investigation, three cases of problem-solving by virtual math teams demonstrate the mix of individual, group, and social levels of cognition. They show how a resource like a mathematical topic can bridge the different levels. Focusing on the under-researched phenomena of group cognition, the presentation highlights three preconditions for the constitution of group cognition: longer sequences of responses, persistent co-attention, and shared understanding. Together, these structure a virtual analog of physical embodiment: being-virtually-there-together, where what is virtually there is understood as co-experienced.

Keywords

Group cognition · Longer sequences · Response pairs · Persistent co-attention · Shared understanding · Embodiment · Co-experience

Cognition at Multiple Levels

There is a venerable tradition in philosophy that cognition is a mysterious faculty of individual human beings. Increasingly since the late nineteenth century, it has become clear that even when thoughts appear to be expressed by an individual, they are the product of more complex factors. Cognitive abilities and perspectives develop over time through ones embeddedness in a physical, social, cultural, and historical world. Thinking is closely related to speaking, a form of communication with others.

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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Particularly in our technological world, thinking is mediated by a broad variety of artifacts and by other features of the context in which we are situated.

Rather than thinking about thinking, I try to explore cognition by generating data in which one can observe cognitive processes at work (Stahl, 2006, 2009, 2013, 2016). I do this by having small groups of students collaborate on mathematical problems in a computer-mediated setting, where their whole interaction can be captured. The motivation for this approach is the theory of Vygotsky (1930/1978), the sociocultural psychologist who proposed that higher-level human mental abilities are acquired first in small-group interactions. In exploring such group cognition, I have found that there is a rich interplay of processes at individual, small-group, and community levels of cognitive processing.

In the following, I will summarize three case studies of online collaborative problem-solving in order to illustrate how cognitive processes at multiple levels can work together. (1) In the first case, two students solve a high-school math problem that has stumped them for some time. The problem-solving steps the dyad goes through as a team are typical for how proficient students solve problems individually. In the discourse captured in this case, one can see how the *group* integrates contributions from the two *individual* participants to accomplish a task in accordance with *community* standards of practice—illustrating the productive interplay between cognitive levels. The sequence of ten discourse moves by the group details their extended *sequential approach* to the problem. (2) In the second study, three students develop techniques for helping each other to see what they are seeing in the diagram they have drawn for a math problem. This *persistent co-attention* to a shared object of analysis allows the team to solve their problem as a group. (3) Similarly in the third example, the students are able to work together because they effectively manage their *shared understanding* of the problem.

I propose that it is often fruitful to analyze cognition on multiple levels and that the processes at the different levels work together. A variety of *interactional resources* are typically at work bridging the levels. In the three illustrative case studies, topics in high-school mathematics centrally figure as resources that bring together individual, small-group, and community cognitive processes.

Virtual Math Teams

The study of group cognition requires careful review and analysis of all the interaction within a group during the achievement of a cognitively significant task, such as solving a challenging problem. I have arranged for this by designing an online software environment in which several people can meet and interact effectively to solve math problems. This virtual math teams (VMT) environment supports synchronous text-chat and a shared whiteboard for drawing figures (Stahl, 2009). During the project, it was expanded to incorporate a multiuser version of dynamic geometry, in which geometric figures can be interactively constructed and dynamically dragged (Stahl, 2013). The software is instrumented to capture all interaction and to allow it to be displayed, replayed, and analyzed. This avoids the many problems of audio and video recording in classrooms. Students communicate online, avoiding the interpretational issues of eye gaze, bodily gesture, and vocal intonation. When possible, groups are composed of students who do not know each other outside of the online setting, so that researchers reviewing a record of interaction can know everything about the participants and their background knowledge that the participants know about each other. Since group cognition is defined as consisting of those knowledge-building or problem-solving processes that take place in the group interaction (Stahl, 2006), the VMT environment can capture a complete history of group-cognitive events.

When a group enters the VMT environment, it is presented with a challenging math problem, designed to guide the group interaction in an academically productive direction. The problem acts as a resource for the group. The group must interpret the problem statement, elaborate the way in which it wants to conceive the problem, and determine how to proceed. A math problem can serve as an effective interactional resource for bridging across cognitive levels. Typically, it introduces content—definitions, elements, procedures, principles, practices, proposals, theorems, and questions—from the cultural traditions of mathematics and from school curriculum. In so doing, it recalls or stimulates individual cognitive responses—memories, skills, knowledge, calculations, and deductions. It is then up to the group interaction to bring these together, to organize the individual contributions as they unfold in the ongoing interaction in order to achieve the goals called for by the community, institutional, disciplinary, and historical sources. In this way, the group interaction may play a central role in the multilevel cognition, interpreting, enacting, and integrating elements from the other levels, producing a unified cognitive result, and thereby providing a group experience that can subsequently lead to community practice or individual skill.

Constructing Diamonds

Cognition is neither a unitary phenomenon nor a temporally fixed one. Hegel described the logical stages he thought were involved in the development of cognition in his *Phenomenology of Mind* (1807/1967). Vygotsky explored the development of a person's cognition through psychological experiments reported in *Mind in Society* (1930/1978), emphasizing the priority of intersubjective group cognition:

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (*interpsychological*), and then *inside* the child (*intrapsychological*). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher [human mental] functions originate as actual relations between human individuals. (p. 57)

Research on computer-supported collaborative learning (CSCL) (Stahl, Koschmann, & Suthers, 2013) can make visible the development and the unfolding of cognitive functions in small groups, shedding light on the less visible processes that can subsequently be carried out by people individually or "internally." A research method for undertaking such analysis is suggested by the field of conversation analysis (CA) (Sacks, 1965/1995). CA was inspired by ethnomethodology, a sociological approach focused on describing the "work" that people typically do in interactions with others to establish social order and to construct meaning (Garfinkel, 1967). CA applies this approach to analyzing everyday conversation. A central finding of CA is that the work of conversation is accomplished through the sequential construction of "adjacency pairs," short sequences in which one person's utterance elicits a response in the form of a following utterance by an interlocutor—for instance, a question-answer pair. In looking at examples of mathematical problem-solving by groups, we are more interested in "longer sequences," in which a series of adjacency pairs are constructed to accomplish the larger cognitive goal.

Longer sequences have only been suggested in CA (Sacks, 1965/1995, II p. 354; Schegloff, 2007, pp. 12, 213), not actually analyzed. In the final excerpt from a VMT interaction among three students, I analyzed their successful problem-solving effort as a longer sequence, consisting of ten discourse moves, each linguistically organized as an adjacency pair (Stahl, 2011) [Investigation 25]. I treated their 4-hour-long online interaction in terms of a temporal hierarchy of a group event, four scheduled sessions, several conversational topics, many discourse moves, adjacency pairs, textual utterances, and indexical references [Investigation 24]. In the first session, the students had been asked to work on a topic in mathematical combinatorics, determining the number of squares and composite sticks needed to build a stair-step pattern at different stages of growth. By the fourth session, the students had set themselves the topic of analyzing a diamond pattern, illustrated by them at stages n = 2 and n = 3 in the screen image of the VMT software interface in Fig. 19.1.

In their final conversational topic, two students with login names of Bwang and Aznx decide to try again to solve this problem, despite not being able to do so for the past 2 h and despite the fact that their scheduled online time is already over. In the course of 10 minutes, 100 chat lines of text are

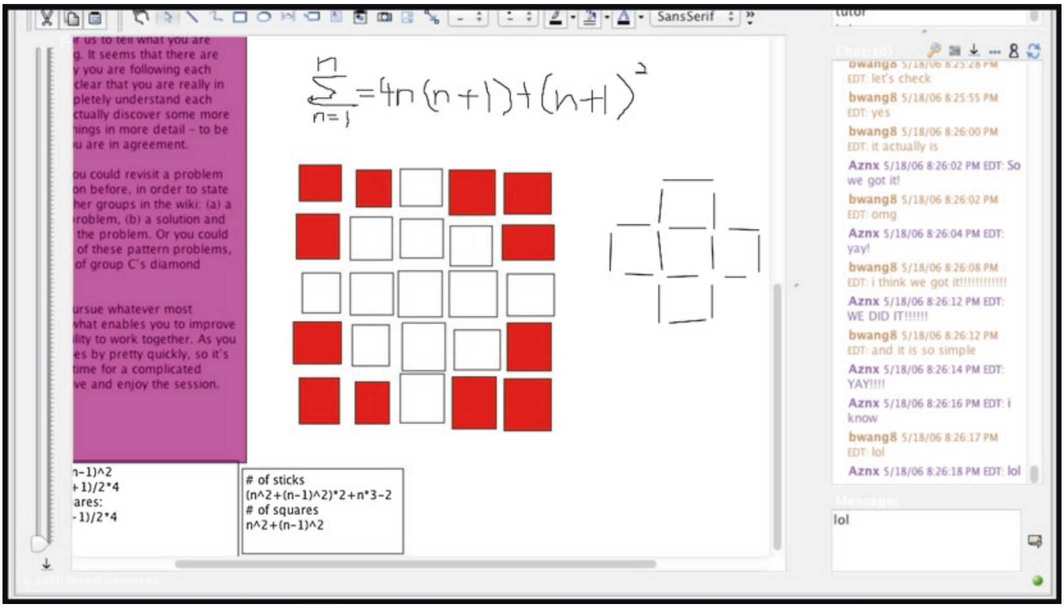

Fig. 19.1 Discussion and drawings of diamond pattern

posted. The analysis of these chat lines highlights ten adjacency pairs, which were central to this discourse. Each adjacency pair is listed in Log 19.1, under an added descriptive heading. This selection from the interaction should give a sense of the problem-solving process—see Investigation 25 for a more detailed analysis.

There are several things to note here:

- Most importantly, the sequence of identified moves is strikingly similar to how an experienced math problem-solver might approach the topic individually, as described at a particular granularity.
- The two students take turns contributing to the shared topic. The group direction is not set by either individual but results from their interaction.
- Most opening utterances solicit a response, often in the explicit form of a question, and they always await a response.
- Each move is a situated response to the current state of the students' understanding of the topic as expressed in the discourse—rather than some kind of logical progression following a plan based on anything like a goal-subgoal hierarchy (Suchman, 2007).
- The focus of the group discourse moves is on the sharing, negotiation, and agreement about their progress, rather than on details of mathematical facts or computations.
- The math content is handled by the individuals and contributed by them into the collaborative setting, for instance, in move #3 or #5.
- The temporal structure of topics, moves, and adjacency pairs is not imposed by the analyst but is projected in the remarks of the participants as integral to how they sense for themselves what they are doing and proceed.

If one follows the development of the students' understanding in their postings across the four sessions, one is struck by changing roles and confidence levels, as well as by their mastery of practices that one or the other introduced into the group. It is quite plausible that over time, the lessons acquired

Log 19.1 Ten moves of the problem-solving topic

Move 1. Open the topic
```
        Bwang: i think we are very close to solving the problem here
        Aznx: We can solve on that topic.
```
Move 2. Decide to start
```
        Bwang: well do you want to solve the problem
        Aznx: Alright.
```
Move 3. Pick an approach
```
        Aznx: How do you want to approach it?
        Bwang: 1st level have 1*4 … 4th level have (1+3+5+7)*4
```
Move 4. Identify the pattern
```
        Aznx: So it’s a pattern of +2s?
        Bwang: yes
```
Move 5. Seek the equation
```
        Bwang: what is it
        Aznx: n^2 … or (n/2)^2
```
Move 6. Negotiate the solution
```
        Aznx: its n^2
        Bwang: so that’s wrong
```
Move 7. Check cases
```
        Aznx: would be 4n^2
        Bwang: it actually is
```
Move 8. Celebrate the solution
```
        Bwang: i think we got it!!!!!!!!!!!!
        Aznx: WE DID IT!!!!!!
```
Move 9. Present a formal solution
```
        Aznx: So you're putting it in the wiki, right?
        Bwang: yes
```
Move 10. Close
```
        Aznx: we should keep in touch
        Bwang: yeah
```

in their collaborative interactions will become manifested in their individual cognitive skills. The longer sequences of argumentation or problem-solving become “internalized” (as Vygotsky called it) or adopted as cognitive practices of individuals. The power of collaborative learning is partially to bring together multiple perspectives, which can be debated, negotiated, synthesized, contextualized, structured, and refined. However, another advantage is to extend the cognitive effort into *longer sequences* of argumentation through the stimulation and enjoyment of productive social interaction, increasing the time-on-task as needed to solve challenging problems. Thus, groups can achieve cognitive accomplishments that their members cannot—and the members can learn from these achievements.

Visualizing Hexagons

Elsewhere, we have analyzed in some detail the intimate coordination of visual, narrative, and symbolic activity involving the text-chat and shared whiteboard in VMT sessions [Investigation 12]. Here, we want to bring out the importance of literally looking at some mathematical object together in order to share the visual experience and to relate to—to “intend” or to “be at”—the entity together. People often use the expression “I do not see what you mean” in the metaphorical sense of not understanding what someone else is saying. In our second case study, we often encounter the expression used literally for not being able to visually perceive a graphical object, at least not being able to see it in the way that the speaker apparently sees it.

Log 19.2 Seeing a hexagonal array collaboratively

705	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:45	qwertyuiop	What's the shape of the array? a hexagon?
707	19:16:02	137	Ya.
708	19:16:15	qwertyuiop	ok...
709	19:16:41	Jason	wait - can someone highlight the hexagonal array on the diagram? i don't really see what you mean...
710	19:17:30	Jason	hmm.. okay
711	19:17:43	qwertyuiop	oops
712	19:17:44	Jason	so it has at least 6 triangles?
713	19:17:58	Jason	in this, for instance

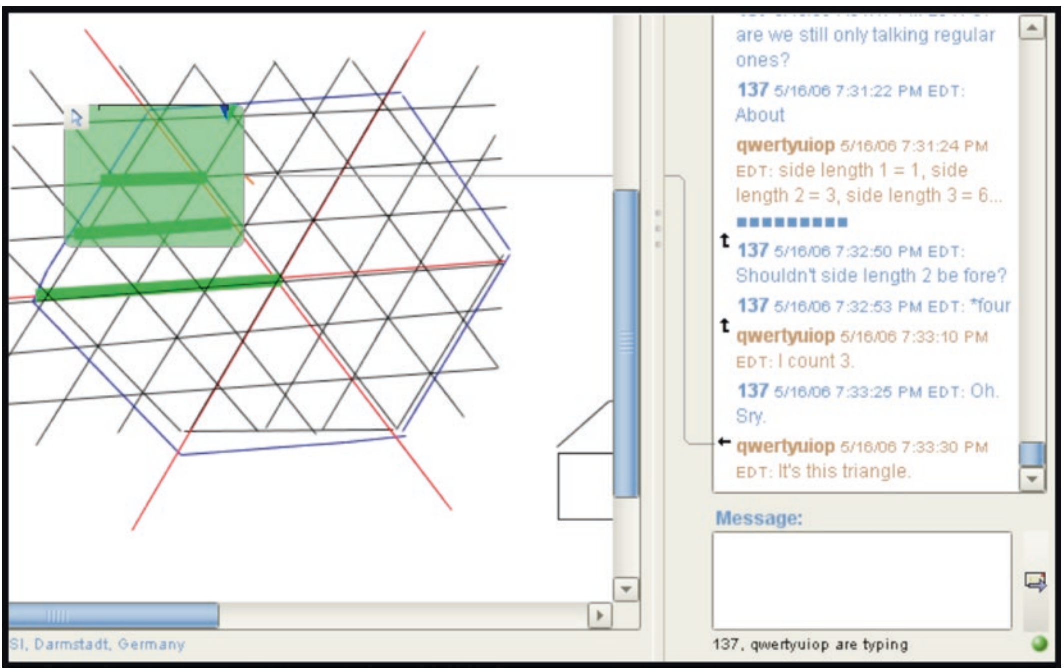

Fig. 19.2 Discussion and drawing of hexagon grid

While empiricist philosophy refers to people taking in uninterpreted sense data much like arrays of computer pixels, post-cognitive philosophy emphasizes the phenomenon of "seeing as." Wittgenstein notes that one immediately sees a wire-frame drawing of a cube not as a set of lines but as a cube oriented either one way or another (1953, §177). For Heidegger, seeing things as already meaningful is not the result of cognitive interpretation but the precondition of being able to explicate that meaning further in understanding (1927/1996, pp. 139f). For collaborative problem-solving and mathematical deduction, it is clearly important that the participants see the visual mathematical objects as the same, in the same way. This seems to be an issue repeatedly in the online session excerpted in Log 19.2, involving three high school students with login handles of Jason, Qwertyuiop, and 137 [Investigation 17].

Student 137 proposes a mathematical task for the group in line 705 of Log 19.2. This is the first time that the term, "`hexagonal array`," has been used. Coined in this posting, the term will become sedimented (Husserl, 1936/1989, p. 164) as a mathematical object for the group as the discourse continues. However, at this point it is problematic for both Qwertyuiop and Jason. In line 706, Qwertyuiop poses a question for clarification and receives an affirmative but minimal response. Jason, unsatisfied with the response, escalates the clarification request by asking for help in seeing the diagram in the whiteboard *as* a "hexagonal array," so he can see it *as* 137 sees it. Between Jason's request in line 709 and acceptance in line 710, Qwertyuiop and 137 work together to add lines outlining a large hexagon in the triangular array. Demonstrating his ability to now see the hexagons, Jason thereupon proceeds with the mathematical work, which he had halted in the beginning of line 709 in order to keep the group aligned. Jason tentatively proposes that every hexagon "has at least 6 triangles," and he makes this visible to everyone by pointing to an illustrative small hexagon from the chat posting, using the VMT graphical pointing tool. Later, the students take turns using these group-defined methods of supporting shared vision and attention: using colored lines and the pointing tool, as seen in Fig. 19.2.

Jason dramatically halted group work with his "wait." For him, it was impossible to continue until everyone could see the same thing in the way that 137 saw it. During this session, the students taught each other how to change the color and thickness of lines they constructed in the shared whiteboard. These were affordances of the VMT software, but the students had to learn how to use the features, and they developed certain shared group practices of using colored lines to outline, highlight, and draw attention to specific elements of the hexagonal grid. For instance, in Fig. 19.2, blue lines outline a hexagon of side-length 3; red lines divide that hexagon into six symmetric triangles; thick green lines pick out the three horizontal lines of length 1, 2, and 3 in one of the triangles; and the VMT pointing tool focuses attention on that triangle.

There are many ways to count the number of unit sticks in the large hexagon. In order to count them as a group, everyone's attention much be focused on the same elements, such as the green horizontals. Then it is possible for each participant to count that subset visually: 1 + 2 + 3 = 6. Through similar shared attention to structural elements of the hexagon, all the group members know that there are three such arrays of lines like the green ones at different orientations in each of the six triangles.

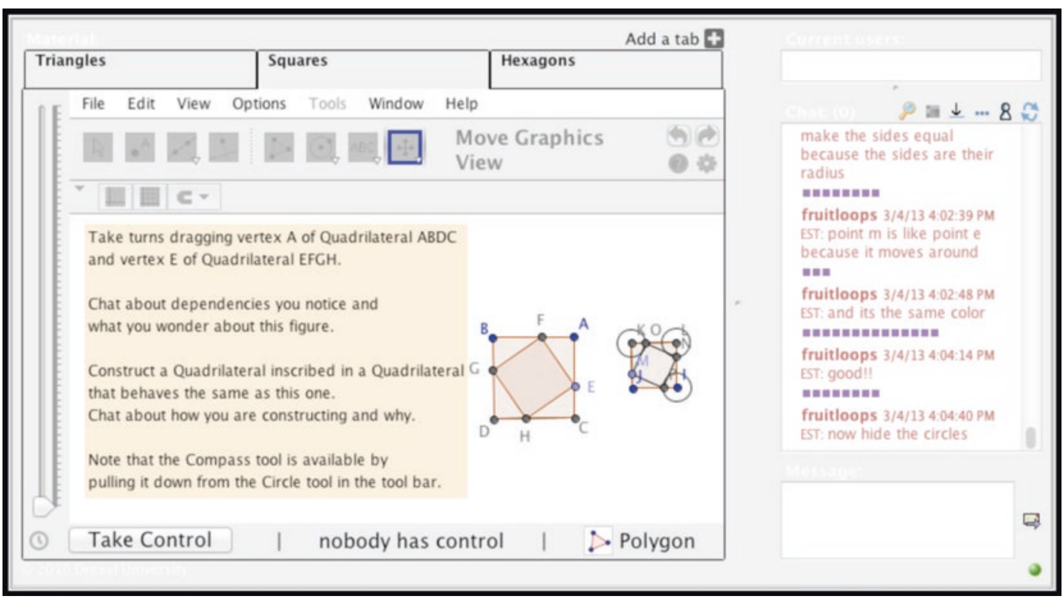

Fig. 19.3 Discussion and constructions of inscribed squares

They can also see how this array of lines will increase as the hexagon itself progresses to successively longer side-lengths. The achievement of the necessary *persistent co-attention* to construct and to follow this complicated analysis was the result of subtle interactions and the development of shared practices within the group.

Inscribing Triangles

Our final case involves a group of three middle-school students given a topic in dynamic geometry (Stahl, 2013, Sect. 7.3). The students have not yet had a course in geometry but have already spent 4 h together in a version of VMT that incorporates interactive, multiuser support for dynamic geometry. In this topic, the students are given constructions of an equilateral triangle inscribed inside another equilateral triangle and a square inscribed inside another square (see Fig. 19.3). In dynamic geometry, a student can drag one point of a figure like the inscribed squares, and all the other points and lines will move accordingly, maintaining the geometric relationships or dependencies that have been built into the construction of the figure. In previous sessions, the students had learned the dynamic-geometry equivalent of Euclid's first two propositions: the construction of an equilateral triangle (using software tools equivalent to a straight edge and compass) and the copying of a line-segment length.

In their fifth session, the three students took turns dragging points of the equilateral triangles and discussing the dependencies that were maintained. Then they tried to duplicate the given figure and to build in the relevant dependencies. For instance, the dependency defining the equilateral character of the outer triangle is that the lengths of the second and third sides must always be the same as the length of the base, even when the endpoints of the base segment are dragged, changing its length. Euclid's construction maintains this dependency because the lengths of all three sides are radii of circles of equal radius. Read today, Euclid's *Elements* (300 BCE/2002) in effect provides instructions for dynamic-geometry constructions. The "elements" of geometry are not so much the points, lines, circles, triangles, and quadrilaterals but the basic operations of constructing figures with important relationships, such as congruence or symmetry. Just as Euclidean geometry contributed significantly to the development of logical, deductive, and apodictic cognition in Western thought and in the formative minds of many prospective mathematicians, so collaborative experiences with dynamic geometry may foster in students ways of thinking about dependencies in the world.

The students in the case study used Euclid's method to construct the outside triangle but soon realized that the same procedure could not be used to construct the inscribed triangle because of the additional constraint that its vertices all had to be on the sides of the inscribing triangle, which they had constructed. Considerable further dragging of points in the given figure and experimentation with various construction approaches were tried. Finally, the students noticed that when one point of the inner triangle was dragged along a side of the outer triangle, the other vertices of the inner triangle moved in a corresponding way, such that their positions along their sides of the outer triangle were the same as that of the dragged vertex on its side. Then they quickly decided to use the method they had learned for copying a line-segment length. They copied the length from one outer vertex of their new equilateral triangle to a point for an inner vertex. Then they placed this length along the other sides, starting at both of the other vertices. This determined the locations of the other inner vertices. When they connected the three points, they formed an inscribed triangle. When any point or line was dragged, both the inner and outer triangles remained equilateral and inscribed.

In their sixth session, the students tackled the topic of inscribed squares. All their previous work in dynamic geometry had involved triangles, and they had not been exposed to a method of constructing a dynamic square. They spent most of the hour exploring possible construction methods, eventually inventing a method that was elegantly similar to that of the triangle construction. All three students then immediately saw how to construct the interior square by copying the length from a corner of the exterior square to a corner of the interior one along a side. In Fig. 19.3, the circles used for copying the length are still visible. The clarity with which each of the students understood how to inscribe a square—once they were able to construct the exterior dynamic square—shows how well they had each individually mastered the technique from their prior collaborative experience involving the dynamic triangles.

Their collaborative solution of the inscribed-triangles topic is quite typical. We have observed a number of small groups working on this topic, including math teachers, researchers, graduate students, and middle-school students. They all go through a similar process of dragging the original figure, experimenting with construction attempts, discovering the dependency of the distances between the interior and exterior vertices, then realizing how to copy that distance, and finally checking that their construction has the same behavior as the given figure. While this topic poses a problem that is difficult for individuals, small groups often stick with it and solve it through collaborative effort within an hour or less. It takes a combination of many trials, observations, and connections to accomplish the task. The collaborative approach allows individuals to contribute specific pieces of the puzzle, to build on each other's proposals, and to discuss the implications.

The chat discourse is striking in how much the students make sure that everyone agrees with and understands each step that the group as a whole takes in constructing their figures. In addition to expressing agreement and affirming understanding, the students also demonstrate their *shared understanding* by fluidly building on each other's contributions. Successive steps are generally taken by different students, indicating that they are all following the logic of the collaborative effort.

Contributing to Group Cognition

The cognition in group cognition is not the same as individual cognition; it relies upon individual cognition to make essential contributions. However, one cannot say that all of the cognition should be analyzed at the individual unit, because the work of assembling the high-level argumentative structure occurs at the group unit of analysis. Surely, putting together longer sequences of problem-solving arguments must be considered a cognitive activity as much as the work that goes into making the detailed contributions to individual steps. In addition, the personal contributions of individual utterances are largely responses to what has gone before in the group interaction. Not only are these contributions expressions that would not have occurred without the preceding opening up for them and elicitation of them by the group process, but many of the contributions are largely reactions at the group level, which reference and interrelate resources available in the discourse context more than they introduce new elements from the personal perspective and individual background of the actor. The important cognitive achievement of solving the problem is emergent at the group level, rather than a simple collection of expressions of individual cognitive accomplishments.

Coherent and impressive examples of group cognition—such as solving a math problem that the group members would not have been able to solve on their own—do not occur whenever a number of people come together in conversation. In fact, the research field of computer-supported collaborative learning has documented that desirable forms of collaborative knowledge-building are hard to find. The three studies summarized above indicate some reasons for this. First, it is difficult to set up a group interaction where everything relevant to the cognition at the group level of analysis is captured in a form adequate for detailed analysis. It took years of research to develop and deploy the VMT environment to successfully generate adequate data for the analysis of group cognition. Secondly, the group interaction must be directed and guided to focus on an appropriate cognitive task. Certain challenging math problems, carefully presented, seem to provide effective resources for stimulating interesting episodes of group cognition.

Additionally—as the three studies summarized here have documented—the groups must work consistently to ensure the presence of certain preconditions of effective group cognition. They must persist in building *longer sequences* of responses to each other, they must maintain continuous *co-attention* to a shared focus of discussion, and they must build and sustain a *shared understanding* of the topic of conversation.

The Constitution of Group Cognition

The phenomenological tradition has always conceived of cognition as embodied in the world, rather than as a Cartesian mental process. Husserl (1929/1960, §14) emphasized that cognition is cognition *of* something; it is located at its object, not at some internal representation of that external object. Heidegger (1927/1996) therefore started from the experience of being-in-the-world instead of thinking-in-the-head. For him, cognition is a matter of being-with and caring-for things and people. The world is a shared world, and the things we are there with are always already understood as meaningful. In Merleau-Ponty's (1945/2002) famous example of the blind man with the cane, the cane does not so much augment or extend the man's senses and mental awareness of external reality as it locates his cognition in the physical world at the tip of the cane; he senses the object at the tip directly, without focusing on the cane or the intervening distance.

If we look at the presented examples of group cognition, we see that the students are "there" in their group interaction with virtual mathematical objects, seen in specific ways. Aznx and Bwang have drawn the horizontal sticks and the vertical sticks separately (not shown in the summary above). They have noticed a four-way symmetry, which allows them to reduce the problem of counting the sticks to a tractable pattern. They are focused together on the diamond as that symmetric pattern of sticks. Similarly, Jason, Qwertyuiop, and 137 have worked hard to view their hexagonal array as a symmetrical pattern of sticks forming lines within triangles that make up a hexagon. As these groups work out their algebraic solutions to the topic, they are present together in a shared virtual world at an object of interest, which they all see as structured in the same way. In the third case, after much work individually and collaboratively, and incorporating ideas from the ancient tradition of Euclidean geometry, the three students working on the inscribed squares all observe that when square `EFGH` is dragged within square `ABCD`, the following segments along the outer square change but stay equal in length to each other: `AE`, `CH`, `DG`, and `BF`. They then can all see that they have to construct square `MONP` within square `IJKL` so that segments `IP`, `JM`, `KO`, and `LN` stay the same (see Fig. 19.3). They collaborate in a shared world, manipulating a shared object physically (i.e., by moving a mouse), visually, and imaginatively within a shared approach to their problem, the geometric objects, the dynamic dependencies, the representational figure, and the software affordances.

Following the phenomenologists, ethnomethodologists showed that the shared social world is constituted continuously through group interaction (Garfinkel, 1967). In our VMT data, we can study precisely how that is accomplished. We see that it takes place over longer sequences of discourse moves, each centered on elicitation/response adjacency pairs. Carrying out these longer sequences requires maintaining persistent co-attention to a shared object; the being-there-together at the object provides a shared focus for the discourse. Accompanying this, there must be a shared understanding of the object and of the discourse context so that group members understand each other. If someone does not know what someone else means by a "hexagonal array" or by its "side-length" and does not see the same elements of a symmetrical pattern or the same set of line segments moving together, then the collaborative problem-solving cannot continue productively.

Kant (1787/1999) argued that the human mind constitutes meaningful reality through a process of creative discovery, in which structure is imposed by the mind to create and discover (constitute) objects in the world. In the preceding examples, we see how group interaction can constitute the character of objects in the shared world, and we have suggested that the shared meaningful world is itself constituted through such interaction. The nature of reality—such as the symmetries of diamond patterns, hexagonal arrays, and inscribed squares—is discovered through the creation of interpretive views of objects. Effective perspectives are constrained by reality, which is not knowable except through these views.

The creation of perspectives at the level of group cognition shifts the constitutive role from Kant's individual cognition to group and social cognition. Like the students in the virtual math teams, *we first learn to see things as others see them in group-cognitive processes* (which generally incorporate culturally sanctioned approaches). Subsequently—due to the power of language (e.g., naming, verbal description)—we can be there with those objects (diamonds, hexagons, squares) when we are not physically (or virtually) present with them in a shared group setting. We can even "internalize" (to use Vygotsky's metaphor) our ability to be there with these meaningful objects in the internal speech of individual thought.

However, the fact that introspection of adults discovers (and assumes) the existence of many individual mental objects does not mean that those objects were not at some point in our development internalized from group-cognitive experiences in community contexts. An adequate analysis of cognition should recognize the constitutive roles of group cognition and their integration with phenomena of individual and social cognition.

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Investigation 20. Theories of Shared Understanding

Gerry Stahl

Abstract
Recent research on instructional technology has focused increasingly on the potential of computer support to promote collaborative learning, shared understanding, and collaborative knowledge building. Sociocultural theories have been imported from cognate fields to suggest that cognition and learning take place at the level of groups and communities as well as individuals. Various positions on this issue have been proposed, and a number of theoretical perspectives have been recommended. In particular, the concept of common ground has been developed to explain how meanings and understandings can be shared by multiple individuals. This Investigation takes a critical look at the concept of shared meaning as it is generally used and proposes an empirical study of how group cognition is constituted in practice.

Keywords
Shared meaning · Knowledge building · Shared understanding · Common ground · Group cognition · Interpretation · Perspectives · Participation metaphor

Among those researchers working on computer-assisted learning, a community has emerged in the past decade known as computer-supported collaborative learning or CSCL (Crook, 1994; Dillenbourg, 1999; O'Malley, 1995). In an influential attempt to define this paradigm of research, Koschmann (1996) argues that previous forms of instructional technology research "approach learning and instruction as psychological matters (be they viewed behavioristically or cognitively) and, as such, are researchable by the traditional methods of psychological experimentation" (p. 10f). That is, they focus on the mind of the individual student as the unit of analysis when looking for instructional outcomes, learning, meaning-making, or cognition. By contrast, the paradigm of CSCL "is built upon the research traditions of those disciplines—anthropology, sociology, linguistics, communication science—that are devoted to understanding language, culture and other aspects of the social setting" (p. 11). This radical paradigm shifts, focusing on "the social and cultural context as the object of

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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study, produces an incommensurability in theory and practice relative to the paradigms that have come before" (p.13).

The incommensurability between CSCL and other paradigms of computer-assisted learning becomes clear if we phrase it this way: in the CSCL perspective, it is not so much the individual student who learns and thinks, as it is the collaborative group. Given that we have for millennia become used to taking learning and thinking as activities of individual minds, it is hard to conceive of them as primarily group activities. Of course, this approach does not deny that individuals often think and learn on their own, but rather that in situations of collaborative activity, it is informative to study how processes of learning and cognition take place at the group level.

Thus the question of group cognition can be viewed as largely a methodological, rather than ontological issue: it is a call to analyze case studies of collaboration at the group unit of analysis, rather than a claim that some kind of group mind exists beyond the situated and transient group discourse itself. As Stahl (2003) argued, one can identify processes of meaning-making or knowledge-building in the interaction that cannot be attributed to any individual group members, although the participation of the individuals in the group process is necessary as sources of contributed utterances and as interpreters of the shared meaning.

In fact, analysis at the group level of description often demonstrates that even when someone learns or thinks in seeming isolation, this activity is essentially conditioned or mediated by important social considerations. This was a general claim of Vygotsky (1930/1978): that intersubjective or inter-psychological or group learning generally preceded individual or intra-psychological learning, which resulted from the internalization of what took place socially. Koschmann points out that Vygotsky—one of the principle theoretical sources for CSCL—proposed the "zone of proximal development" as "a mechanism for learning on the inter-psychological plane" (p. 12).

Vygotsky (1930/1978) contrasted his conception of potential social development to the traditional psychological focus on individual learning, saying "In studies of children's mental development it is generally assumed that only those things that children can do on their own are indicative of mental abilities" (p. 85). Vygotsky's alternative social conception of development was meant to measure a child's position in the "process by which children grow into the intellectual life of those around them" (p. 88; italics in original), as opposed to their mental position in doing tasks on their own.

The italicized phrase is strikingly similar to the definition of situated learning by Lave and Wenger (1991)—another central source of CSCL's theory of learning. Related foundations of the CSCL paradigm include Hutchins' (1996) presentation of distributed cognition and Suchman's (1987) discussion of situated action. Despite the attempt by these traditions within CSCL to overcome the traditional focus of educational and psychological theories on the individual as cognitive agent, none of them have worked out a satisfactory theory of group cognition.

Stahl (2003) drew on the aforementioned and other sources to argue for taking *meaning* that is constructed in successful processes of collaboration as a shared group product, which is, however, necessarily subject to *interpretation* by the individuals involved. As much as the writings on situated action, distributed cognition, social constructivism, activity theory, social practice, etc. have foregrounded the social nature of learning and thinking, it is still hard for most people to overcome their individualistic conceptual traditions and come to terms with group learning or group cognition. This Investigation is an attempt to further that effort by considering just what is meant by shared meaning and group cognition.

The Problem of Shared Meaning

The analysis by Stahl (2003) tried to provide insight into the nature of the *group perspective*. In particular, its Chapter 16 argued for a view of both shared group *meaning* and individual *interpretation*. Shared meaning was not reduced to mental representations buried in the heads of individuals. Such mental contents could only be inferred from introspection and from interpretation of people's speech and behavior, whereas socially shared meaning can be observed in the visibly displayed discourse that takes place in group interactions, including non-verbal communication and associated artifacts. This approach does not result in a behaviorist denial of human thought in bracketing out inferred mental states and focusing on observable interaction, because of the methodological recognition of interpretive perspectives. People are considered to be interpreting subjects, who do not simply react to stimuli but understand meanings.

It is true that only individuals can interpret meaning. But this does not imply that the group meaning is just some kind of statistical average of individual mental meanings, an agreement among preexisting opinions, or an overlap of internal representations. A group meaning is constructed by the interactions of the group's members, not by the individuals on their own. It is an emergent property of the discourse and interaction. It is not necessarily reducible to assumed personal opinions or isolated understandings of individuals.

Stahl (2004) presented an example of how this works. The discourse transcribed there is strikingly elliptical, indexical, and projective; that means that it implies and requires a (perhaps open-ended) set of references to complete its meaning. These references are more a function of the history and circumstances of the discourse than of intentions attributable to specific participants. The words in the analyzed collaborative moment refer primarily to each other, to characteristics of the artifacts discussed, and to group interactions. In fact, one can only attribute well-defined opinions and intentions to the individual students after one has extensively interpreted the meanings of the discourse as a whole.

As seen in the example transcript, the shared meaning was collaboratively created by the group as a whole. But the establishment of that meaning as shared involved a process of negotiation through which the individual group members had to interpret the meaning from their own personal perspectives, to display their understanding of the meaning, and to affirm that meaning as shared. The collaborative process itself entailed corresponding individual processes. In a sense, one can say both that the individuals learned as a result of the group learning and that the group could only learn by ensuring that the individuals learned.

Of course, the kind of "learning" that happens in a brief interaction is not the kind of learning that educators look for over months. It is perhaps better referred to as "knowledge building," in which some word or utterance takes on a new shared meaning. To understand what takes place in collaborative interactions, it seems important to become clearer about the nature of shared knowledge—how it is produced, negotiated, distributed, and internalized.

The major difficulty in understanding shared knowledge and group cognition is that it is habitual to attribute thoughts and intentions to individual actors—and to reduce group phenomena to actions of the individual group members. One typically assumes that a speaker's words are well defined in advance in the speaker's mind and that the discourse is just a way for the speaker to express some preconceived meaning and to convey it to the listeners. This reveals a conflict. If meaning is socially constructed, why do researchers feel compelled to treat it as private property; if it takes place in isolated minds, how can it ever be shared and understood collaboratively? The possibility of shared meaning must be somehow explained. This is particularly important in cases of collaborative learning, where the knowledge that is constructed must be shared among the learners (or may be shared first, before it can become part of an individual's knowledge).

The term "shared knowledge" is ambiguous. It can refer to:

- Similarity of individuals' knowledge: The knowledge in the minds of the members of a group happens to overlap, and their intersection is "shared."
- Knowledge that gets shared: Some individuals communicate what they already knew to the others, who then "share" it.
- Group knowledge: Knowledge is interactively achieved in discourse and may not be attributable as originating from any particular individual. It is part of a "shared" world.

The ambiguity of this term corresponds to different paradigms of viewing group interaction: whether it is taken to be a result of individual knowledge, reducible to knowledge held by individual thinkers, or an emergent property of the group discourse as an irreducible unit for purposes of analysis. If CSCL is to be conceived as a fundamentally new educational form, rather than just a technique for fostering individual learning, then it seems that something like the third reading of "shared knowledge" needs to be explicated.

A Conflict of Paradigms

Research on learning and education is troubled to its core by the conflict of paradigms we are considering. Sfard (1998) reviewed some of the history and consequences of this conflict in terms of the incompatibility of the acquisition metaphor (AM) of learning and the participation metaphor (PM). AM conceives of education as a transfer of knowledge commodities and their subsequent possession by individual minds. Accordingly, empirical research in this paradigm looks for evidence of learning in changes of mental contents of individual learners. PM, in contrast, locates learning in intersubjective, social or group processes, and views the learning of individuals in terms of their changing participation in the group interactions. AM and PM are as different as day and night, but Sfard argues that we must learn to live in both complementary metaphors.

The conflict is particularly pointed in the field of CSCL. Taken seriously, the term "collaborative learning" can itself be viewed as self-contradictory given the tendency to construe learning as something taking place in individual minds. Having emerged from the paradigm shift in thinking about instructional technology described by Koschmann (1996), the field of CSCL is still enmeshed in the paradigm conflict between opposed cognitive and sociocultural focuses on the individual and on the group (Kaptelinin & Cole, 2002). In his keynote at the CSCL '02 conference, Koschmann (2002a) argued that even exemplary instances of CSCL research tend to adopt a theoretical framework that is anathema to collaboration. Koschmann recommended that talk about "knowledge" as a thing that can be acquired should be replaced with discussion of "meaning-making in the context of joint activity" in order to avoid misleading images of learning as mental acquisition and possession of knowledge objects.

Although Koschmann's alternative phrase can describe the intersubjective construction of shared meanings achieved through group interaction, the influence of AM can re-construe meaning-making as something that must perforce take place in individual human minds, because it is hard for most people to see how a group can possess mental contents. Stahl (2003) argued in effect that both Koschmann's language and that of the researchers he critiqued is ambiguous and is subject to interpretation under either AM or PM. A simple substitution of wording is inadequate; it is necessary to make explicit when one is referring to individual subjective understanding and when one is referring to group intersubjective understanding—and to make clear to those under the sway of AM how intersubjectivity is concretely possible.

The problem with recommending that researchers view learning under both AM and PM or that they be consistent in their theoretical framing is that our commonsense metaphors and widespread folk theories are so subtly entrenched in our thinking and speaking. The languages of Western science reflect deep-seated assumptions that go back to the *ideas* of Plato's *Meno* (350 BCE/ 1961) and the *ego cogito* of Descartes' *Meditations* (1633/1999). It is hard for most people to imagine how a group can have knowledge, because we assume that knowledge is a substance that only minds can acquire or possess and that only physically distinct individuals can have minds (somewhere in their physical heads). The term *meaning* as in *shared meaning* carries as much historical baggage as the term *knowledge* in *knowledge building*.

The Range of Views

CSCL grows out of research on cooperative learning that demonstrated the advantages for individual learning of working in groups (e.g., Johnson & Johnson, 1989). There is still considerable ambiguity or conflict about how the learning that takes place in contexts of joint activity should be conceptualized. While it has recently been argued that the key issues arise from ontological and epistemological commitments deriving from philosophy from Descartes to Hegel (Koschmann, 2002b; Packer & Goicoechea, 2000), Stahl (2004) argued that it is more a matter of focus on the individual (cognitivist) versus group (sociocultural) as the unit of analysis.

Theoretical positions on the issue of the unit of learning (e.g., in the compilations of essays on shared cognition (Resnick, Levine & Teasley, 1991) or distributed cognition (Salomon, 1993)) take on values along a spectrum from individual to group. The following is an attempt to characterize possible positions along this spectrum, most of which have been advocated for in the literature:

- Learning is always accomplished by individuals, but this individual learning can be assisted in settings of collaboration, where individuals can learn from each other.
- Learning is always accomplished by individuals, but individuals can learn in different ways in settings of collaboration, including learning how to collaborate.
- Groups can also learn, and they do so in different ways from individuals, but the knowledge generated must always be located in individual minds.
- Groups can construct knowledge that no one individual could have constructed alone by a synergistic effect that merges ideas from different individual perspectives.
- Group knowledge can be spread across people and artifacts; it is not reducible to the knowledge of any individual or the sum of individuals' knowledge.
- Groups construct knowledge that may not be in any individual minds but may be interactively achieved in group discourse and may persist in physical or symbolic artifacts such as group jargon or texts or drawings.
- Learning is always a mix of individual and group processes; the analysis of learning should be done with both the individual and group as units of analysis and with consideration of the interplay between them.
- Individual learning takes place by internalizing or externalizing knowledge that was already constructed interpersonally; even modes of individual thought have been internalized from communicative interactions with other people.
- All human learning is fundamentally social or collaborative; language is never private; meaning is intersubjective; knowledge is situated in culture and history.

These different positions imply different answers to why CSCL is important. At one extreme of the spectrum, collaboration is only valued to the extent that it results in desirable learning outcomes for individual minds. At the other extreme, collaborative learning can benefit a whole community of practice by developing cultural artifacts like theories. Intermediate positions may acknowledge that benefits accrue at group and individual levels in parallel, through reciprocal influences.

The different positions listed above are supported by a corresponding range of theories of human learning and cognition. Educational research on small group process in the 1950s and 1960s maintained a focus on the individual as learner (Johnson & Johnson, 1989; see review in Stahl, 2000). Classical cognitive science in the next period continued to view human cognition as primarily an individual matter—internal symbol manipulation or computation across mental representations inside an individual's brain, with group effects treated as secondary boundary constraints (Simon, 1981; Vera & Simon, 1993).

In reaction to these views, a number of sociocultural theories have become prominent in the learning sciences in recent decades. To a large extent, these theories have origins in much older works that conceptualized the situatedness of people in practical activity within a shared world (Bakhtin, 1986; Heidegger, 1927/1996; Husserl, 1936/1989; Marx, 1867/1976; Schutz, 1967; Vygotsky, 1930/1978).

The following list describes some representative theories that focus on the group as a possible unit of knowledge construction. Of course, each theory is itself too complex to be summarized meaningfully in a sentence, consisting of multiple texts and redefining terms like "learning" and "knowledge" in the process of developing a theory:

- *Collaborative Knowledge Building*. A group can build knowledge that cannot be attributed to an individual or to a combination of individual contributions, but that exists as textual artifacts that can be critiqued by others (Bereiter, 2002; Donald, 1991).
- *Social Psychology*. One can and should study knowledge construction at both the individual and group unit of analysis, as well as studying the interactions between them (Fischer & Granoo, 1995; Resnick et al., 1991; Salomon, 1993).
- *Distributed Cognition*. Knowledge can be spread across a group of people and the tools that they use to solve a problem (Hutchins, 1996; Norman, 1993).
- *Situated Cognition*. Knowledge often consists of resources for practical activity in the world more than of rational propositions or mental representations (Schön, 1983; Suchman, 1987; Winograd & Flores, 1986).
- *Situated Learning*. Learning is the changing participation of people in communities of practice (Lave & Wenger, 1991; Shumar & Renninger, 2002).
- *Zone of Proximal Development*. Children grow into the intellectual life of those around them; they develop in collaboration with adults or more capable peers (Vygotsky, 1930/1978).
- *Activity Theory*. Human understanding is mediated not only by physical and symbolic artifacts but also by the social division of labor and cultural practices (Engeström, 1999; Nardi, 1996).
- *Ethnomethodology*. Human understanding, interpersonal relationships, and social structures are achieved and reproduced interactionally (Dourish, 2001; Garfinkel, 1967).

One does not have to commit to one of these theories in particular in order to gain a sense from them all of the possible nature of group knowledge.

Most of these theories hinge on the question of how it is possible for shared knowledge to be established. Despite this, none of these authors have explained how groups can learn in sufficient detail to overcome widespread resistance to thinking about learning at the group level of description.

Common Ground or Group Cognition?

Within CSCL, it is usual to refer to the theory of "common ground" to explain how collaborative understanding is possible. Baker et al. (1999), for instance, note that collaboration requires mutual understanding among the participants, established through a process of "grounding."

It is certainly clear that effective communication is generally premised on the sharing of a language, of a vast amount of practical background knowledge about how things work in the physical and social world, of many social practices implicit in interaction, and of an orientation within a shared context of topics, objects, artifacts, previous interactions, etc. Much of this sharing we attribute to our socialization into a common culture or into overlapping sub-cultures.

Most common ground is taken for granted as part of what it means to be human. The phenomenological hermeneutics of Heidegger (1927/1996) and Gadamer (1960/1988)—building on the traditions of Dilthey and Husserl—made explicit the ways in which human understanding and our ability to interpret meaning rely upon a shared cultural horizon. It emphasized the centrality of interpretation to human existence as being engaged in the world. It also considered cases where common ground breaks down, such as in interpreting ancient texts or translating from foreign languages—e.g., how can a modern German or American understand a theoretical term from a Platonic dialogue or from a Japanese poem?

The current discussion of common ground within CSCL is, however, more focused. It is concerned with the short-term negotiation of common ground during brief interactions. Such negotiation is particularly visible when there is a breakdown of the common ground, an apparent problem in the mutual understanding. A breakdown appears through the attempt of the participants to repair a misunderstanding or lack of mutuality. For instance, in the presentations of Roschelle (1996) and Stahl (2004), much of the transcribed discourse was analyzed as attempts to reach shared understandings in situations in which the group discussion had become problematic.

It is not always clear whether repairs to breakdowns in such common ground come from ideas that existed in someone's head and are then passed on to others until a consensus is established or whether the common ground might be constructed in the interaction of the group as a whole. It is possible that shared knowledge can sometimes be best explained in one way, sometimes another. At any rate, it seems that the question of the source of shared knowledge should generally be treated as an empirical question. This is what is proposed in the next section of this Investigation. But first, this alternative should be made a bit clearer.

The theory of common ground that Baker et al. (1999), Roschelle (1996), and many others in CSCL refer to is that of Clark and his colleagues. Clark and Brennan (1991) situate their work explicitly in the tradition of conversation analysis (CA), although their theory has a peculiarly mentalist flavor uncharacteristic of CA. They argue that collaboration, communication, and "all collective actions are built on common ground and its accumulation" (p. 127). The process of updating this common ground on a moment-by-moment basis in conversation is called "grounding." Grounding, according to this theory, is a collective process by which participants try to reach mutual belief. It is assumed that understanding (i.e., mutual belief) can never be perfect (i.e., the participants can never have beliefs that are completely identical). It suffices that "the contributor and his or her partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for current purposes" (p. 129). Clark and Brennan (1991) then show how various conversational moves between pairs of people can conduct this kind of grounding and achieve a practical level of mutuality of belief. They go on to show how different technologies of computer support mediate the grounding process in different ways.

Clark's contribution theory—where one participant "contributes" a personal belief as a proposed addition to the shared common ground and then the participants interact until they all believe that they have the same understanding of the original belief, at which point their common ground is "updated" to include the new contribution—is articulated in the language of individual mental beliefs, if not to say in the jargon of computer models of rational memories. Thus, it is not surprising that Schegloff (1991) responds polemically to Clark and Brennan (1991) by opposing the tradition of ethnomethodology and CA to this theory of mental beliefs: Schegloff points out that Garfinkel (1967) "asked what exactly might be intended by such notions as 'common' or 'shared' knowledge. In the days when computers were still UNIVACS, Garfinkel viewed as untenable that notion of common or shared knowledge that was more or less equal to the claim that separate memory drums had identical contents" (p. 151f). Schegloff then presented an analysis of repair in talk-in-interaction that contrasted with Clark's by construing what took place as a social practice following social patterns of interaction. According to Schegloff's approach, repair is a form of socially shared cognition that takes place in the medium of discourse (in the broad sense of social interaction-in-talk), following established conversational patterns, rather than a transfer and comparison of beliefs between rationalist minds.

In a later critique of Clark's contribution theory of common ground, Koschmann and LeBaron (2003) present video data of an interaction in an operating room. A resident, an attending doctor, and an intern are discussing the location of internal organs as viewed indirectly through a laparoscopic camera. Koschmann and LeBaron argue that the discourse that takes place does not match Clark's rubric and that the very notion of belief contributions to some kind of common ground storage space is not useful to understanding the construction of shared understanding in this situation. Although the medical operation is successful and although technology-supported collaborative learning takes place, the beliefs of the individual participants afterward do not agree in Clark's sense. Thus, there seems to be a group shared understanding, which is effective in the practice of the operation, but which does not correspond to the understanding of any of the individual participants when considered outside their working team—as Clark's theory of common ground would have it.

Perhaps the case of the operating room (OR) illustrates Vygotsky's contrast between a person's individual developmental level and their social developmental level (separated by the zone of proximal development). The intern was able to participate in the collaborative activity even though he could not correctly identify key items on his own afterward, outside the group. This might indicate that what takes place in group interactions cannot reliably be reduced to behaviors of the individuals involved. The knowledge and abilities of people in individual and group settings are quite different. The group cognition of the OR team would then not be a simple sum of the individual cognitive acts of its members; the group understanding would not be a simple intersection or overlap of individual beliefs, as identifiable outside of the group context.

Of course, the OR situation was a special case which differed in significant ways from most everyday conversation. Often, interaction can be adequately analyzed as the exchange of personal beliefs. This is particularly true of dyadic conversations, such as those in Clark's examples, rather than in the more complex interactions of small groups of three or more in the OR—or in CSCL generally. The question for CSCL is: Can sets of students be transformed into groups that learn collaboratively in ways that encourage the emergence of collaborative group cognition in a significant sense? This is, above all, an empirical question, although it requires a clear conceptual framework for defining and interpreting the data.

Empirical Inquiry into Group Cognitive Practices

At Drexel University, an interdisciplinary group of researchers and staff of the Math Forum—a popular online site with resources and problems related to K-12 school mathematics—undertook a research project to investigate empirically whether knowledge sharing in community contexts can construct group knowledge that exceeds the individual knowledge of the group's members. Their hypothesis was that precisely such a result is, in fact, the hallmark of collaborative learning, understood in an emphatic sense, as a vision of the future. This research is based on earlier work that indicated the possibility of observing group cognition in recordings or transcripts of team discourse.

Roschelle's (1996) study of two students constructing a new (for them) conception of acceleration can be construed as an analysis of shared knowledge building. As Koschmann (2002a) pointed out, the analytic paradigm of that paper is ambiguous. Its focus on the problematic of convergence posits the conceptual change as taking place in the minds of the two individual students while at the same time raising the issue of the possibility of shared (i.e., convergent) knowledge. The study reported by Stahl (2004) was an attempt to analyze knowledge building at the group level by a group of five students. That analysis was in some respects similar to Roschelle's.

Our proposed new research at the Math Forum takes Stahl's (2004) study as a pilot study and aims to generate a corpus of group interactions in which problem-solving and knowledge building can be most effectively observed at the group level.[1] Like many studies of collaborative learning (but unlike the proposed study), the pilot study involved face-to-face interaction with an adult mentor present. Close analysis of student utterances during an intense interaction during that study suggested that the group developed an understanding that certainly could not be attributed to the utterances of any one student. In fact, the utterances themselves were meaningless if taken in isolation from the discourse and its activity context.

There were a number of limitations to the pilot study:

1. Although the mentor was quiet for the specific interaction analyzed, it might be possible to attribute something of the group knowledge to the mentor's guiding presence.
2. The digital videotape was limited in capturing gaze and even some spoken wording.
3. The data included only two sessions, too little to draw conclusions about how much individual students understood of the group knowledge before, during or after the interaction.

To overcome such limitations, in our proposed study:

1. Mentors are not active in the collaborative groups—although the groups work on problems that have been carefully crafted to guide student inquiry and advice can be requested by email from Math Forum staff.
2. The online communication is fully logged, so that researchers have a record of the complete problem-solving interaction, essentially identical to what the participants see online.
3. Groups and individuals are studied during longer, more multi-faceted problem-solving sessions—and in some cases over multiple sessions.

Despite its limitations, the pilot study clearly suggested the feasibility of studying group knowledge. It showed how group knowledge can be constructed in discourse and how discourse analysis can "make visible" that knowledge to researchers. We want to study this in more detail.

We are investigating not only whether computer-supported collaborative learning can construct novel group knowledge but also what community contexts are favorable to fostering such an outcome. We are doing this by designing and implementing an experimental service in the Math Forum. Students visiting the site are invited to join small virtual teams to discuss and solve math problems

[1]This discussion is largely drawn from an early proposal to the National Science Foundation for funding what became the Virtual Math Teams (VMT) Project from 2003 to 2015. It reflects the author's understanding of theoretical issues of CSCL in the early 2000s. For the original proposals, see (Stahl, 2010).

collaboratively online. We analyze the interactions in these teams to determine how they build shared knowledge within the Math Forum virtual community.

We are addressing the issue of the nature of shared understanding by studying online collaborative learning in the specific context of Math Forum problems, with the aim of presenting empirical examples of concrete situations in which groups can be seen to have knowledge that is distinct from the knowledge of the group members. By analyzing these situations in detail, we will uncover mechanisms by which understanding of mathematics passes back and forth between the group as the unit of analysis and individual group members as units of analysis.

One example might be a group of five middle-school students collaborating online. They solve an involved algebra problem and submit a discussion of their solution to the Math Forum. By looking carefully at the computer logs of their interactions in which they collaboratively discussed, solved, and reflected upon the problem, we can see that the group solution exceeds the knowledge of any individual group members before, during, or after the collaboration. For instance, there may be some arguments that arose in group interaction that none of the students fully understood but that contributed to the solution. Or a mathematical derivation might be too complicated for any of the students to keep "in mind" without reviewing preserved chat archives or using an external representation the group developed on an online whiteboard. By following the contributions of one member at a time, it may also be possible to find evidence of what each student understood before, during, and after the collaboration and thereby to follow individual trajectories of participation in which group and individual understandings influenced each other.

While we do not anticipate that group knowledge often exceeds that of all group members under generally prevailing conditions, we hypothesize that it can do so at least occasionally under particularly favorable conditions. We believe that we can set up naturalistic conditions as part of a Math Forum service and can collect sufficient relevant data to demonstrate this phenomenon in multiple cases. The analysis and presentation of these cases should help to overcome the AM/PM paradigm conflict by providing concrete illustrations of how knowledge can be built through group participation as distinct from—but intertwined with—individual acquisition of part of that knowledge. It should also help to clarify the theoretical framing of acts of meaning-making in the context of joint activity.

Student discourse is increasingly recognized as of central importance to science and math learning (Bauersfeld, 1995; Lemke, 1990). Discourse analysis is a rigorous human science, going under various names: conversation analysis, interaction analysis, micro-ethnography, and ethnomethodology (Garfinkel, 1967; Heritage, 1984; Jordan & Henderson, 1995; Sacks, 1965/1995; Streeck & Mehus, 2003). This method of analysis will allow us to study what takes place through the collaborative interactions. We will be looking for evidence of learning at the micro-level, where shared meanings are developed and knowledge is built up as part of solving a challenging math problem.

The focus on discourse suggests a solution to the confusion between individual and group knowledge and to the conceptual conflict about how there can be such a thing as group knowledge distinct from what is in the minds of individual group members. One way of putting it is that meaning is constructed in the group discourse. The status of this meaning as shared by the group members is itself something that must be continually achieved in the group interaction; frequently the shared status "breaks down" and a "repair" is necessary. In the pilot study, the interaction of interest centered on precisely such a repair of a breakdown in shared understanding among the discussants.

While *meaning* inheres in the discourse, the individual group members must construct their own *interpretation* of that meaning in an ongoing way. Clearly, there are intimate relationships between the meanings and their interpretations, including the interpretation by one member of interpretations by other members. However, it is also true that language can convey meanings that transcend the understandings of the speakers and hearers. It may be precisely through divergences among different interpretations or among various connotations of meaning that collaboration gains much of its creative power (Stahl, 2003).

These are questions that we will investigate as part of our micro-analytic studies of collaboration data, guided by our central working hypothesis:

- H0 (collaborative learning hypothesis): A small online group of learners can—on occasion and under favorable conditions—build group knowledge and shared meaning that exceeds the knowledge of the group's individual members.

We believe that such an approach can maintain a focus on the ultimate potential in CSCL, rather than losing sight of the central phenomena of collaboration as a result of methods that focus exclusively on statistical trends (Stahl, 2002).

Issues for Investigation

While we believe that it is possible to clarify the nature of shared knowledge and group cognition by serious reflection upon the existing theoretical discussions and case studies that touch on these concepts (many of which have been referenced here), we are convinced that significant progress and convincing arguments will require further empirical research.

Collaborative success is hard to achieve and probably impossible to predict. CSCL represents a concerted attempt to overcome some of the barriers to collaborative success, like the difficulty of everyone in a group effectively participating in the development of ideas with all the other members, the complexity of keeping track of all the interconnected contributions that have been offered, or the barriers to working with people who are not visually co-located. As appealing as the introduction of technological aids for communication, computation, and memory seem, they inevitably introduce new problems, changing the social interactions, tasks, and physical environment. Accordingly, CSCL study and design must take into careful consideration the social composition of groups, the collaborative activities, and the technological supports.

In order to observe effective collaboration in an authentic educational setting, we are adapting a successful math education service to create conditions that will likely be favorable to the kind of interactions that we want to study. We must bring together groups of students who will work together well, both by getting along with and understanding each other and by contributing a healthy mix of different skills. We must also carefully design mathematics curriculum packages that lend themselves to the development and display of deep math understanding through collaborative interactions—open-ended problems that will not be solved by one individual, but that the group can chew on together in online interaction. Further, the technology that we provide to our groups must be easy to use from the start while meeting the communicative and representational needs of the activities.

As part of our project, we will study how to accomplish these group-formation, curriculum-design, and technology-implementation requirements. This is expressed in three working hypotheses of the project: H1, H2, and H3. Two further working hypotheses define areas of knowledge building that the project itself will engage in based on our findings. H4 draws conclusions about the interplay between group and individual knowledge, mediated by physical and symbolic artifacts that embody knowledge in persistent forms. H5 reports on the analytic methodology that emerges from the project:

- H1 (collaborative-group hypothesis): Small groups are most effective at building knowledge if members share interests but bring to bear diverse backgrounds and perspectives.
- H2 (collaborative-curriculum hypothesis): Educational activities can be designed to encourage and structure effective collaborative learning by presenting open-ended problems requiring shared deep understanding.

- H3 (collaborative-technology hypothesis): Online computer-support environments can be designed to facilitate effective collaborative learning that overcomes limitations of face-to-face communication.
- H4 (collaborative-cognition hypothesis): Members of collaborative small groups can internalize group knowledge as their own individual knowledge, and they can externalize it in persistent artifacts.
- H5 (collaborative-methodology hypothesis): Quantitative and qualitative analysis and interpretation of interaction logs can make visible to researchers the online learning of small groups and individuals.

We believe that the theoretical confusion surrounding the possibility of group knowledge presents an enormous practical barrier to collaborative learning. Because students and teachers generally believe that learning is necessarily an individual matter, they find the effort at collaborative learning to be an unproductive nuisance. For researchers, too, the misunderstanding of collaborative learning distorts their conclusions, leading them to look for effects of pedagogical and technological innovation in the wrong places.

If these people understood that groups can construct knowledge in ways that significantly exceed the sum of the individual contributions and that the power of group learning can feed back into individual learning, then we might start to see the real potential of collaborative learning realized on a broader scale. This project aims to produce rigorous and persuasive empirical examples of collaborative learning to help bring about the necessary public shift in thinking.

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Investigation 21. Academically Productive Interaction

Gerry Stahl

Abstract
Studies of computer-supported collaborative learning have begun to explore processes of online group cognition—such as small-group methods of problem-solving—and how they can be mediated by various technological and interactional mechanisms to promote academically productive discourse. This investigation first presents (1) an analysis of *co-presence* as a foundational aspect of online interaction in an excerpt of chat discourse. Based on how the students in this excerpt actually interact, it develops (2) a notion of *intersubjective shared understanding* as necessary for the possibility of collaborative knowledge-building dialog. The essay concludes with (3) a discussion of consequences for the design of computer support of academically productive online *group cognition*.

Keywords
Co-presence · Shared understanding · Group cognition · Software agent · Invasiveness · Over-scripting

An Excerpt of Computer-Supported Discourse

The studies of digital interaction by virtual math teams presented in Stahl (2009) adopt an ethnomethodological interest in how interaction is actually carried out in particular online contexts. They assume that the member methods or group practices of computer-mediated interaction developed by small groups of students may differ significantly from commonsense assumptions of researchers based on experience with face-to-face interaction. If this is true, then it is important to explore actual instances of digital interaction before designing interventions in such settings.

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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The first section of this investigation reviews how a team of three students collaboratively achieved a cognitive accomplishment as a distributed online group. The log of their interaction makes visible mechanisms by which academically productive discourse or accountable talk (Michaels, O'Connor, & Resnick, 2008) can arise naturally in settings of computer-supported collaborative learning or CSCL (Stahl, Koschmann, & Suthers, 2006). The data analysis presented in this initial section is not intended as an illustration of pre-existing theories; rather, the theory in the next section emerges through the analysis of this and similar data.

"Wait… I Don't Really See": Establishing Co-presence

Figure 21.1 shows a screenshot of the virtual math teams (VMT) software environment, being used by three middle-school students. They volunteered to participate in this online, synchronous math activity with other students from around the world. The students are collaboratively investigating mathematical patterns (combinatorics) related to sequences of geometric figures. In the lower right of the whiteboard is a stair-step pattern of blocks remaining on the board from their previous day's ses-

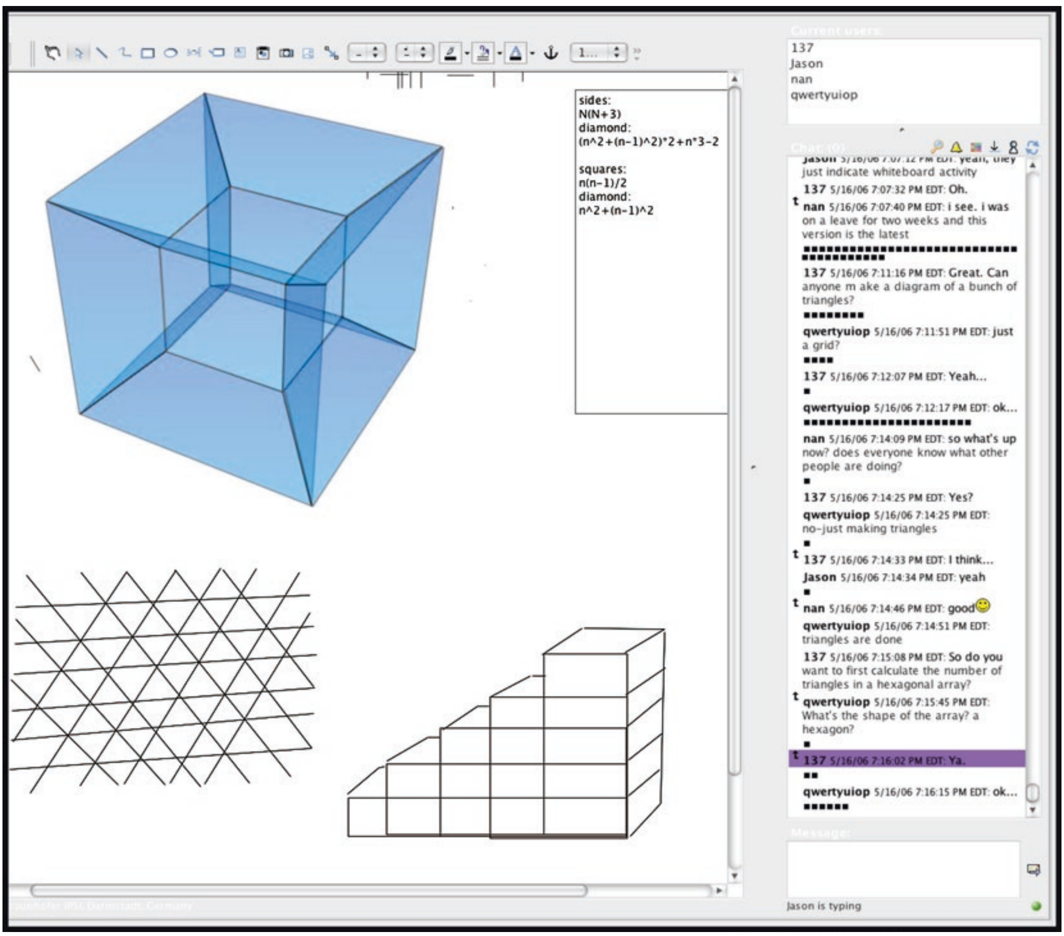

Fig. 21.1 The VMT interface near the beginning of the excerpt

705	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:45	qwertyuiop	What's the shape of the array? a hexagon?
707	19:16:02	137	Ya.
708	19:16:15	qwertyuiop	ok...
709	19:16:41	Jason	wait-- can someone highlight the hexagonal array on the diagram? i don't really see what you mean...
710	19:17:30	Jason	hmm.. okay
711	19:17:43	qwertyuiop	oops
712	19:17:44	Jason	so it has at least 6 triangles?
713	19:17:58	Jason	in this, for instance
714	19:18:53	137	How do you color lines?
715	19:19:06	Jason	there's a little paintbrush icon up at the top
716	19:19:12	Jason	it's the fifth one from the right
717	19:19:20	137	Thanks.
718	19:19:21	Jason	there ya go :-)
719	19:19:48	137	Er... That hexagon.
720	19:20:02	Jason	so... should we try to find a formula i guess
721	19:20:22	Jason	input: side length; output: # triangles
722	19:20:39	qwertyuiop	It might be easier to see it as the 6 smaller triangles.
723	19:20:48	137	Like this?
724	19:21:02	qwertyuiop	yes
725	19:21:03	Jason	yup
726	19:21:29	qwertyuiop	side length is the same...
727	19:22:06	Jason	yeah
728	19:22:13	Jason	so it'll just be x6 for # triangles in the hexagon
729	19:22:19	137	Each one has 1+3+5 triangles.
731	19:22:29	qwertyuiop	the "each polygon corrisponds to 2 sides" thing we did last time doesn't work for triangles
732	19:23:17	137	It equals 1+3+...+(n+n-1) because of the "rows"?
733	19:24:00	qwertyuiop	yes- 1st row is 1, 2nd row is 3...
734	19:24:49	137	And there are n terms so... n(2n/2)
735	19:25:07	137	or n^2
736	19:25:17	Jason	yeah
737	19:25:21	Jason	then multiply by 6
738	19:25:31	137	To get 6n^2

Log 21.1 Log of the chat excerpt

sion. Currently, the students are considering a pattern of regular hexagons, which they will visualize in a grid of triangles they construct in the lower left.

VMT is a prototypical CSCL environment, with a text-chat tool integrated with a shared whiteboard. Log 21.1 shows a chat excerpt. Three students—whose online names are 137, Qwertyuiop, and Jason—are chatting.

In line 705, student 137 poses a math question of potential interest to the small group. Then Qwertyuiop seeks to understand the math shape that 137 proposed. Qwertyuiop next draws the grid of triangles to see if he understands what 137 means by "hexagonal array."

Jason effectively halts the discussion (line 709) to seek help in seeing the hexagonal form that 137 and Qwertyuiop see. Jason's posting is designed to bring the group work to a halt because he does not see what 137 and Qwertyuiop are talking about. This is an important collaboration move, asking the others to clarify what they are talking about. Jason is referring to the group meaning-making process and halting it so he can fully participate.

Jason phrases his request in terms of "seeing" what the others "mean." This seeing should be taken literally, in terms of vision and graphics. Jason asks the others to "highlight the hexagonal array on the diagram" so he can see it in the graphics.

137 outlines a large hexagon with extra lines, as shown in Fig. 21.2. This provides what Jason needs to be part of the group problem-solving effort. Jason not only says, "okay," but he contributes a next step (line 712) by proposing a math result and giving a visible demonstration of it with a highlighted small hexagon. In giving a next step, Jason shows his understanding and also takes the shared idea further. Jason points from his chat posting. Note the green rectangle highlighting a small hexagon and the line connecting Jason's current chat posting (713) to this highlighted area; this is an important feature of the VMT system supporting online pointing or deixis [see Investigation 22]. Pointing is a critical function for focusing shared understanding and establishing joint attention—and must be supported explicitly in a digital environment, where bodily gestures are not visible to others.

After Jason draws the visual attention of the other participants to a particular example of a smallest hexagon, consisting of six triangles, 137 asks Jason how to change the color of lines in the white-

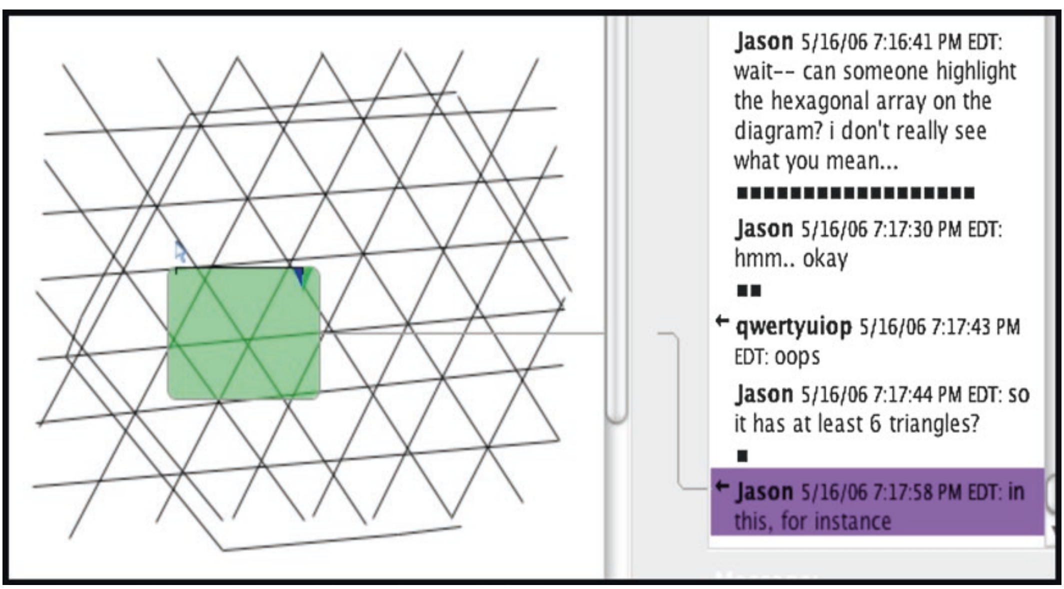

Fig. 21.2 The VMT interface near the middle of the excerpt

board. In line 715, Jason responds, and 137 changes the color of the lines outlining the larger black-and-white hexagon. Color becomes an effective method for orienting the team to a shared object. This use of colored lines to help each other see focal things in the whiteboard will become an important group practice in the team's continuing work. In line 719, 137 outlines a larger hexagon, with edge of three units.

At this point, the group has established an effective *co-presence* at a mathematical object of interest. Through a variety of interactional practices—which the group members have adapted from past experiences or constructed on the spot—the group has regulated its interaction and focused its common vision into a "being-there-together" [see Investigation 17] with the object that they have constituted as a hexagonal array. The group is now in a position to explore this object mathematically.

"Like This": Building Intersubjective Shared Understanding

In line 720, Jason explicitly proposes finding a formula for the number of elemental triangles in a hexagonal array with side-length of N. Qwertyuiop suggests a way of seeing the hexagonal array as consisting of six identical sectors, which he ambiguously refers to as "the six smaller triangles." 137 checks what Qwertyuiop means by asking him, "like this?" and then dividing up the large hexagon with three red lines, forming six triangular forms inside of the blue outline (see Fig. 21.3). This is a move by Qwertyuiop to *see* the representation of their problem as a much simpler problem. As Jason notes, now they only have to compute the number of elemental triangles in one of the six identical triangular sectors and then multiply that result by six to get the total. Furthermore, the simpler problem can be solved immediately by just looking. As Jason says, each sector has 1 + 3 + 5 triangles. The human eye can recognize this at a glance, once it is properly focused on a relevant sector.

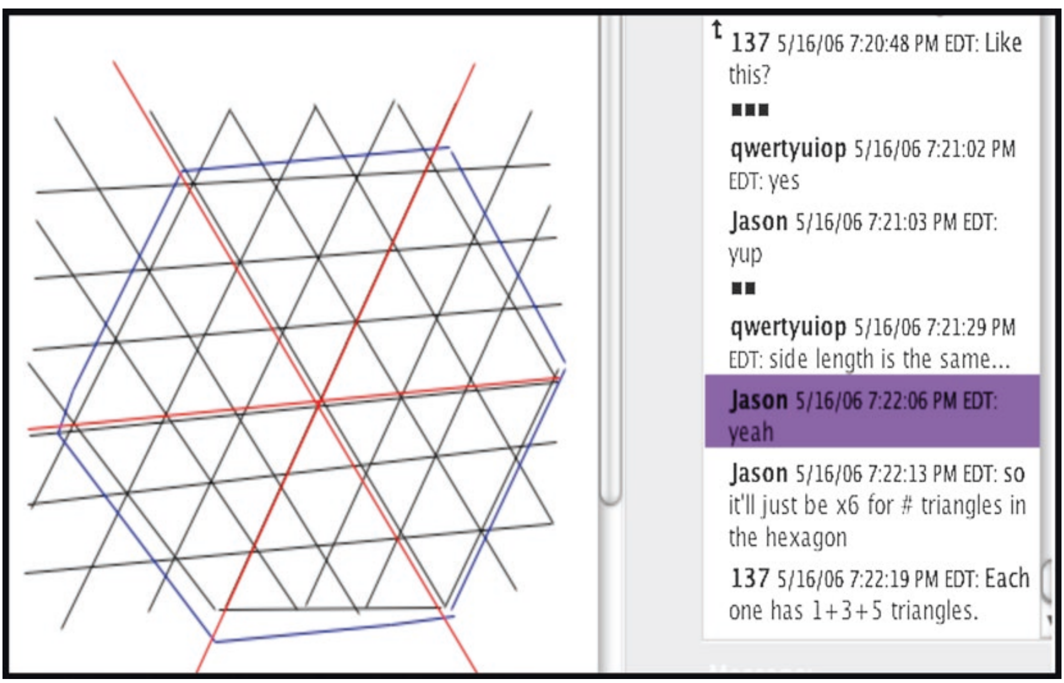

Fig. 21.3 The VMT interface near the end of the excerpt

The important mathematical problem-solving move here is to see the problem in a new way. Qwertyuiop sees the hexagon *as* a set of six symmetrical sectors. The important discourse move is to share this new view with the team. This is accomplished collaboratively in lines 722–725: Qwertyuiop proposes a new way of seeing the array; 137 outlines it, using their new technique of colored lines; and Jason aligns with them. They each participate in seeing the same thing (seeing the hexagon as composed of six triangles), in demonstrating to each other that they see this new way, and then in building on each other to count the small triangles visually. They thereby collectively go beyond the co-presence of seeing the same thing to actually build knowledge about the object. This group knowledge is *intersubjectively shared understanding* of the mathematical structure of the object. Through the sequence of steps outlined above, the members of the group have articulated an understanding that they share as a result of their co-presence and of their shared textual and graphical actions.

"To Get $6n^2$": Accomplishing Group Cognition

Note in the chat how the three students build on each other to construct the general formula for any size array: $6n^2$. Having collaboratively deconstructed the complicated problem into visually simple units, they now take turns in reconstructing the problem symbolically and for any size regular hexagon. They are able to work on this together because of their co-presence, which allows them to orient to the same objects, with a shared understanding of the terms (e.g., "hexagonal array," "side-length"), graphics (colored border lines), procedures (spatially divided into six, then algebraically multiplied by six), and goals ("find a formula").

The group's collaborative learning continues. Having counted the number of triangles in the array during this excerpt, the students next want to count the number of line segments. This is more complicated, but the group extends the methods we have just observed to accomplish their task. Taking advantage of multiple symmetries, they again use colored lines to break the pattern down into visually simple patterns, outline specific focal areas, and attend to shared objects, where their optical systems can do the counting. Some of the smaller units are harder to visualize, and there are issues of possible overlap among the sectors. But using the skills we observed and further developing those skills incrementally, the group succeeds in achieving a continuing sequence of cognitive accomplishments (for a detailed analysis, see Çakir & Stahl, 2013).

Intersubjective Shared Understanding

The establishment of shared understanding in a small group through co-attending to shared objects is essential for collaboration (Evans, Feenstra, Ryon, & McNeill, 2011; Mercer & Wegerif, 1999). However, in an online context, the usual techniques of body positioning, gaze, and explicit pointing with fingers are not available for creating and maintaining shared attention. Virtual teams must invent new methods to coordinate attention or make use of special tools in the software that may be provided to support this.

Previous VMT studies have analyzed cases in which small groups of online students have developed methods for creating, maintaining, and repairing shared understanding—similar to what was seen in the previous section. For instance, small groups working in the VMT environment have:

- Co-experienced a shared world (Stahl, Zhou, Çakir, & Sarmiento-Klapper, 2011) by developing shared group practices (Medina, Suthers, & Vatrapu, 2009; Stahl, 2011b).

- Used the posing of questions to elicit details needed to establish and confirm the sharing of understandings (Zhou, Zemel, & Stahl, 2008).
- Built a "joint problem space" (Teasley & Roschelle, 1993)—i.e., a shared understanding about a set of topics, with ways of referencing them, an "indexical ground" (Hanks, 1992)—that is shared and supports co-attending (Sarmiento & Stahl, 2008).
- Developed group methods for bridging across temporal breaks in interaction to reestablish a group memory or shared understanding of past events (Sarmiento & Stahl, 2007).
- Repaired their shared understanding in the face of breakdowns (Stahl, Zemel, & Koschmann, 2009).
- Integrated text-chat and sequences of whiteboard actions to communicate complex mathematical relationships (Çakir, Zemel, & Stahl, 2009).
- Solved math problems by proceeding through logical sequences of steps collaboratively (Stahl, 2011a).

The analysis of the excerpt of interaction presented above, and these other studies of VMT have identified the following features of the mediation of digital interaction: co-presence, intersubjective shared understanding, and group cognition. We will now review the theoretical articulation of these three features as foundations that make possible the goals of academically productive discourse.

Co-presence

Co-presence—through co-attending as a basis for shared understanding—by a small group includes many of the basic features of an individual attending to and interpreting an object of interest. Attending to something involves focusing on it as the foreground object, assigning everything else to its background context (Polanyi, 1966). For instance, the students in the excerpt above foreground a specific hexagon against the background of the larger array of lines by coloring its outline borders or highlighting its area with the pointing tool. Attending to an object involves seeing it "as" something or some way (Goodwin, 1994; Heidegger, 1927/1996; Wittgenstein, 1953). Co-attending supports a shared interpretation, viewing, or understanding by creating co-presence attending to a shared object in a shared world in a shared way. For instance, the students view the larger hexagon "as" a set of six triangular sectors by visually dividing the hexagon with red lines that outline the sectors and by texting, "it might be easier to see it as the 6 smaller triangles." (Note that the terminology Qwertyuiop naturally uses here explicitly involves "to see it as….")

Intersubjective Shared Understanding

One can distinguish two paradigms of shared understanding. A rationalist paradigm assumes that individuals each have a stock of propositions in their minds that represent their current beliefs or opinions. The corresponding conception of shared understanding starts from individual understanding of two people and tries to establish equivalence of one or more propositions they hold. This is sometimes called "cognitive convergence," where the goal is to converge the two mental models: sharing as mutual individual possession.

The alternative paradigm of shared understanding—exemplified by the analysis in this investigation—starts from the shared world and a view of intentionality as consciousness of an object, rather than as a mental construct by an ego. This is the view of situated and distributed cognition, where individuals are situated in and active with a shared, intersubjective world consisting of meaningful objects for which they care: sharing as doing together.

Twentieth-century philosophy from Hegel (1807/1967) and Husserl (1936/1989) through Marx (1858/1939), Heidegger (1927/1996), Sartre (1968), Merleau-Ponty (1945/2002), and Wittgenstein (1953) has rejected the starting point of a transcendental ego in favor of consciousness as a social and fundamentally shared phenomenon [Investigation 18]. Now, even at the neuron level, the discovery of mirror neurons points to a physiological, specifically human, basis for shared cognition (Gallese & Lakoff, 2005). We can immediately experience the world through the eyes and body of other people. We can feel their pain when we see another person's body hurt. As Wittgenstein (1953) argued in other ways, there is no such thing as private feelings of pain or private meanings of language: we are co-present in an intersubjectively shared and commonly understood world.

Group Cognition

Vygotsky (1930/1978) claimed that intersubjective (group) cognition precedes intra-subjective (individual) cognition. He conducted controlled experiments to show that children were able to accomplish cognitive tasks in collaboration with others at an earlier developmental age than they were able to accomplish the same tasks on their own. Individual-cognitive acts are often preceded by and derivative from group-cognitive acts. For instance, individual reasoning or action (dividing a figure, coloring a border) by a student in the VMT data may be based upon earlier group practices. According to Vygotsky, individual mental thinking is fundamentally silent self-talk. Thus, individual-student reasoning can often be seen as reflective self-talk about what the group accomplished. In such cases, self-reports about individual cognition—through think-aloud protocols, survey answers, or interview responses—are what Suchman (2007) refers to as post hoc rationalizations. They are reinterpretations by the individual (responsive to the interview situation) of group cognitions. In this reading of Vygotsky, group cognition has a theoretical priority over individual cognition. If one accepts this, then the theoretical analysis of shared understanding and the practical promotion of it become priorities. The emerging technologies of networked digital interaction provide promising opportunities for observing and supporting the establishment of shared understanding in online educational environments.

Based on experiments in computer support of small-group knowledge building from 1995 to 2005, Stahl (2006) proposed the construct of *group cognition* to begin to define the relevant focus on group-level cognitive achievements. Analyses of studies from 2006 to 2009 continued to explore the practicalities of supporting group-level cognition in Stahl (2009). From 2010 to 2015, the VMT project focused on sessions of student groups learning collaborative dynamic geometry, resulting in studies of extended interaction in which the teams adopted group practices, reported in Stahl (2013c, 2016).

Group cognition is not a physical thing, a mental state, or a characteristic of all groups. It is a unit of analysis. What it recommends is that analysts who are scientifically studying digital interaction should look at the small-group unit of analysis (Stahl, 2010). Too often, collaborative-learning researchers reduce group-level phenomena either to individual psychological constructs or to societal institutions and societal practices (Stahl, 2013b). However, one can also identify group methods and processes taking place at the small-group unit of analysis that are not reducible to the mental behaviors of an individual or to the institutions of a community.

For instance, the three students working on hexagon patterns collaboratively solved their problem through a sequence of postings that elicit and respond to each other. Qwertyuiop proposed the view of the hexagon as six sectors; 137 summed the series of triangles in one sector to n^2; and Jason provided the answer by multiplying the value for one sector by the number of sectors. The result was a group product of the group interaction. If one student had derived this result, we would call it a cognitive achievement of that student. Since the group derived it, it can be called an achievement of group cognition. This does not mean there is some kind of "group mind" at work or anything other than the interaction of the three students. Rather, it means that the analysis of that cognitive achievement is most appropriately conducted at the group unit of analysis, in terms of the interplay of the posting and drawing actions shared by the group.

The absolute centrality of public discourse and shared understanding to the success of group cognition—successful knowledge building at the group level—in the context of digital interaction implies the need for productive forms of talk within the group. Digital environments to support collaborative knowledge building must be carefully designed to foster co-presence, intersubjective shared understanding, and group cognition through supporting academically productive talk.

Consequences for Computer Support of Discourse

The theory of academically productive discourse—or accountable talk (Michaels et al., 2008)—has been primarily oriented toward affecting individual cognition in contexts of face-to-face instruction. Accordingly, it is based on the paradigm of cognitive convergence, trying to guide individual students to converge their individual understandings with the understandings of other students, the teacher, or the community. In the alternative paradigm presented in this investigation, for group cognition in online contexts, one tries to maintain and build on intersubjective shared understanding and then guide the group of students to articulate clearly, explicitly, and scientifically its largely tacit shared group understanding.

Computer technology suggests many tools for supporting group cognition. Computers can provide computational supports, such as spreadsheets and graphing calculators, for assisting individuals and groups in computing tasks. They can provide digital media for communication (text, audio, video, drawing, mapping, etc.). They can provide domain-specific visualizations and work environments, such as the multiuser dynamic-geometry system that VMT has recently incorporated (Stahl, 2013c; Stahl & Powell, 2012). Perhaps most importantly, computers allow people to interact with others around the world. This suggests the possibility of global collaboration.

A particularly intriguing potential of computer technology is to have software agents that interact directly with groups of people—in analogy with human teachers or tutors who support face-to-face groups. For instance, an accountable-talk agent could interact with students to prompt them to engage in accountable-talk moves. As promising as this sounds, it is equally problematic. Detailed studies of online interaction by small groups of students in the VMT environment show that students are creative at adapting their subtle linguistic skills to the characteristics of online media. They are able to achieve impressive accomplishments of group cognition in exploring mathematical phenomena through dialogic interaction. However, this interaction is fragile and easily disrupted by external interventions of educators and surrogate educators. In particular, software agents—designed to guide groups of students to maintain focus and to engage in productive discourse—can be particularly distracting.

This concluding section of the investigation will address three issues related to the potential of using software agents to promote accountable talk within small online groups of students: invasiveness, automated agency, and over-scripting—which, respectively, threaten to disrupt co-presence, shared understanding, and group cognition.

Invasiveness

We have seen above that a primary cognitive need is to maintain focal attention; for group cognition, this means maintaining shared attention. Software agents and other scaffolds can distract attention from what the group has created as its focus. An automated agent might raise issues at inopportune moments, interrupting the flow of discourse and group problem-solving. We call this possibility "invasiveness."

If software agents are introduced as participants in a group interaction and their status is left ambiguous in order to catch the fancy of students, this will likely raise false expectations. Students may assume that the agent knows answers, has teacher powers, or understands student intentions. The agent can itself become the focus of attention, distracting from both the peer interaction and the problem-solving, as students try to test, fool, or relate to the agent.

Collaboration involves following the lead of the students (individually and as a group); but software agents are not good at understanding student thinking, let alone group cognition. In experiments investigating the use of software agents in the VMT environment to scaffold and guide group cognition, we have seen how problematic accountable-talk agents can be (Stahl, 2013a). Agents were sometimes distracting, confusing, and disruptive. The agents did not always listen well to the students or follow their lead. While some of the problems in our initial experiments with agents were substantially reduced through reprogramming the agents in response to detailed analyses of the results by multiple researchers (Suthers, Lund, Rosé, & Law, 2013), agents may be ultimately incapable of being well "situated" in a group's shared world. Since they are not co-present, attending to the shared object of attention in human ways, but are following generic algorithms designed outside of the current context of interaction, their contributions can disrupt the delicate focus of group co-attention.

Automated Agent

Agents and other automated techniques for guiding student groups to achieve academic goals are often modeled on the role of an excellent teacher. But even trained, experienced teachers find the task of orchestrating student discussion overwhelming. Teachers should ideally anticipate student misconceptions, monitor their ideas, and have them presented to the class in a strategic sequence (Stein, Engle, Smith, & Hughes, 2008). This requires a shared understanding by the teacher of the students' articulations of ideas.

It is unlikely that software agents will soon be able to effectively engage in anticipating, monitoring, selecting, sequencing, and making connections between student responses. It is not just a matter of the high level of sophistication required in understanding the students. In theory, it is questionable whether software agents can ever participate as human peers in small-group interaction. They cannot be situated in the world or understand meaning the ways that humans do—largely based on human bodily presence in the physical world (Lakoff, 1987) and intersubjective experiences (Vygotsky, 1930/1978).

Suchman (2007, p.179) derived "three outstanding problems for the design of interactive machines" in her groundbreaking empirical study of interactions with intelligent help systems in copier machines. These problems centered on the lack of a shared understanding between the machines and the humans. Suchman stressed that the limits of software supports should be made very clear to users, to avoid unrealistic expectations that lead to problems of interaction with the systems. While it is possible to address some of these concerns, it is probably important to make explicit to the users the limits of agents and other software functions. For instance, anthropomorphizing the agent with a human-sounding name and having the agent use colloquial-sounding speech forms may be counterproductive.

Over-Scripting

A danger of automated guidance and scripted support (Kobbe et al., 2007), such as prompts to be answered, is that they miss the engagement of when a listener really wants an explanation. Dillenbourg (2002) noted the problem of scripted agents distracting from the student-centered nature of collaborative learning; they may appear superficially collaborative but may fail to trigger the cognitive, social, and emotional mechanisms that are expected to occur during collaboration. If academic discourse moves are not well situated in student discourse, the effect may be disruptive to authentic group-cognitive processes.

Three implications for research on the computer support of academically productive discourse and for the design of effective supports follow from the discussion in this investigation:

- It is possible to observe and analyze in chat logs how online small groups establish co-presence, maintain intersubjectivity, and accomplish group-cognitive tasks. This can often reveal cognitive processes and the effects on them of different media more clearly than in studies of individuals or face-to-face groups.
- Digital collaboration environments can support co-attention, shared understanding, and group cognition in online modes that are essentially different from situations of physical embodiment. However, this requires careful design of technology, pedagogy, and interventions based on iterative trials.
- Usage analysis is needed to compare the results of different approaches to the use of mechanisms such as software agents or other scaffolding. The results are often unintuitive, since they may differ from analogous effects in the context of individual cognition or face-to-face interaction.

These conclusions tend to support key hypotheses proposed in Investigation 20, motivating the research reported here.

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Investigation 22. Supporting Group Cognition with a Cognitive Tool

Gerry Stahl

Abstract
The Virtual Math Teams project is exploring how to create, structure, support, and assess an online chat-based collaborative community devoted to mathematics discourse. It is analyzing the forms of group cognition that emerge from the use of shared cognitive tools with specific functionalities. Centered on a case study of a synchronous online interchange, this Investigation discusses the use of a graphical referencing tool in coordination with text chat to achieve a group orientation to a particular mathematical object in a shared whiteboard. Deictic referencing is seen to be a critical foundation of intersubjective cognitive processes that index objects of shared attention. The case study suggests that cognitive tools to support group referencing can be important in supporting group alignment, intentionality, and cognition in online communities such as this one for collaborative mathematics.

Keywords
Referencing · Deixis · Cognitive tool · Gesture · Common ground · Boundary objects and intentionality · Group cognition · Collaborative knowledge building · Cognition · Intentionality · Reference · Sense making · Temporality · Learning · Epistemology · Adjacency pair

The Problem of Supporting Group Cognition

Suppose one wanted to establish a collaborative community with a certain focus, say to explore mathematics (e.g., the kind of math taught in school or accessible to interested students). How might one go about doing this? How would one invite people, where would they congregate, how would they communicate, what kinds of social practices would emerge, who would provide leadership, whence would knowledge appear? The obvious approach today is to build an online community of people who

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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want to discuss math. Research in computer-supported collaborative learning and working (CSCL and CSCW) has taught us that this requires a well-integrated infrastructure, not just a simple cognitive tool or a generic communication medium. For instance, the following range of issues would have to be addressed: how should the software environment be designed; what kind of curriculum or domain content should be included; how are working groups to be formed; how will participants be recruited? The design of cognitive tools to support such an online collaborative community would involve many interrelated considerations, most of which are not yet well understood.

Cognitive tools for collaborative communities are essentially different from cognitive tools for individuals. A number of publications detail the following considerations (Dillenbourg & Traum, 2006; Jones, Dirckinck-Holmfeld, & Lindström, 2006; Stahl, 2006a):

1. The use of cognitive tools by a collaborative community takes place through many-to-many interactions among people, not by individuals acting on their own.
2. The cognition that the tools foster is inseparable from the collaborative interaction that they support.
3. The relevant cognition is the "group cognition" that is shared at the small-group unit of analysis; this is a linguistic phenomenon that takes place in discourse, rather than a psychological phenomenon that takes place in an individual's mind.
4. The tools may be more like communication media than like a hand calculator—they do not simply amplify individual cognitive abilities, they make possible specific new forms of group interaction.
5. Rather than being relatively simple physical artifacts, tools for communities may be complex infrastructures.
6. Infrastructures do not have simple, fixed affordances designed by their creators; they are fluid systems that provide opportunities that must be specified by users and enacted by them.
7. The community must interpret the meanings designed into the tools, learn how to use the tools, share this understanding, and form social practices or methods of use.
8. Analyzing the effectiveness of these tools requires a special methodology that can analyze the methods developed by the community for taking advantage of the infrastructure to accomplish its collaborative activities.
9. The community with its tools forms a complex, non-linear system that cannot be modeled through simple causal relationships, because the whole is both over-determined and open-ended; the community is made possible by its infrastructure but also interprets the meaning of its tools and adapts their affordances.

This Investigation tries to respond to these considerations without having the space to present them in depth. It reports on an effort to develop a cognitive tool for an online community of mathematics discourse. Experience—along with the preceding considerations—has shown that the design of software tools for collaborative learning must consider above all else how people will actually use the tool. Therefore, our design effort was structured as a design-based research experiment, in which a relatively simple solution is first tried out in a realistic small-scale setting. The results of actual usage are analyzed to assess what worked and what barriers were encountered. Successive re-design cycles attempt to overcome the barriers that users encountered and to evolve a tool and approach (conceptualizations, theory, methodology) that provide increasingly effective support for a gradually emergent online community. This user-centered approach—applied to a growing community of users rather than to subjects representing an imagined "typical" individual user—focuses on the details of how the community interacts through the tool.

More specifically, we will look at a cognitive tool that was recently added to the infrastructural support for the Math Forum, a community of mathematics teachers and students. The tool allows users to relate work in a text-chat stream with work done in a shared whiteboard drawing area. The tool draws lines from a chat message to other chat messages and/or to areas in the whiteboard. We call this tool a "graphical referencing tool" because it supports the ability of a message to reference an item already existing in the online environment by drawing a line from the message to the graphical item.

After briefly describing our research project and discussing our methodology for analyzing usage, we will present a case study of how students used the cognitive tool for referencing. Close analysis of a brief excerpt from an actual student interaction using the tool will illustrate both how complex the achievement of shared references can be and how crucial referencing can be for the group cognition that takes place. Findings of the case study will then motivate consideration of conceptual issues in understanding referencing: reflections on the epistemology and pedagogy of referencing will provide insight into issues of gesture, common ground, boundary objects, and intentionality in group cognition.

An Experiment in Designing an Online Chat Community

The Virtual Math Teams (VMT) project at the Math Forum is a research project to explore some of the issues posed above. In order to understand the experience of people and groups collaborating online in the VMT service, the researchers in the project look in detail at the interactions as captured in computer logs. In particular, the project studies groups of three to six middle- or high-school students discussing mathematics in chat rooms. The logs that are collected capture what the participants see to a close approximation.

The VMT project was designed to foster, capture, and analyze instances of "group cognition" (Stahl, 2006a). The project is set up so that every aspect of the communication can be automatically captured when student groups are active in the online community, so that the researchers have access to virtually everything that enters into the communication and that is shared by the participants. All interaction takes place online, so that it is unnecessary to videotape and transcribe. Each message is logged with the name of the user posting it and the time of its submission. Similarly, each item placed in the shared whiteboard is tagged with the name of its creator and its creation or modification time. The chat is persistent and the history of the whiteboard can also be scrolled by participants, and later by researchers.

Although many things happen "behind the scenes" during chat sessions—such as the production of the messages, including possible repairs and retractions of message text before a message is sent, or things that the participants do but do not mention in the chat—the researcher sees practically everything that the participants share and all see. While the behavior of a participant may be influenced on an individual basis—such as by interactions with people outside of the chat or by the effects of various social and cultural influences—the researchers can generally infer and understand these influences to the same extent as the other participants (who typically do not know each other outside of the chats). These "external" factors (including the participants' age, gender, ethnicity, culture) only play a role in the group interaction to the extent that they are somehow brought into the discourse or "made relevant" in the chat. In cases where they play a role in the group, then, they are also available to the researchers in the same ways as to the participants.

In particular, the sequentiality of the chat messages and of the actions in the whiteboard are maintained so that researchers can analyze the phenomena that take place at the group level. The other way in which the group interaction may be influenced from outside of activities recorded in the chat room is through general background knowledge shared by the participants, such as classroom culture, pop culture, or linguistic practices. If the participants meet on the Internet and do not all come from the same school and do not share any history from outside of the VMT chats, then researchers are likely to share with the participants most of the background understanding that the participants themselves share.

This is not to say that the researchers have the same experience as the participants, but their resources for understanding the chat are quite similar to the resources that the participants had for understanding and creating the chat, despite the dramatic differences between the participant and researcher perspectives. Participants experience the chat in real time as it unfolds on their screen. They are oriented toward formulating their messages to introduce into the chat with effective timing. Researchers are engaged in analyzing and recreating what happened, rather than participating directly in it. They are oriented toward understanding why the messages were introduced when and how they were. They are behaving under very different motivations, timings, and constraints.

We want to understand how groups construct their shared experience of collaborating online. While answers to many questions in human-computer interaction have been formulated largely in terms of individual psychology, questions of collaborative experience require consideration of the group as the unit of analysis. Naturally, groups include individuals as contributors and interpreters of content, but the group interactions have structures and elements of their own that call for different analytic approaches. In particular, the solving of math problems in the chat environment gets accomplished collaboratively, interactionally. That is, the cognitive work is done by the group.

We call this accomplishment *group cognition*—a form of distributed cognition that may involve advanced levels of cognition like mathematical problem solving, and that is visible in the group discourse where it takes place. It is possible to conduct informative analyses of chats at the group unit of analysis, without asking about the individuals—e.g., their motivations, internal reflections, unexpressed feelings, intelligence, skills, etc.—beyond their participation in the group interaction. Of course, there are also fascinating questions about the interplay between group cognition and individual cognition, but we will not be considering those here.

The VMT project is studying how small groups of students do mathematics collaboratively in online chat environments. We are particularly interested in the new *group methods* that the teams must develop to conduct their interactions in an environment that presents new affordances for interaction. "Member methods" (Garfinkel, 1967) are interactional patterns that participants in a community adopt to structure and give meaning to their activities. A paradigmatic example of member methods is the set of conventions used by speakers in face-to-face conversation to take turns talking (Sacks, Schegloff, & Jefferson, 1974). The use of such methods is generally taken for granted by the community and provides the social order, meaning, and accountability of their activities. Taken together, these member methods define a group culture, a shared set of ways for people interacting to make sense together of their common world. The methods adopted by VMT participants are subtly responsive to the chat medium, the pedagogical setting, the social atmosphere, and the intellectual resources that are available to them. These methods help define the nature of the collaborative experience for the small groups that develop and adopt them. Through the use of these methods, the groups construct their collaborative experience. The chat takes on a flow of interrelated ideas for the group, analogous to an individual's stream of consciousness. The referential structure of this flow provides a basis for the group's experience of intersubjectivity and of a shared world.

As designers of educational chat environments, we are particularly interested in how small groups of students construct their interactions in chat media that have various specific technical features. How do the students learn about the affordances that designers embedded in the environment, and how do they negotiate the methods that they adopt to turn technological possibilities into practical means for mediating their interactions? Ultimately, how can we design with students the technologies, pedagogies, and communities that will result in desirable collaborative experiences for them? Our response to the question of how cognitive tools mediate collaborative communities is to point to the methods that interactive small groups within the community spontaneously co-construct to carry out their activities using the tools.

To explore this complex topic within the confines of this Investigation, we will look at a brief excerpt of one dyad of students within an online small group using the affordances of the technological environment of the VMT project at one point in its development. Specifically, we look at how the students reference a particular math object in the virtual environment. We will see a number of methods—or group practices [Investigation 16]—being used within a 16-line excerpt. We will also mention other methods that we have observed students employing for referencing in similar chat sessions.

Technology for Referencing in a Chat Environment

In our design-based research at the Virtual Math Teams project (Stahl, 2005), we started by conducting chats in a variety of commercially available environments, including AOL Instant Messenger, Babylon, WebCT, and Blackboard. Based on these early investigations, we concluded that we needed to include a shared whiteboard for drawing geometric figures and for persistently displaying notes. We also found a need to minimize "chat confusion" by supporting explicit referencing of response threads (Cakir, Xhafa, Zhou, & Stahl, 2005; Fuks, Pimentel, & de Lucena, 2006). We decided to adopt and adapt ConcertChat, a research chat environment with special referencing tools (Mühlpfordt &

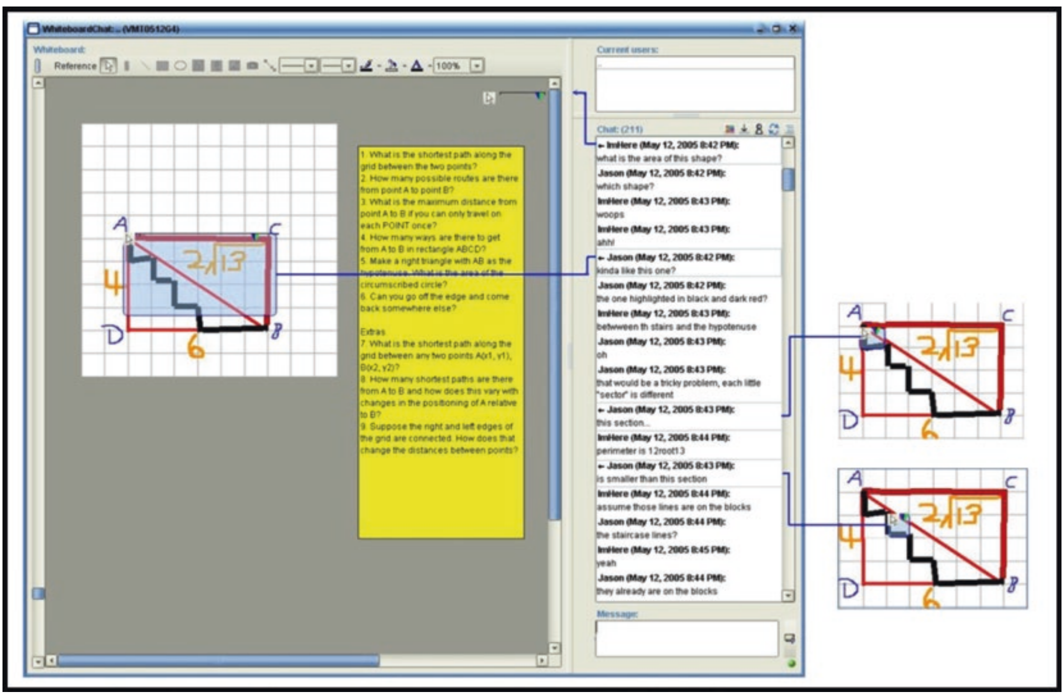

Fig. 22.1 Screen view of ConcertChat with referencing. The image has been modified to show graphical references from chat lines 1, 5, 10, and 12 to the whiteboard. The drawing from the whiteboard has been duplicated in the figure's margin twice to accommodate this. Only the reference from a single selected chat line would actually appear at any given time

Log 22.1 Line numbers have been added and names anonymized. Graphical references to the whiteboard are indicated by "[REF TO WB]"

1.	ImH:	what is the area of this shape? [REF TO WB]
2.	Jas:	which shape?
3.	ImH:	woops
4.	ImH:	ahh!
5.	Jas:	kinda like this one? [REF TO WB]
6.	Jas:	the one highlighted in black and dark red?
7.	ImH:	between th stairs and the hypotenuse
8.	Jas:	oh
9.	Jas:	that would be a tricky problem, each little "sector" is different
10.	Jas:	this section [REF TO WB]]
11.	ImH:	perimeter is 12root3
12.	Jas:	is smaller than this section [REF TO WB]
13.	ImH:	assume those lines are on the blocks
14.	Jas:	the staircase lines?
15.	ImH:	yea
16.	Jas:	they already are on the blocks

Wessner, 2005). By collaborating with ConcertChat's developers, our educational researchers have been able to successively try out versions of the environment (see Fig. 22.1) with groups of students and to gradually modify the environment in response to what we find by analyzing the chat logs.

The ConcertChat environment allows for a variety of referencing methods in math chats:

- *Referencing the whiteboard from a posting*. When someone types a new chat message, they can select and point to a rectangular area in the whiteboard. When that message appears in the chat as the last posting or as a selected posting, a bold line appears connecting the text to the area of the drawing (see Fig. 22.1).
- *Referencing between postings*. A chat message can point to one or more earlier textual postings with a bold connecting line, like whiteboard references. ConcertChat includes a threaded view of the chat postings that, based on the explicit references between postings, displays them like a typical threaded discussion with responses indented under the posting that they reference.
- *Referencing a recent drawing*. The shared whiteboard allows chat participants to create drawings. As new objects are added to the drawing by participants, an implicit form of referencing occurs. Participants typically refer with a deictic term in their textual chat to a new addition to the drawing, whose recent appearance for the group makes it salient.
- *Linguistic referencing*. Of course, one can also make all the usual verbal references to an object on the whiteboard or posting in the chat stream: using deictic terms (*that*, *it*, *his*, *then*); quoting part of an earlier posting; or citing the author of a previous posting.

In May 2005, we conducted a series of chats using ConcertChat (VMT SpringFest 2005). We formed five virtual math teams, each containing about four middle-school students selected by volunteer teachers at different schools across the USA. The teams engaged in online math discussions for 4 h-long sessions over a 2-week period. They were given a brief description of a non-traditional geometry environment: a grid world where one could only move along the lines of a grid (Krause, 1986). The students were encouraged to come up with their own questions about the grid world, such as questions about shortest paths between points A and B in this world (as in Fig. 22.1).

The chats were each facilitated by a member of our research project team. The facilitator welcomed students to the chat, pointed them toward the task, briefly demonstrated the graphical referencing tool, and then kept generally quiet until it was time to end the session. We then analyzed the resultant chat logs in order to draw design implications for revising the tools and the service.

An Analysis of a Case of Referencing

The chat log excerpt visible in Fig. 22.1 is reproduced in Log 22.1 (with line numbers added to enable referencing in this Investigation). In this interactional sequence, two students discuss parts of a drawing that has already been constructed in the shared whiteboard by the larger group to which they belong. The group had created the drawing as part of discussions about shortest paths between points A and B in a grid world. In particular, a red triangle, ABD, was drawn with sides of length 4, 6, and $2\sqrt{13}$. A thick black staircase line was drawn as a path on the grid from A to B. In this excerpt, the students propose a math problem involving this drawing.

The message in line 1 of the chat excerpt (see Log 22.1) makes a bid at proposing a mathematical question for the group to consider: "What is the area of this shape?" This is accompanied by a graphical reference to the whiteboard. The reference does not indicate a specific area—apparently ImH did not completely succeed in properly using this new referencing tool. Line 2 raises the question, "Which shape?" pointing out the incompleteness of the previous message's reference. The proposal bid in line 1 calls for a proposal response, such as an attempt to answer the question. However, the question was incompletely formed because its reference was unclear, so it received a call for clarification as its immediate response. Lines 3 and 4 display a recognition and agreement of the incomplete and problematic character of the referencing.

Lines 5 and 6 offer a repair of line 1's problem. First, line 5 roughs in the area that may have been intended by the incomplete reference. It includes a complete graphical reference that points to a rectangular area that includes most of the upper area of rectangle ACBD in the drawing. The graphical referencing tool only allows the selection of rectangular areas, so line 5 cannot precisely specify a more complicated shape. The text in line 5 ("kinda like this one?") not only acknowledges the approximate nature of its own referencing but also acknowledges that it may not be a proper repair of line 1 (by ending with a question mark) and accordingly requests confirmation from the author of line 1. At the same time, the *like* reflects that this act of referencing is providing a model of what line 1 could have done. Peer instruction in the use of the software is taking place among the students as they share the group's growing understanding of the new chat environment.

Line 5 is accompanied by line 6, which provides a textual reference or specification for the same area that line 5 pointed to: the one highlighted in black (the staircase line) and dark red (lines AC and CB). The inexact nature of the graphical reference required that it be supplemented by this more precise textual reference. Note how the sequence of indexical attempts in lines 1, 2, 5, and 6 successively focuses shared attention on a more and more well-defined geometric object. This is an interactive achievement of the group. The reference was not a simple act of an individual. Rather, it was accomplished through an extended interaction between ImH and Jas, observed by others and situated among the math objects constructed by the whole group of students in the chat room environment.

Lines 5 and 6 were presented as questions calling for confirmation by ImH. Clarification follows in line 7 from ImH: "between the stairs and the hypotenuse." Line 8's "Oh" signals mutual understanding of the evolving reference and the establishment of an agreed upon boundary object (Star, 1989) for carrying on the mathematical investigation incompletely proposed in line 1. Now that the act of referencing has been successfully completed by the group, the group can use the referenced area as a mathematical object whose definition or meaning is intersubjectively understood. Viewed at the individual unit of analysis, the referenced area can serve as a boundary object shared among the interpretive perspectives of the interacting individuals. In other words, it becomes part of the common ground (Clark & Brennan, 1991) shared by the students. The referencing interaction established or grounded this. Note, however, that what took place was not an aligning of pre-existing individual opinions—as the theory of common ground is often taken to imply—but a group process of co-constructing a shared reference through a complex interaction involving many resources and social moves.

Now that a complete reference has been constructed to a math object that is well enough specified for the practical purposes of carrying on the chat, Jas launches into the problem solving by raising an issue that must first be dealt with. Line 9 says that calculating the area now under consideration is tricky. The tricky part is that the area includes certain little "sectors" whose shapes and areas are nonstandard. Line 9 textually references "each little 'sector'." *Little* refers to sub-parts of the target area. *Each* indicates that there are several such sub-parts—and *sector*, put in scare quotes, is proposed as a name/description of these hard-to-refer-to sub-parts.

Clarification of the reference to sectors is continued by lines 10 and 12. These lines compare two sectors, demonstrating that they are different by showing that one is smaller than the other. Lines 10 and 12 reference two different sectors, both with the same textual, deictic description: *this section*. It is possible to use the identical description twice here because the text is accompanied by graphical references that distinguish the two sectors. Line 10 points to the small grid square inside of rectangle ACBD in the upper left-hand corner adjacent to point A. Line 12 points to the next grid down the hypotenuse (see Fig. 22.1).

Because of the limitations of the graphical reference tool, lines 10 and 12 can only indicate the squares of the grid, not the precise odd-shaped sectors that are of concern in the group discourse. On the other hand, the textual clause, *this section* has been given the meaning of the odd-shaped sub-areas of the area "between the stairs and the hypotenuse," although it cannot differentiate easily among the different sections. The carefully constructed combination of graphical and textual referencing accomplished in lines 10 and 12 was needed to reference the precise geometric objects. The combination of the two textual lines, with their two contrasting graphical references, joined into one split sentence was necessary to contrast the two sectors and to make visible the tricky circumstance. In this way, the discourse succeeded in constituting the complicated geometric sectors despite the limitations of the tool on its own and of textual description by itself.

Line 13 responds to the tricky issue by treating it as a non-essential consequence of inaccurate drawing. By proposing that the group "assume those lines are on the blocks," this posting treats the difference among the sectors as due to the inaccuracy of the drawing of the thick black staircase line in not precisely following the grid lines. Physical drawings are necessarily rough approximations to idealized mathematical objects in geometry. Lines drawn with a mouse on a computer screen tend to be particularly rough representations. The implication of line 13 is that the tricky issue is due to the inaccurate appearance of the lines but that the faults of the physical drawing do not carry mathematical weight and can be stipulated away. However, line 14 questions this move. It first makes sure that line 13's reference to *those lines* was a reference to *the staircase lines* that form part of the perimeter of the target area and of its different-sized sectors. When line 15 confirms that line 13 indeed referenced the staircase lines, line 16 responds that "they already are on the blocks"—in other words, the tricky situation was not due to inaccuracies in the drawing but the staircase lines were indeed already *taken as* following the grid for all practical purposes. The problem was still seen to be a tricky one once the mathematical object was clearly referenced and specified.

We see here that referencing can be a complex process in online mathematical discourse. In a face-to-face setting, the participants could have pointed to details of the drawing, could have gesturally described shapes, and could have traced outlines or shaded in areas either graphically or through gestures with ease. Conversationally, they could have interrupted each other to reach faster mutual orientation and understanding. Online, the interaction is more tightly constrained and burdensome due to the restricted nature of the affordances of the software environment. On the other hand, we have seen that middle-school students who are new to the graphical tools of ConcertChat, as well as to online collaborative mathematics, can call upon familiar resources of textual language, drawing, pointing, and school mathematics to construct interaction methods that are seen to be amazingly sophisticated, efficient, creative, and effective when analyzed in some detail.

Methods of Making Referential Sense

We have here only been able to look at what took place in a single effort to reference a mathematical object. In the series of chats that this effort was taken from, we observed groups of students engaging in a variety of other referencing methods within this version of ConcertChat. (For additional uses of the referencing tool, see Mühlpfordt & Wessner, 2005). Common methods used by groups in our chats included the following:

- Graphical references to previous messages were sometimes used to make salient a message from relatively far back in the chat. Without the graphical referencing functionality, this would have required a lengthy textual explanation justifying change of topic and quoting or describing the previous message.
- Some students used graphical references to previous messages to specify a recipient for their new posting. If a student wanted to address a question to a particular student rather than to the group as a whole, he or she would accompany the question with a graphical reference to a recent posting by that student. (This was a use of graphical referencing not at all anticipated by the ConcertChat software tool designers or VMT researchers.)
- It is common in chat for someone to spread a single contribution over two or more postings (e.g., lines 10 and 12). In conversation, people often retain their turn at talk by indicating that they are not finished in various ways, such as saying "ummm." In generic chat systems, people often end the first part of their contribution with an ellipsis (…) to indicate that they will continue in a next posting. In ConcertChat, students sometimes graphically referenced their first posting while typing their second. Then the two parts would still be tied together even if someone else's posting (like line 11) appeared in the meantime.
- Similarly, students graphically referenced their own previous posting when repairing a mistake made in it. The reference indicates that the new posting is to replace the flawed one.
- In chat, where the flow of topics is not as constrained as in conversation, it is possible for multiple threads of discussion to be interwoven. For instance, line 11 starts to discuss perimeter, while area is still being discussed. Graphical references are used to tie together contributions to the same thread. For instance, line 12 might have referenced line 10 graphically.
- The graphical referencing tool is treated as one of many available referencing resources. Deictic terms are frequently used—sometimes in conjunction with graphical referencing (e.g., line 5).
- In textual chat, as in spoken conversation, sequential proximity is a primary connection. By default, a posting is a response to the immediately preceding post. Chat confusion arises because sequentiality is unpredictable in chat; people generally respond to the most recent posting that they see when they start to type, but by the time their response is posted other postings may intervene. Interestingly, the recency of drawings may function as a similar default reference. Students frequently refer to a line that was just added to the whiteboard as *that line* without needing to create a graphical reference to it.

- Of course, purely textual references are also widely used to point to postings, people, groups, drawings, abstractions, and math objects.

The many forms of referencing in chat tie together the verbal and graphical contributions of individual participants into a tightly woven network of shared meaning. Each posting is connected in multiple ways—explicit and implicit—to the flow of the shared chat (Stahl, 2005). The connections are highly directional, granting a strong temporality to the chat experience (hard to fully appreciate from a static log).

The being-there-together in a chat is temporally structured as a world of future possible activities with shared meaningful objects. The possibilities for collaborative action are made available by the social, pedagogical, and technical context (world, situation, activity structure, network of relevant significance) (Heidegger, 1927/1996, §18). While the shared context is opened up, enacted, and made salient by the group in its chat, aspects of the discourse context appear as designed, established, or institutionalized in advance. They confront the participants as a world filled with meanings, priorities, resources, and possibilities for action. An online environment is a world whose features, meanings, and co-inhabitants are initially largely unknown.

We are interested in providing cognitive tools to help groups of students navigate worlds of online collaborative mathematical discourse. We want to support their efforts to build collaborative knowledge. Since the Greeks and especially following Descartes, the issue of how people can know has been called "epistemology." We have seen in our case study that methods of referencing can play an important role in grounding the construction of shared knowledge in an environment like VMT. Conceptually, referencing can be seen as a key to the question of how groups can construct collaborative knowledge and how they can know.

Epistemology of Referencing

Referencing is a primary means for humans to establish joint attention and to make shared meaning within a (physical or virtual) world in which they find themselves together. Vygotsky, in a particularly rich passage, described the interactional origin of pointing as an example of how gestures become meaningful artifacts for individual minds through social interaction:

> A good example of this process may be found in the development of pointing. Initially [e.g., for an infant], this gesture is nothing more than an unsuccessful attempt to grasp something, a movement aimed at a certain object which designates forthcoming activity…. When the mother comes to the child's aid and realizes this movement indicates something, the situation changes fundamentally. Pointing becomes a gesture for others. The child's unsuccessful attempt engenders a reaction not from the object he seeks but from another person. Consequently, *the primary meaning* of that unsuccessful grasping movement *is established by others*…. The grasping movement changes to the act of pointing. As a result of this change, the movement itself is then physically simplified, and what results is the form of pointing that we may call a true gesture. (Vygotsky, 1930/1978, p. 56, italics added)

The pointing gesture is perhaps the most fundamental form of deictic referencing. In its origin where the infant begins to be socialized into a shared world, the meaning of the gesture emerges interactionally as the participants orient to the same object and recognize that they are doing so jointly. This fundamental act of collaborative existence simultaneously comes to be symbolized for them by the pointing gesture, which is practiced, repeated, and abstracted by them together over time and thereby established as meaningful. The mother and infant become an organic small group, caring for shared objects by being-in-the-world-together and understanding as collaborative practice the symbolic meaning of the physical gesture as a referencing artifact.

In grasping, the infant's being-in-the-world is intentionally directed at the object; the existence of the pointing infant is a being-at-the-object (Husserl, 1929/1960). When the mother joins the infant by transforming his individual grasp into a joint engagement with the object, the intentionality of the infant's grasp becomes intersubjective intentionality, constituting the infant and mother as being-there-together-at-the-object (Heidegger, 1927/1996, §26). For Husserl, consciousness is always consciousness-of-something. Human consciousness is intentional in the sense that the conscious subject intends an object, so that the subject as consciousness is at the object (i.e., not "in the head"). Heidegger transformed this idealist conception into an embedded analysis of human being-there as being involved in the world. Heidegger's analysis builds up to the brink of a foundational social philosophy of being-there-together but then retreats to an individualistic concern with the authentic self (Nancy, 2000; Stahl, 1975). Vygotsky points the way to a fully social foundation, interpreting Marx' social *praxis* in social-psychological terms, such as in the intersubjective interaction of the infant-mother bonding.

Epistemology as a philosophic matter is a consequence of the Platonic and Cartesian separation of mind and meaning from the physical existence of objects in the world. The "problem of epistemology" is the question of how the mind can know facts—how one can bridge the absolute gulf that Plato (340 BCE/1941) and Descartes (1633) drew between the mental realm of ideas and the physical world of matter.

Vygotsky's social philosophy overcomes this problem by showing how interactions among people achieve shared involvement in the world. In Descartes' system, there was no way to put together the mother's understanding, the infant's understanding, the physical grasp, and the symbolic meaning of pointing. In Vygotsky's analysis, the interaction between mother and infant creates the shared meaningfulness of the pointing grasp as an intersubjectively achieved unity. There is no longer any reason to ask such questions as: where is the meaning of the gesture, how does the mother know the infant's intention, or whether there is common ground. These are pseudo-problems caused by trying to reduce a social phenomenon at the group unit of analysis to issues at an individual unit of analysis.

These philosophical issues are intimately related to issues of empirical methodology. They imply that certain matters should be analyzed as group phenomena and not reduced to individual psychic acts or mental representations.

As researchers, we can empirically observe new referencing gestures being created within interactions among collaborating people, particularly when their interaction is taking place via a new medium that they must learn how to use. In the analysis above, a chat posting—"What is the area of this shape?"—constitutes the participants in the chat as a group by designating them as the intended collective recipient and as the expected respondent to the question (Lerner, 1993). The group is the intended agent who will work out the mathematics of the proposal to compute the area. Simultaneously, by referencing a mathematical object ("this shape"), the posting constitutes the group as a being-there-together-at-the-object—at an object that is constituted, identified, referenced, and made meaningful by the group interaction.

We saw how both these aspects of being a group and maintaining the group's joint attention necessitated considerable interactional work by the participants. Before the elicited answer about area could be given in response to the question, the group had to negotiate what it as a group took the object to be. Also, it required a number of actions for group participants to co-construct the shared object and their being-there-together-at-the-object. In attempting to do this, they constituted themselves as a group, and they established referential gestures and terms that took on the shared meaning of intending the new math object.

The interactional work of the group involved making use of the resources of the environment that mediated their interaction. This is particularly noticeable in online interaction. Vygotsky's infant and mother could use fingers, gaze, touch, and voice. Online participants are restricted to exchanging textual postings and to using features of the mediating software (Garcia & Jacobs, 1999; Stahl, 2006b). The chat participants must explicitly formulate through text, drawings, or graphical references actions that can be observed by their fellow group members. These actions are also available to researchers retroactively.

The textual interactions in the chat excerpt as the cognitive actions of the group are in intimate contact with the details of the drawing as the physical intentional object. For instance, as we saw above, in the interchange in lines 13–16, the group attention is focused on a particularly interesting and ambiguous drawn line. Group methods of proceeding often involve *adjacency pairs*, sequences of utterances by different people that construct group meaning and social order through their paired unity. The meaning is constituted at the group unit of analysis by means of the interaction of the pair of utterances, not as a presumed pre-interactional meaning in the heads of individuals.

Line 13 is a bid at opening up a math proposal adjacency pair (Stahl, 2006b) [Investigation 25]: it offers a new step for mathematical discussion and elicits an uptake response from the rest of the group. Line 16 is the elicited response that takes up the bid with a kind of repair. It indicates that the proposed assumption is unnecessary and thereby attempts to re-establish a shared understanding of the situation. Lines 14 and 15 form a question/answer adjacency pair inserted in the middle of the proposal pair in order to make sure that the group really is together at the same detail of their shared math object.

The issue that is worked out by the group as it looks carefully at the drawing together illustrates the subtlety of abstract mathematical thinking that the group is engaged in as a group. The issue involves the lines that were drawn with the whiteboard's rough cognitive tools for drawing and whether or not these lines coincide with lines of the grid (i.e., if the group should "assume those lines are on the blocks"). The issue is not one that is resolved by a close analysis of the actual pixels on the screen. Rather, it is a conceptual question of the meaning of those lines for the group: What do they mean in the drawing and how should they be taken by the group in its math discourse?

In being together at the lines, the group makes sense of the meaning of the lines. There is no separation of fact and meaning here—or, if there is, the group interaction engages in meaning-making processes that fluidly overcome such a gulf. This is particularly important in math discourse, where rough sketches are used to represent (mean and reference) abstract objects. Maintaining a shared understanding by a group of students working in a mathematical context like this is a subtle and intricate matter.

As designers of online education, we are interested in understanding how students collaboratively create new communicative gestures or interactional methods, including ways of referencing objects for joint consideration. More generally, an interactional understanding of referencing and meaning-making leads to a theory of group cognition—rather than individual cognition based on mental representations—as a basis for studying collaborative learning (Stahl, 2006a).

All the technical terms like *cognition*, *intentionality*, *reference*, *sense making*, *temporality*, and *learning* needed to articulate a theory of group cognition must be re-conceptualized at the group unit of analysis. In some cases, the nature of these phenomena are actually easier to see at the group level, where participants have to make things visible to each other in order to coordinate their actions as group activities, as was the case with referencing in the excerpt discussed above.

Pedagogy of Referencing Math Objects

Our case study suggests that cognitive tools for referencing can be important supports for group cognition and collaborative knowledge building, particularly in a setting of computer-supported collaborative mathematics.

In the investigation reported here, we tried to encourage relatively open-ended explorations of mathematical inquiry by online teams of math students. We presented them with a non-traditional form of geometry in which notions like distance, area, or shortest-path have to be renegotiated—i.e., the meanings of these terms must be jointly constructed anew. While trains of inquiry can go in many directions, in a collaborative effort, each step of the path may be clarified and shared. New math objects emerge and develop out of the discourse, including both geometric figures (the tricky area) and terminology ("distance along the grid").

In this Investigation, the analysis of a snippet of a group-cognitive process in a concrete empirical case has suggested the centrality of joint referencing to collaboration. This may serve as an additional clarification of what is meant by defining collaboration as "a continued attempt to construct and maintain a shared conception of a problem … an emergent, socially-negotiated set of knowledge elements that constitute a Joint Problem Space" (Roschelle & Teasley, 1995, p. 70) and what goes into actually doing such a thing.

The persistent whiteboard serves as a "group external memory" that plays a useful role in grounding shared understanding at the scale of analysis of CSCL problem solving (Dillenbourg & Traum, 2006, p. 122f). The view of the whiteboard as the group's evolving joint problem space contrasts with Clark and Brennan's (1991) psycholinguistic version of common ground as located in individual minds. The intertwining uses of the dual workspaces of whiteboard and chat mirror the intertwining of content space and problem space that is characteristic of collaborative learning (Barron, 2003, p. 310).

Given the complexity resulting from dual spaces—whether split for work vs. reflection (Fischer, Nakakoji, Ostwald, Stahl, & Sumner, 1998; Schön, 1983) or transitory vs. persistent (Dillenbourg & Traum, 2006, p. 143f)—and the concomitant substantially increased burden of coordination within the group, we can clearly see the importance of cognitive tool support for referencing from one space to the other, e.g., from text chat to graphical workspace.

Referencing in mathematical worlds has its own domain-specific characteristics and priorities. Widespread conceptions of math learning as the memorization of "math facts" or the mastery of formulaic algorithmic solutions are oriented to the routine application of arithmetic rather than to the creative process that inspires mathematicians. The history of mathematics as a branch of scientific inquiry and knowledge building is a systematic unfolding of new domains through the shared construction of new math objects, like complex numbers, fractals, and curved spaces. To share these created math objects as boundary objects within their discourse community, mathematicians have had to define new vocabularies, symbols, and representations for referencing objects that do not exist as such in the physical world. Referencing such abstractions presents special cognitive challenges.

People who do not understand mathematical references can scarcely be expected to share the wonder and excitement that mathematicians feel who can see what is being referenced (Lakoff & Núñez, 2000). It is likely that much of the general population simply does not share the understanding of what is referenced in most mathematical proofs and discussions. Since our goal is to increase mathematical appreciation and participation through opportunities for online math discourse, we are keen to support shared referencing in our environments with effective cognitive tools.

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Investigation 23. Sustaining Interaction in a CSCL Environment

Gerry Stahl

Abstract

Learning takes place over long periods of time that are hard to study directly. Even the learning experience involved in solving a single challenging math problem in a collaborative online setting can be spread across hundreds of brief postings during an hour or more. Such long-term interactions are constructed out of posting-level interactions, such as the strategic proposing of a next step. This investigation identifies a pattern of exchange of postings that it terms *math-proposal adjacency pair* and describes its characteristics. Drawing on the methodology of conversation analysis, the investigation adapts this approach to examining mathematical problem-solving communication and to the computer-mediated circumstances of online chat. Math proposals and other interaction methods constitute the collaborative group as a working group, give direction to its problem solving, and help to sustain its intersubjective meaning making or group cognition. Groups sustain their online social and intellectual work by building up longer sequences of math proposals, other adjacency pairs, and a variety of interaction methods. Experiences of collaboration and products of group cognition emerge over time.

Keywords

Longer sequences · Math-proposal adjacency pair · Failed proposal · Design-based research · Sustaining interaction

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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Sustaining Interaction in a CSCL Environment

Research in learning has traditionally focused on psychological processes at the individual unit of analysis. With the shift to sociocultural approaches in recent years, the community unit of analysis came to the fore. In my writings on group cognition, I identified small groups as defining a middle ground between individual people and communities of practice:

> Small groups are the engines of knowledge building. The knowing that groups build up in manifold forms is what becomes internalized by their members as individual learning and externalized in their communities as certifiable knowledge. At least, that is a central premise of this book. (Stahl, 2006b, p. 16)

The concept of group cognition, however, retains a certain ambiguity of scale. On the micro level, it is based on the discovery by conversation analysis that a smallest element of interaction in discourse is the adjacency pair, a product of interaction within a dyad or small group, and not an expression of one or more individuals' cognition (Duranti, 1998; Schegloff, 1991). On the macro level, it is a vision of collaborative knowledge building, where knowledge arises through community, interpersonal or social interaction (Scardamalia & Bereiter, 1996; Vygotsky, 1930/1978; Lave & Wenger, 1991, respectively). Taking one approach or the other, we can analyze how participants in a small group of students build a detailed point of shared knowledge, how they develop their mediated cognition, or how they apprentice participation in the community of math discourse. The question remains: how can we understand not just the results, but also what happens in the group at the interesting meso level of the small group itself during a 1-hour math chat consisting of many detailed interactions but perhaps not measurably increasing the group's knowledge, skills, or community participation?

This investigation tries to address the gap in the methodology of the learning sciences in a preliminary way. It begins with a detailed analysis of a particular interaction that actually occurred in a student chat. It then gradually broadens the discussion of online math chat sessions, discussing various aspects of how the elemental adjacency pairs in such a momentary interaction contribute to a sustained group experience over a somewhat longer period of time. The presentation proceeds through these steps:

- The setting of online math chats, which provide the experimental context for our observations, is first motivated and described.
- The concept of adjacency pairs from conversation analysis is adapted to the situation of online math chats and is particularized as "math-proposal adjacency pairs."
- A specific adjacency pair is analyzed as a "failed proposal," which by contrast sheds light on the nature of successful proposals.
- We then describe our design-based research approach in which we revise our software and pedagogy in response to issues observed during a sequence of evolving trials.
- Next, we look at a more extended interaction that occurred in our revised chat environment, involving methods of computer-supported deictic referencing that build from adjacency pairs to longer sequences of cognitive work.
- To extrapolate beyond one or two detailed interactions and analyze more extended sessions with some generality would require volumes of exposition. We therefore rely on our other studies and our general impressions from observing and participating in many online math chats and from related work by others to discuss a number of relevant aspects of sustained group cognition.
- We conclude with reflections on how groups construct and sustain their ongoing sense of shared experience. This points to future work.

Doing Mathematics Together Online

Technology-enhanced learning offers many opportunities for innovation in education. One of the major avenues is by supporting the building of collaborative meaning and knowledge (Stahl, 2006b). For instance, it is now possible for students around the world to work together on challenging math problems. Through online discussion, they can share problem-solving experiences and gain fluency in communicating mathematically. Research on mathematics education stresses the importance of student discourse about math (NCTM, 2000; Sfard, 2002), something that many students do not have opportunities to practice face-to-face.

While much research on computer-supported collaborative learning (CSCL) has analyzed the use of asynchronous threaded discussion forums, there has been relatively little research on the use of synchronous chat environments in education. The research reported here suggests that chat has great promise as a medium for collaborative learning if the medium and its use are carefully configured. Here, we investigate how math discourse takes place within the chat medium and how we use our analyses to inform the design of effective math chat environments.

In the beginning of the Virtual Math Teams (VMT) research project at the Math Forum, we invited middle-school students to participate in online chats about interesting problems in beginning algebra and geometry. The following math problem, discussed in the chat excerpt analyzed below, is typical:

> If two equilateral triangles have edge-lengths of 9 cubits and 12 cubits, what is the edge-length of the equilateral triangle whose area is equal to the sum of the areas of the other two?

We rely on a variety of approaches from the learning sciences to guide our research and to analyze the results of our trials, including coding along multiple dimensions (Strijbos & Stahl, 2005), analysis of threading (Cakir, Xhafa, Zhou, & Stahl, 2005), and ethnography (Shumar, 2006). In particular, we have developed an ethnomethodologically informed (Garfinkel, 1967; Heritage, 1984) chat analysis approach based on conversation analysis (Pomerantz & Fehr, 1991; Psathas, 1995; Sacks, 1992; Sacks, Schegloff, & Jefferson, 1974; ten Have, 1999) to understand the structure of interactions that take place in student chats. In this paper, we adapt a finding of conversation analysis to math chats and analyze a specific form of adjacency pairs that seem to be important for this context. Before presenting these findings, it may be useful to describe briefly how the notion of adjacency pairs differs from naïve conceptions of conversation.

There is a widespread common sense or folk theory (Bereiter, 2002; Dennett, 1991) view of conversation as the exchange or transmission of propositions. This view was refined and formalized by logicians and cognitive scientists as involving verbal “expression” in meaningful statements by individuals, based on their internal mental representations (Shannon & Weaver, 1949). Speech served to transfer meanings from the mind of a speaker to the mind of a listener, who then interpreted the expressed message. Following Wittgenstein (1953) in critiquing this view, speech act theory (Austin, 1952; Searle, 1969) argued that the utterances spoken by individuals were ways of acting in the world and were meaningful in terms of what they accomplished through their use and effects. Of course, the expression, transmission, and interpretation of meaning by individuals can be problematic, and people frequently have to do some interactional work in order to re-establish a shared understanding. The construction of common ground has been seen as the attempt to coordinate agreement between individual understandings (Clark & Brennan, 1991).

Conversation analysis takes a different view of conversation. It looks at how interactional mechanisms, like the use of adjacency pairs, co-construct intersubjectivity.

Adjacency pairs are common sequences of utterances by different people—such as mutual greetings or question/answer interchanges—that form a meaningful speech act spanning multiple utterances, which cannot be attributed to an individual or to the expression of already formed mental states. They achieve meaning in their very interaction.

We are interested in what kinds of adjacency pairs are typical for math chats. The topic of adjacency pairs is taken up extensively in two sections below. Stahl (2006b) further discusses the implications that viewing adjacency pairs as the smallest elements of interactional meaning making has for the intersubjective foundation of group cognition, a process of jointly constructing meaning in discourse.

The medium of online chat has its own peculiarities (Lonchamp, 2006; Mühlpfordt & Wessner, 2005; O'Neill & Martin, 2003). Most importantly, it is a text-based medium, where interaction takes place by the sequential response of brief texts to each other (Livingston, 1995; Zemel, 2005). As a quasi-synchronous medium (Garcia & Jacobs, 1999), chat causes confusion because several people can be typing at once, and their texts can appear in an order that obscures to whom or to what they are responding. Furthermore, under time pressure to submit their texts so that they will appear near the post to which they are responding, some chat participants break their messages into several short texts. Because of these peculiarities of chat, it is necessary for researchers to carefully reconstruct the implicit threading of texts that respond to each other before attempting to interpret the flow of interaction (Cakir et al., 2005; Strijbos & Stahl, 2005).

Math chats differ from ordinary informal conversation in a number of additional ways. They are focused on the task of solving a specific problem, and they take place within a somewhat formal institutional setting. They involve the *doing* of mathematics (Livingston, 1986). And, of course, they are computer-mediated rather than face-to-face. The approach of conversation analysis is based on ethnomethodology (Garfinkel, 1967), which involves the study of the *methods* that people use to accomplish what they are doing. So, we are interested in working out the methods that are used by students in online math chats. In this paper, we discuss a particular method of collaboration in math chats that we have elsewhere called *exploratory participation*: participants engage each other in the conjoint discovery and production of both the problem and possible solutions (Wegerif, 2006; Zemel, Xhafa, & Stahl, 2005).

Math-Proposal Adjacency Pairs

In order to begin to analyze the methods that students use in math chats, we take a close look at an excerpt from an actual chat. Log 23.1 shows an excerpt from near the beginning of the log of one of our first online collaborative math problem-solving sessions. Three students—named Avr, Sup, and Pin—have just entered the chat room, said hello to each other, and read the problem involving three triangles.

Log 23.1. Excerpt of 3½ min from a One-Hour Chat Log. Three Students Chat About a Geometry Problem. Line Numbers have been Added and Screen-Names Anonymized; Otherwise the Transcript is Identical to What the Participants Saw on their Screens

```
1. Avr (8:21:46 PM): Okay, I think we should start with the formula for the area
of a triangle
2. Sup (8:22:17 PM): ok
3. Avr (8:22:28 PM): A = 1/2bh
4. Avr (8:22:31 PM): I believe
5. pin (8:22:35 PM): yes
6. pin (8:22:37 PM): i concue
7. pin (8:22:39 PM): concur*
```

```
8. Avr (8:22:42 PM): then find the area of each triangle
9. Avr (8:22:54 PM): oh, wait
10. Sup (8:23:03 PM): the base and heigth are 9 and 12 right?
11. Avr (8:23:11 PM): no
12. Sup (8:23:16 PM): o
13. Avr (8:23:16 PM): that's two separate triangles
14. Sup (8:23:19 PM): ooo
15. Sup (8:23:20 PM): ok
16. Avr (8:23:21 PM): right
17. Avr (8:23:27 PM): i think we have to figure out the height by ourselves
18. Avr (8:23:29 PM): if possible
19. pin (8:24:05 PM): i know how
20. pin (8:24:09 PM): draw the altitude'
21. Avr (8:24:09 PM): how?
22. Avr (8:24:15 PM): right
23. Sup (8:24:19 PM): proportions?
24. Avr (8:24:19 PM): this is frustrating
25. Avr (8:24:22 PM): I don't have enough paper
26. pin (8:24:43 PM): i think i got it
27. pin (8:24:54 PM): its a 30/60/90 triangle
28. Avr (8:25:06 PM): I see
29. pin (8:25:12 PM): so whats the formula
```

The first thing to notice here is a pattern of proposals, discussions, and acceptances similar to what takes place in face-to-face discourse. Bids for proposals about steps in solving the math problem are made by Avr in lines 1, 3, 8, and 17 and by Pin in lines 20 and 27. These proposals are each affirmed by someone else in lines 2, 6, 10, 19, 22, and 28, respectively.

To avoid chat confusion, note that line 21 responds to line 19, while line 22 responds to line 20. The timestamps show that lines 20 and 21 effectively overlapped each other chronologically: Avr was typing line 21 before he/she saw line 20. Similarly, lines 24 and the following were responses to line 20, not line 23. We will correct for these confusions later, in Log 23.2, which reproduces a key passage in this excerpt.

In Log 23.1, we see several examples of a three-step pattern:

(a) A proposal bid is made by an individual for the group to work on: "`I think we should`…"
(b) A proposal acceptance is made on behalf of the group: "`Ok`," "`right.`"
(c) There is an elaboration of the proposal by members of the group. The proposed work is begun, often with a secondary proposal for the first sub-step.

The three-step pattern consists of a pair of postings—a bid and an acceptance—that form a proposal about math and some follow-up effort. This suggests that collaborative problem-solving of mathematics may often involve a particular form of adjacency pair. We will call this a *math-proposal adjacency pair*.

Here are six successful math-proposal adjacency pairs from Log 23.1:

```
1. Avr: Okay, I think we should start with the formula for the area of a triangle
2. Sup: ok
3. Avr: A = 1/2bh
6. pin: i concue
8. Avr: then find the area of each triangle
```

```
10. Sup: the base and heigth are 9 and 12 right?
17. Avr: i think we have to figure out the height by ourselves
19. pin: i know how
20. pin: draw the altitude'
22. Avr: right
27. pin: its a 30/60/90 triangle
28. Avr: I see
```

Note from the line numbers that the response is not always literally immediately adjacent to the bid in the chat log due to the complexities of chat posting. But the response is logically adjacent as an uptake of the bid.

Many varieties of adjacency pairs allow for the insertion of other pairs between the two parts of the original pair, delaying completion of the original pair. For instance, a question/answer pair may be delayed by utterances seeking clarification of the question. As we will see below, the clarification interaction may itself consist of question/answer pairs, possibly with their own clarifications—this may continue recursively. With math-proposal adjacency pairs, the subsidiary pairs seem to come after the completion of the original pair, in the form of secondary proposals, questions, or explanations that start to do the work that was proposed in the original pair. This characteristic leads to their role in sustaining group inquiry.

Math proposals tend to lead to some kind of further mathematical work as a response to carrying out what the proposal. Often—as seen in the current example—that work consists of making further proposals. In this way, the three-step structure of the math-proposal adjacency pair starts to sustain the group interaction. The proposal bid by one person calls forth a proposal response by someone else. If the response is one of acceptance, it in turn calls forth some further work to be done or a bid for another proposal. If the response is a rejection, it may lead to justification, discussion, and negotiation. Since the "preferred" response to a proposal is a statement of acceptance, a response of rejection tends to require some further work.

It is striking that the work proposed by a proposal is not begun until there is agreement with the proposal bid. This may represent consent by the group as a whole to pursue the proposed line of work. Of course, this idea is not so clear in the current example, where there are only three participants and the interaction often seems to take place primarily between pairs of participants. As confirmed by other chat examples, however, the proposal generally seems to be addressed to the whole group and opens the floor for other participants to respond. The use of "`we`" in "`we should`" or "`we have to`" (stated or implied) constitutes the multiple participants as a plural subject—an effective unified group (Lerner, 1993).[1] Anyone other than the proposer may respond on behalf of the group. The fact that the multiple participants are posited as a group for certain purposes, like responding to a proposal bid, by no means rules out their individual participation in the group interaction from their personal perspectives, or even their independent follow-up work on the math. It simply means that the individual who responds to the bid may be doing so on behalf of the group.

Moreover, there seems to be what in conversation analysis is called an interactional *preference* (Schegloff, Jefferson, & Sacks, 1977) for acceptance of the proposal. That is, if one accepts a proposal, it suffices to briefly indicate agreement: "ok." If one wants to reject a proposal, however, then one has to account for this response by giving reasons. If the group accepts the bid, one person's

[1] The fact that the students use "we" indicates that they are taking the set of participants to be a functional group. From an ethnomethodological perspective, this justifies the analysis of the chat as a group product since the participants themselves adopt this stance.

response may serve on behalf of the group; if the group rejects the bid, several people may have to get involved.

We would like to characterize in more detail the method of making math-proposal adjacency pairs. Often, the nature of an interactional method is seen most clearly when it is breached (Garfinkel, 1967). Methods are generally taken for granted by people; they are not made visible or conducted consciously. It is only when there is a *breakdown* (Heidegger, 1927/1996; Winograd & Flores, 1986) in the smooth, tacit performance of a method that people focus on its characteristics in order to overcome the breakdown. The normally transparent method becomes visible in its breach. In common-sense terms, we say, "The exception proves the rule," meaning that when we see why something is an exceptional case it makes clear the rule to which it is an exception. Heidegger made this into an ontological principle, whereby things first become experience-able during a breakdown of understanding. Garfinkel uses this, in turn, as a methodological fulcrum to make visible that which is commonly assumed and is effective but unseen.

We can interpret Sup's posting in line 23 as a *failed proposal*. Given the mathematics of the triangle problem, a proposal bid related to proportionality, like Sup's, might have been fruitful. However, in this chat, line 23 was effectively ignored by the group. While its character as a failed proposal did not become visible to the participants, it can become clear to us by comparing it to successful proposal bids in the same chat and by reflecting on its sequential position in the chat in order to ask why it was not a successful bid. This will show us by contrast what the characteristics are that make other proposal bids successful.

A Failed Proposal

Let us look at line 23 in its immediate interactional context in Log 23.2. We can distinguish a number of ways in which it differed from successful math proposal bids that solicited responses and formed math-proposal adjacency pairs:

Log 23.2. Part of the chat Log excerpt in Log 23.1, with order revised based on threading of the postings

```
17, 18. Avr (8:23:29 PM): i think we have to figure out the height by ourselves
… if possible
19. pin (8:24:05 PM): i know how
21. Avr (8:24:09 PM): how?
20. pin (8:24:09 PM): draw the altitude'
22. Avr (8:24:15 PM): right
24. Avr (8:24:19 PM): this is frustrating
23. Sup (8:24:19 PM): proportions?
```

(a) All the other proposal bids (1, 3, 8, 17, 20, 27) were stated in relatively complete sentences. Additionally, some of them were introduced with a phrase to indicate that they were the speaker's proposal bid (1. "`I think we should …`"; 17. "`I think we have to …`"; 20. "`i know how …`"; and 27. "`i think i got it …`"). The exceptions to these were simply continuations of previous proposals: line 3 provided the formula proposed in line 1 and line 8 proposed to "then" use that formula. Line 23, by contrast, provided a single word with a question mark. There was no syntactic context (other than the question mark) within the line for interpreting that word, and there was no reference to semantic context outside of the line. Line 23 did not respond in any clear way to a previous line and did not provide any alternative reference to a context in the original problem statement or elsewhere. For instance, Sup could have said, "`I think we should compute the proportion of the height to the base of those equilateral triangles.`"

(b) The timing of line 23 was particularly unfortunate. It exactly overlapped a line from Avr. Because Avr had been setting the pace for group problem-solving during this part of the chat, the fact that she was involved in following a different line of inquiry spelled doom for any alternative proposal around the time of line 23. Pin either seemed to be continuing on his own thread without acknowledging anyone else at this point or else he was responding too late to previous postings. So a part of the problem for Sup was that there was little sense of a coherent group process—and what sense there was did not include him. If he was acting as part of the group process, for instance, posing a question in reaction to Pin and in parallel to Avr, he was not doing a good job of it and so his contribution was ignored in the group process. It is true that a possible advantage of text-based interaction like chat over face-to-face interaction is that there may be a broader time window for responding to previous contributions. In face-to-face conversation, turn-taking rules may define appropriate turns for response that expire in a fraction of a second as the conversation moves on. In computer-based chat, the turn-taking sequence is more open. However, even here if one is responding to a posting that is several lines away, it is important to make explicit somehow the post to which one is responding. Sup could have said, "`I know another way to find the height: using proportions.`" His posting does not do anything like that; it relies purely upon sequential timing to establish its context, and that fails in this case.

(c) Sup's posting 23 came right after Pin's proposal bid 20: "`draw the altitude`." Avr had responded to this with 22 ("`right`"), but Sup seems to have ignored that. Pin's proposal had opened up work to be done, and both Avr and Pin responded after line 23 with contributions to this work. So Sup's proposal bid came in the middle of an ongoing line of work without relating to it. In sequential terms, he made a bid for a proposal when it was not time to make a proposal. Sup's proposal bid was not positioned within the group effort to sustain a promising line of inquiry. It is like trying to take a conversational turn when there is not a pause that creates a turn-taking opportunity. Now, it is possible—especially in chat—to introduce a new proposal at any time. However, to do so effectively, one must make a special effort to bring the ongoing work to a temporary halt and to present one's new proposal as an alternative. Simply saying "`proportions?`" will not do it. Sup could have said, for instance, "`Instead of drawing the altitude, let's use proportions to find it.`"

(d) To get a proposal response to a proposal bid, one can elicit at least an affirmation or recognition. Again, this is a matter of pre-structuring a sustained interaction. Line 23 does not really solicit a response. For instance, Avr's question, 21: "`how?`" called for an answer—that was given by Pin in line 20, which actually appeared in the chat window just prior to the question and with the same time stamp. But Sup's posting does not call for a specific kind of answer. Even Sup's own previous proposal bid in line 10 ended with "`right?`"—requesting agreement or disagreement. Line 10 elicited a clear response from Avr, line 11 ("`no`") followed by an exchange explaining why Sup's proposal was not right.

(e) Other proposal bids in the excerpt are successful in contributing to sustaining the collaborative knowledge building or group problem solving in that they open up a realm of work to be done. One can look at Avr's successive proposal bids on lines 1, 3, 8, and 17 as laying out a work strategy. This elicits a proposal response from Sup trying to find values to substitute into the formula and from Pin trying to draw a graphical construction that will provide the values for the formula. Sup's proposal bid in line 23, however, neither calls for a response nor opens up a line of work. There is no request for a reaction from the rest of the group, and the proposal bid is simply ignored. Since no one responded to Sup, he could have continued by doing some work on the proposal himself. He could have come back and made the proposal more explicit, reformulated it more strongly, taken a first step in working on it, or posed a specific question related to it. But he did not—at least not until much later—and the matter was lost.

(f) Another serious hurdle for Sup was his status in the group at this time. In lines 10 through 16, Sup had made a contribution that was taken as an indication that he did not have a strong grasp of the math problem. He offered the lengths of the two given triangles as the base and height of a single triangle (line 10). Avr immediately and flatly stated that he was wrong (line 11) and then proceeded to explain why he was wrong (line 13). When he agreed (line 15), Avr summarily dismissed him (line 16) and went on to make a new proposal that implied his approach was simply wrong (lines 17 and 18). Then Pin, who had stayed out of the interchange, re-entered, claiming to know how to implement Avr's alternative proposal (lines 19 and 20), and Avr confirmed that (line 22). Sup's legitimacy as a source of useful proposals had been totally destroyed at precisely the point just before he made his ineffective proposal bid. Less than 2 minutes later, Sup tries again to make a contribution but realizes himself that what he says is wrong. His faulty contributions confirm repeatedly that he is a drag on the group effort. He makes several more unhelpful comments later and then drops out of the discourse for most of the remaining chat. Sustaining a math chat discourse involves work to maintain an ongoing social interaction as well as work to continue the math inquiry. Proposal bids and other postings are constrained along multiple dimensions of efforts to sustain the activity.

The weaknesses of line 23 as a proposal bid suggest (by contrast, exception, breach, or breakdown) some characteristics for successful proposals:

- A clear semantic and syntactic structure
- Careful timing within the sequence of postings
- A firm interruption of any other flow of discussion
- The elicitation of a response
- The specification of work to be done
- A history of helpful contributions

In addition, there are other interaction characteristics and mathematical requirements. For instance, the level of mathematical background knowledge assumed in a proposal must be compatible with the expertise of the participants, and the computational methods must correspond with their training. Additional characteristics become visible in other examples of chats. Successful proposals contribute in multiple ways to sustaining the group cognitive process.

As we have just seen, the formulation of effective bids for math proposals involves carefully situating one's posting within the larger flow of the chat. This is highly analogous to taking a turn in face-to-face conversation (Sacks et al., 1974). Where conversation analysis developed a systematics of turn taking, we are discovering the systematics of chat interaction. This describes how math proposals and other chat methods must be designed to fit into—and thereby contribute to—the sustained flow of group interaction.

So far in this investigation, the notion of math-proposal adjacency pairs has been illustrated in just a single chat log excerpt. But in our research we have seen both successful and failed math proposals many times. Other researchers have also noted the role of successful and failed proposals in collaborative problem-solving (Barron, 2003; Cobb, 1995; Dillenbourg & Traum, 2006; Sfard & McClain, 2003).

Each proposal bid and uptake is unique—in its wording and its context. The interactional work that it does and the structuring that it employs are situated in the local details of its sequential timing and its subtle referencing of unique and irreproducible elements of the ongoing chat. Each group of students develops somewhat different methods of engaging with math problems and making math proposals. Even within a given chat, each posting pair that might be a proposal must be analyzed as a unique, meaning-making interaction in order to determine if it is in fact a math-proposal adjacency pair. That is why case studies provide the necessary evidence. The essential details of interaction methods are lost in aggregation, in the attempt to overcome what Garfinkel (1967) terms the "irreducible indexicality" of the event. To the extent that identifying proposal pairs is a useful analytic approach, it is important to determine what interactional methods of producing such proposals are effective (or not) in fostering successful knowledge building and group cognition, as we have begun to do here.

An understanding of methods like proposal making can guide the design of activity structures for collaborative math. As we are collecting and analyzing a corpus of chat logs under different technological conditions, we are evolving the design of computer support through iterative trials and analyses.

Designing Computer Support

If the failure of Sup's proposal about proportions is considered deleterious to the collaborative knowledge building around the triangles problem, then what are the implications of this for the design of educational computer-based environments? One response would be to help students like Sup formulate stronger proposals. Presumably, giving him positive experiences of interacting with students like Avr and Pin, who are more skilled in chat proposal making, would provide Sup with models and examples from which he can learn—assuming that he perseveres and does not drop out of the chat.

Another approach to the problem would be to build functionality into the software and structures into the activity that scaffold the ability of weak proposal bids to survive. As students like Sup experience success with their proposals, they may become more aware of what it takes to make a strong proposal bid.

Professional mathematicians rely heavily upon inscription—the use of specialized notation, the inclusion of explicit statements of all deductive steps, and the format of the formal proof to support the discussion of math proposals—whether posted on an informal whiteboard, scrawled across a university blackboard, or published in an academic journal. Everything that is to be referenced in the discussion is labeled unambiguously. To avoid ellipsis, theorems are stated explicitly, with all conditions and dependencies named. The projection of what is to be proven is encapsulated in the form of the proof, which—at least since Euclid—starts with the givens and concludes with what is proven. Perhaps most importantly, proposals for how to proceed are listed in the proof itself as theorems, lemmas, etc. and are organized sequentially. (This view of proof is an idealization that abstracts from unstated tacit background knowledge of the mathematical community, as Livingston (1999) and Wittgenstein (1944/1956) before him have demonstrated.)

One could imagine a chat system supplemented with a window containing an informal list of proposals analogous to the steps of a proof. After Sup's proposal, the list might look like Fig. 23.1. When Sup made a proposal in the chat, he would enter a statement of it in the proof window in logical sequence. He could cross out his own proposal when he felt it had been convincingly argued against by the group (see dashed lines in Fig. 23.1 crossing out the proposal that base and height = 9 and 12).

The idea is that important proposals that were made would be retained in a visible way and be shared by the group. Of course, there are many design questions and options for doing something like this. Above all, would students understand this functionality and how would they use it? The design sketch indicated in Fig. 23.1 is only meant to be suggestive.

Another useful tool for group mathematics would be a shared drawing area. In the chat environment used by Sup, Pin, and Avr, there was no shared drawing, but a student could create a drawing and email it to the others. Pin did this 12 minutes after the part of the interaction shown in the excerpt.

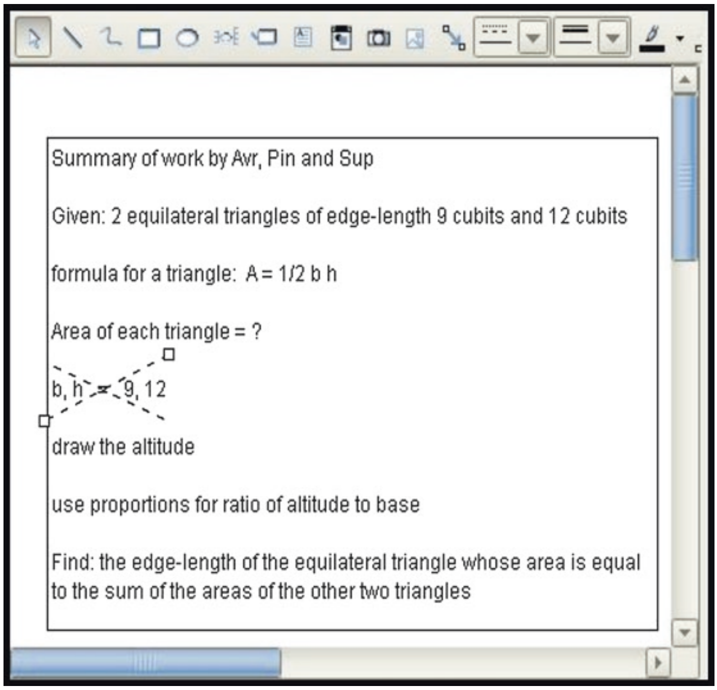

Fig. 23.1 A software interface window with a list of proposals

Before the drawing was shared, much time was lost due to confusion about references to triangles and vertices. For math problems involving geometric figures, it is clearly important to be able to share drawings easily and quickly. Again, there are many design issues, such as how to keep track of who drew what, who is allowed to erase, how to point to items in the drawing, and how to capture a record of the graphical interactions in coordination with the text chatting.

Because we are designing a computer-supported experience that has never before existed and because we want our design to be based on detailed study of how students actually create their collaborative experience in the environment we are designing, we follow a highly iterative try-analyze-redesign cycle of design-based research (Design-Based Research Collective, 2003), in order to gradually approach an effective computer-supported environment and math discourse community.

We started with a simple online service. We used AOL's IM commercial chat system that was already familiar to many students. We invited students into chat rooms and presented a problem from the Math Forum's well-established Problem of the Month service. An adult facilitator was present in the room to help with any technical problems. When we saw how necessary a shared whiteboard was, we tried an open source solution and also WebCT's and Blackboard's interactive classrooms. Eventually we collaborated with researchers in Germany to use and further develop ConcertChat. Together, we have gradually evolved ConcertChat into a sophisticated environment for students, instrumented to capture student interaction for researchers.

Since the early AOL-based chat analyzed above, we have gone through many cycles of design, trial, and analysis. In addition to designing wiki support for persistent summaries of work (such as that in Fig. 23.3) and a shared whiteboard for constructing geometric drawings (discussed in the following section), we have incorporated the following: a referencing tool; a way for users to explicitly thread their chat postings; several forms of social awareness; tutorials on how to use the new features; a help system on using the tools, collaborating and problem-solving; and a lobby to support group formation. We have also experimented extensively with how best to formulate math problems or topics and how to provide feedback to students on their work.

References and Threading

The more we study chat logs, the more we see how interwoven the postings are with each other and with the holistic Gestalt of the interactional context that they form. There are many ways in which a posting can reference elements of its context. The importance of indexicality to creating shared meaning was stressed by Garfinkel (1967). Vygotsky also noted the central role of pointing for mediating intersubjectivity in his analysis of the genesis of the infant-and-mother's pointing gesture (1930/1978, p. 56). Our analysis of face-to-face collaboration emphasized that spoken utterances in collaborative settings tend to be elliptical, indexical, and projective ways of referencing previous utterances, the conversational context, and anticipated responses (Stahl, 2006b, chapter 12).

Based on these practical and theoretical considerations—and working with the ConcertChat developers—we evolved the VMT-Chat environment. As shown in Fig. 23.2, it not only includes a shared whiteboard but has functionality for referencing areas of the whiteboard from chat postings and for referencing previous postings [Investigation 22]. The shared whiteboard is necessary for supporting most geometry problems. (This will save Avr the frustration of running out of paper and also let Pin and Sup see what she is drawing and add to it or reference it.) Sharing drawings is not enough; stu-

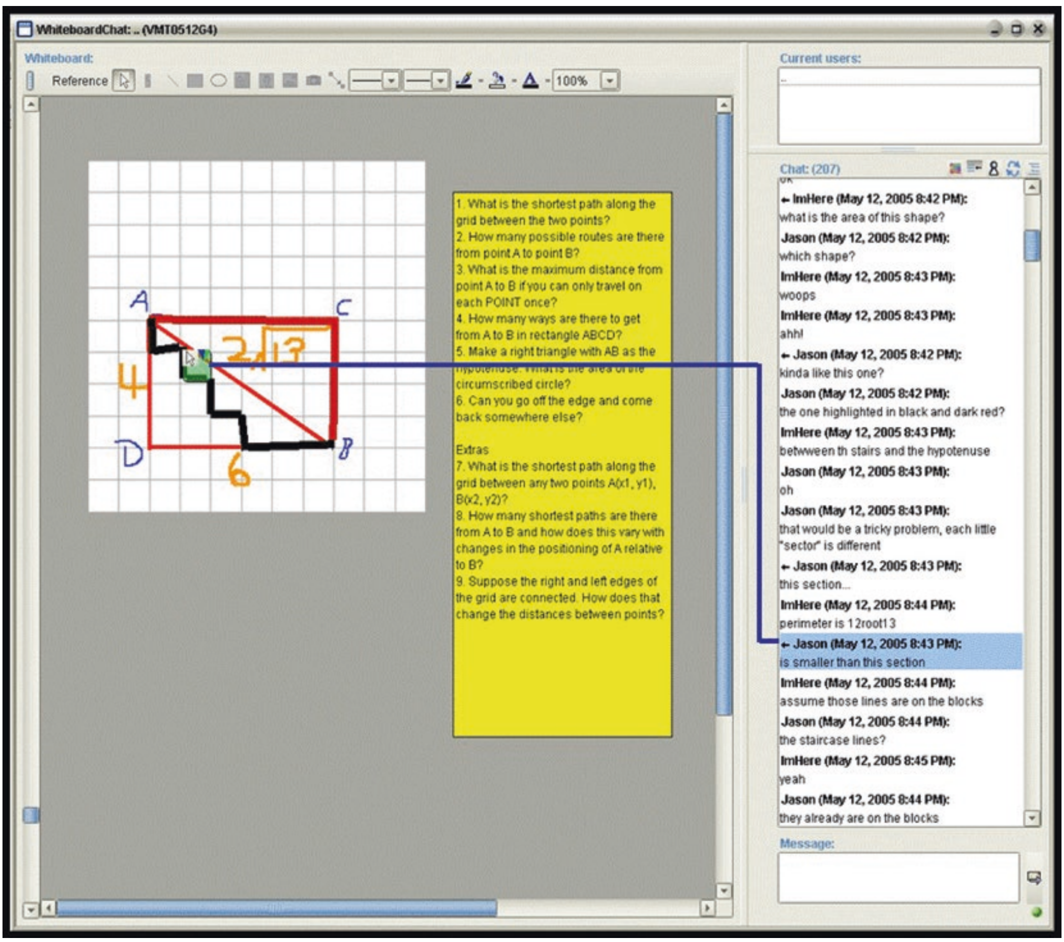

Fig. 23.2 Screen view of VMT-Chat with referencing. Line 12 of the chat is selected

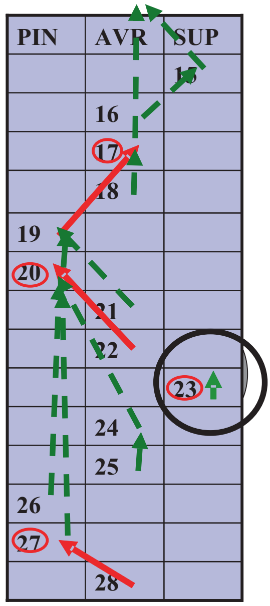

Fig. 23.3 Threading of adjacency pairs and other uptake

dents must be able to reference specific objects or areas in the drawing (e.g., Sup could have pointed to elements of the triangles that he felt to be significantly proportional). The whiteboard also provides opportunities to post text where it will not scroll away. (Sup could have put his failed proposal in a text box in the whiteboard, where he or the others could come back to it later.) The graphical references (see the bold line from a selected posting to an area of the drawing in Fig. 23.2) can also be used to reference one or more previous postings from a new posting in order to make the threads of responses clearer in the midst of "chat confusion" (Fuks, Pimentel, & de Lucena, 2006).

In one of our first chats using VMT-Chat, the students engaged in a particularly complex interaction of referencing a figure in the whiteboard whose mathematics they wanted to explore [Investigation 22]. The chat log from Fig. 23.2 (graphical references to the whiteboard are indicated by "[REF TO WB]" in the log) is listed in Log 23.3.

Log 23.3. Chat Log from Fig. 23.2

1 ImH: what is the area of this shape? [REF TO WB]
2 Jas: which shape?
3 ImH: woops
4 ImH: ahh!
5 Jas: kinda like this one? [REF TO WB]
6 Jas: the one highlighted in black and dark red?
7 ImH: between th stairs and the hypotenuse
8 Jas: oh
9 Jas: that would be a tricky problem, each little "sector" is different
10 Jas: this section [REF TO WB]
11 ImH: perimeter is 12root3
12 Jas: is smaller than this section [REF TO WB]

```
13 ImH: assume those lines are on the blocks
14 Jas: the staircase lines?
15 ImH: yeah
16 Jas: they already are on the blocks
```

Line 1 of the chat in Log 23.3 textually references an abstract characteristic of a complex graphical form in the whiteboard: "`the area of this shape`." The software function to support this reference failed, presumably because the student, ImH, was not experienced in using it and did not cause the graphical reference line to point to anything in the drawing. Line 5 provides a demo of how to use the referencing tool. Using the tool's line, a definite textual reference ("`this one`") and the use of line color and thickness in the drawing, lines 5 and 6 propose an area to act as the topic of the chat. Line 7 makes explicit in text the definition of a sub-area of the proposed area. Line 8 accepts the new definition and line 9 starts to work on the problem concerning this area. Line 9 references the problem as "`that`" and notes that it is tricky because the area defined does not consist of standard forms whose area would be easy to compute and add up. It refers to the non-uniform sub-areas as little "`sectors`." Line 10 then uses the referencing tool to highlight (roughly) one of these little sectors or "`sections`." Line 12 continues line 10 but is interrupted in the chat log by line 11, a failed proposal bid by ImH. The chat excerpt continues to reference particular line segments using deictic pronouns and articles as well as a growing vocabulary of mathematical objects of concern: sectors, sections, lines, and blocks.

Progress is made slowly in the collaborative exploration of mathematical relationships, but having a shared drawing helps considerably. The students use multiple textual and graphical means to reach a shared understanding of mathematical objects that they find interesting but hard to define. In this excerpt, we start to get a sense of the complex ways in which brief textual postings weave dense webs of relationships among each other and with other elements of the collaborative context.

This example shows how creating shared meaning can require more than a simple adjacency pair. In order to establish a reference to "this shape" that could allow the two participants to discuss that math object, the dyad had to construct a complex involving nested question/answer pairs, math proposal pairs, a failed proposal bid, drawing, coloring, labeling, pointing, multiple repairs, and computations. Here we see a more sustained group-cognitive process. Across 16 postings and considerable coordinated whiteboard activity during 2 minutes, the student dyad defines a math object for investigation. The definition is articulated by this whole sequence of combined and intricately coordinated textual and graphical work.

Sustaining the Group Interaction

The goal of our research is to provide a service to students that will allow them to have a rewarding experience collaborating with their peers in online discussions of mathematics. We can never know exactly what kind of subjective experience they had, let alone predict how they will experience life under conditions that we design for them. For instance, it is methodologically illegitimate to ask if ImH already "intended" or "had in mind" in line 1 the shape that the group subsequently arrived at. We know from the log that ImH articulated much of the explicit description, but he only did this in response to Jas. If we interviewed ImH afterward, he might quite innocently and naturally project this explicit understanding back on his earlier state of mind as a retrospective account or rationalization (Suchman, 1987).

Our primary access to information related to the group experiences comes from chat logs (including the whiteboard history). The logs capture most of what student members see of their group on their computer screens. They therefore constitute a fairly complete record of everything that the participants themselves had available to understand their group interaction. We can even replay the logs so that we see how the session unfolded sequentially in time. Of course, we are not engaged in the interaction the way the participants were, and recorded experiences never quite live up to the live version because the engagement is missing. To gain some first-hand experience, we researchers do test out the environments ourselves and enjoy the experience, but we experience math and collaboration differently than do middle-school students. We also interview students and their teachers, but teenagers rarely reveal much of their life to adults.

So we try to understand how collaborative experiences are structured as interpersonal interactions that are sustained over time. The focus is not on the individuals as subjective minds but on the human, social group as constituted by the interactions that take place within the group. Although we generally try to ground our understanding of interaction through close, detailed analysis of excerpts from chat recordings, we do not have room to document our analysis of longer-scale structures at that level of detail here. During Spring Fest 2005, we collected over 50 h of small-group chat about math. We engage in weekly collaborative data sessions (Jordan & Henderson, 1995) to develop case studies of unique chat excerpts. A number of published papers arising from these sessions are available. The discussion in the remainder of this investigation is a high-level summary based on what we have observed.

Replies, Uptake, Pairs, and Triplets

Figure 23.3 provides a diagram of the responses of postings in the chat discussed above involving Avr, Pin, and Sup (Log 23.1). The numbers of the posts by each participant are placed in chronological order in a column for that participant. Math-proposal adjacency pairs are connected with solid arrows and other kinds of responses are indicated with dashed arrows. Note that Sup's failed proposal bid (line 23) is isolated. Most of the chat, however, has coherence, flow, or motion because most postings are responses to previous messages. This high level of responses is due to the fact that many postings elicit responses or uptake, the way that a greeting invariably calls forth another greeting in response or a question typically elicits an answer. In a healthy conversation, most contributions by one participant are taken up by others. Conversationalists work hard to fit their offerings into the timing and evolving focus of the ongoing interaction. In chat, the timing, rules, and practices are different, but the importance of uptake remains [Investigation 4].

The fact that the group process and the cross ties between people are central to collaborative experiences does not contradict the continuing importance of the individuals. The representation of Fig. 23.3 uses columns to indicate the connections and implicit continuity within the sequence of contributions made by an individual (compare the representation in Sfard & McClain, 2003). We may project psychological characteristics onto the unity of an individual's postings, attributing this unity to personal interests, personality, style, role, etc. Such attributions may change as the chat unfolds. The point is that the individual coherence and unfolding of each participant's contributions adds an important dimension of implicit sustaining connections among the postings.

Adjacency pairs like math proposals, greetings, and questionings provide important ties that cut across the connections of individual continuities. They form the smallest elements of interaction precisely by binding together postings from different people. A proposal bid that is not taken up is not a meaningful proposal, but at best a failed attempt at a proposal. A one-sided greeting that is not recognized by the other is not an effective greeting. An interrogative expression that does not call for a response is no real questioning of another. These adjacency pairs are all interactional moves whose meaning consists in a give-and-take between two or more people. When we hear something that we recognize as a proposal bid, a greeting, or a question, we feel required to attempt an appropriate response. We may ignore the proposal bid, snub the greeter, or refuse to answer the question, but then our silence is taken as a response of ignoring, snubbing, or refusing—and not simply a lack of response. The first part of an adjacency pair opens up a space of possibility for other group members to respond. The space if structured to allow certain kinds of utterances and not others. Some of the permitted responses are preferred and others are dis-preferred, requiring additional elaboration.

The way that a response is taken is an integral part of the interaction itself. In discussing the building of common ground, Clark argues that shared understanding by A and B of A's utterance involves not only B believing that he understands A, but also A agreeing that B understands (Clark & Brennan, 1991). This may require an interaction spanning multiple utterances. For instance, the most prevalent interaction in classroom discourse is when a teacher poses a question, a student provides an answer demonstrating understanding and then the teacher acknowledges the student response as such an understanding (Lemke, 1990). Here, the elemental cell of interactional meaning making is a sequence of contributions by different people.

It is clear in this analysis that the meaning is constructed through the interaction of multiple people and is not a simple expression of pre-existing mental representations in any one individual's head. This is the philosophical importance of the concept of adjacency pair: that meaning in groups is made through the interaction of multiple people, not completely by an individual's mental activity. In calling this "group cognition," we extend the term "cognition" from individual psychology to apply to processes in which small groups through their discourse construct meaning structures like logical arguments or mathematical proofs—that is, they engage in processes which are considered thinking when conducted by individual people. This approach is consistent with dialogical theories that actually view higher-level thinking by individuals as derivative of such intersubjective meaning making (Bakhtin, 1986; Linell, 2001; Stahl, Koschmann, & Suthers, 2006; Vygotsky, 1930/1978; Wegerif, 2006).

Longer Sequences

Although much attention has been given to adjacency pairs in conversation analysis and although such pairs can be thought of as the elements of meaning making in collaborative interaction, they form only one of many levels of analysis. For instance, there are *longer sequences* (Sacks, 1992, vol. II, p. 354), *episodes* (Linell, 2001) and *topics* in dialogs and chats (Zemel, Xhafa, & Cakir, 2005) that provide layers of structure and sense. An hour-long chat is not a homogeneous interchange. A typical math chat might start with a period of introductions, greetings, and socializing. Then there could be some problem-solving work. This might be periodically interrupted by joking, playing around, or silliness. People may come and go, requiring catching up and group reorganization, or even bridging across sessions. Each of these episodes has boundaries during which the group members must negotiate whether or not to stop what they were doing and start something else. These transitions may themselves be longer sequences of interaction, especially in large groups. We have barely begun to explore these different layers.

In social conversation, people work hard to strike up conversations, to propose new topics of mutual interest, and to keep the conversation going. Online math chats face similar challenges. Students hesitantly greet each other and get things started. Math proposals are often used to introduce new topics and to carry forward a train of thought together. Finally, participants engage in considerable interaction work to sustain their sessions, intertwining humor, flirting, socializing, and math inquiry—often using one of these modes to sustain others. Eventually every group decides to disband, at least until a future session.

The above referencing excerpt from a VMT-Chat was from the second hour-long session in a series of four chats by the same group. The sessions referred back to previous sessions and prepared for future ones. We hope to foster a community of Math Forum users who come back repeatedly to math chats, potentially with their friends. Their chats will reference other chats and different online experiences, building connections at the community level. This adds more layers of interconnections. It may sustain group interaction, inquiry, and reflection over more significant periods of time.

Constructing Proofs

Learning math involves becoming skillful in the social practices of the math community (Livingston, 1999). The math community is an aspect of the world-historical global community. The most central participants are the great mathematicians, who have invented new mathematical objects and developed new forms of mathematical practice (Sfard & Linchevski, 1994). Most of the population has low math literacy and participates on the periphery of the math discourse community. They are unable to manipulate math concepts fluidly in words or mathematical symbolism (Sfard, 2002). Nevertheless, they can use basic arithmetic methods for practical purposes (Lave, 1988). One of the most fundamental methods of math is counting, which young children are drilled at extensively. Formal math assumes that the practitioner is skilled at following rules, such as the non-formalized rules of numeric sequencing or counting (Wittgenstein, 1944/1956).

In our chats, students work on math problems and themes. In solving problems and exploring math worlds or phenomena, the groups construct sequences of mathematical reasoning that are related to proving. Proofs in mathematics have an interesting and subtle structure. To understand this structure, one must distinguish:

- The problem statement-and-situation
- The exploratory search for a solution
- The effort to reduce a haphazard solution path to an elegant, formalized proof
- The statement of the proof
- The lived experience of following the proof (Livingston, 1986, 1987)

Each of these has its own structures and practices. Each implicitly references the others. To engage in mathematics is to become ensnarled in the intricate connections among them. To the extent that these aspects of doing math have been distinguished and theorized, it has been done as though there is simply an individual mathematician at work. There has been virtually no research into how these could be accomplished and experienced collaboratively—despite the fact that talking about math has for some time been seen as a priority in math education (NCTM, 1989; Sfard, 2002).

The Stream of Group Consciousness

Psychologists like William James and novelists like Jack Kerouac have described narratives that we tell ourselves silently about what we are doing or observing as our stream of consciousness. This “inner voice” rattles on even as we sleep, making connections that Sigmund Freud found significant (if somewhat shocking in his day). In what sense might online chats—with their meanderings, flaming, associative referencing, unpredictable meaning making, and unexpected images—deserve equal status as streams of (group) consciousness? Group cognition can be self-conscious: The group discourse can talk about the existence of the group discourse itself and comment on its own characteristics.

Our sense of sustained time and the rhythms of life are largely reliant upon the narratives we tell ourselves (Bruner, 1990; Sarmiento, Trausan-Matu, & Stahl, 2005). We know that we have already lived through a certain part of the day or of our life because our present is located within a nexus of ties to the past or hopes for the future. In similar ways, a chat's web of references that connects current postings to prior ones to which they respond and to future postings that they elicit defines a temporality of the chat. This is experienced as a lived sense of time that is shared by the group in the chat. Like our individual internal clocks, the group temporality is attuned to the larger world outside—the world of family life that calls the students away from the chat for dinner or the world of school that interrupts a chat with class changes or homework pressures. The temporality that defines a dimension of the collaborative experience is constrained by the nature of the social situation and by the functionality of the technological environment.

Constructing the Group Experience

Groups constitute themselves (Garfinkel, 2006, pp. 189ff; Sacks, 1992, vol. I, pp. 144–149). We can see how they do this in the chat logs. At one level, the VMT service brings several students together and locates them in a chat room together. It may supply a math problem for them to work on and it may provide a facilitator who introduces them to the environment. At this point, they are a potential group with a provisionally defined membership. The facilitator might say something like, "`Welcome to our first session of Virtual Math Teams! I am the facilitator for your session. . . . As a group, decide which question you would like to work on.`" (This is, in fact, part of the facilitator script from the session involving ImH and Jas excerpted above.) Here we can see that the facilitator has defined the group ("`as a` **`group`** … **`you`**") and distinguished her own role as outside the group ("**`I`** `am the facilitator` … **`your`** `session`"). The potential group projected by the facilitator need not necessarily materialize. Individual students may come to the setting, look around, decide it is lame, and leave as individuals. However, this rarely happens. Sometimes an individual will leave without ever interacting, but as long as enough students come there, a group emerges.

Students enter the chat environment with certain motivations, expectations, and experiences. These are generally sufficient to get the group started. One can see the group form itself. This is often reflected in the shift from singular to plural pronouns: "**`Let's`** `get started. Let` **`us`** `do some math.`" We saw this in Avr's proposal: "**`I`** `think` **`we`** `have to figure out the height by` **`our`**`selves`." The proposal bid comes from an individual, but the projected work is for the group. Through her use of "`we`," Avr constitutes the group. Through her proposal bid, she constitutes the group as a recipient of the bid and elicits a response from them. Someone other than Avr must respond to the bid on behalf of the group. When Pin says, "`I know how: draw the altitude`," he is accepting Avr's proposal as a task for the group to work on, and in so doing he makes a proposal about how the group should go about approaching this task (by making a geometric construction). In this interchange, the group (a) is projected as an agent ("`we`") in the math work (Lerner, 1993), and (b) is actually the agent of meaning making because the meaning of Avr's proposal is defined by the interaction within the group (e.g., by a math-proposal adjacency pair).

If the group experience is a positive one for the participants, they may want to return. Some chats end with people making plans to get together again. In some experiments, the same groups attended multiple sessions. We would like to see a community of users form, with teams reforming repeatedly and with old-timers helping new groups to form and learn how to collaborate effectively.

The recognition that collaborative groups constitute themselves interactionally and that their sense making takes place at the group unit of analysis has implications for the design of cognitive tools for collaborative communities. The field of computer-supported collaborative learning (CSCL) was founded in the 1990s to pursue the analysis of group meaning making and the design of media to support it (Stahl, Koschmann et al., 2006). We view the research described here as a contribution to this CSCL tradition.

We are designers of tools for collaborative groups. We want to design an online collaborative service, with strong pedagogical direction and effective computer support. Our goal is to design an environment that fosters exciting mathematical group experiences for students and inspires them to return repeatedly. Our ultimate vision is to foster a sustainable community of math discourse among students. We approach this by trying to understand how groups of students construct their experience in such settings.

When students enter our website now, they are confronted by a densely designed environment. The lobby to our chat rooms is configured to help students find their way to a room that will meet their needs. In the room, there is a daunting array of software functionality for posting and displaying chat notes, drawing geometric forms and annotating them, keeping track of who is doing what, and configuring the space to suit oneself. There may be a statement of a math problem to solve or an imaginary world to explore mathematically. The service, problems, and software are all designed to enhance the user's experience. But how can a student who is new to all this understand the meanings of the many features and affordances that have been built into the environment?

Groups of students spontaneously develop methods for exploring and responding to their environments. They try things out and discuss what happens. A new group may doodle on the whiteboard and then joke about the results. They bring with them knowledge of paint and draw programs and skills from video games, SMS and IM. The individuals may have considerable experience with single-user apps but react when someone else erases their drawing; they must learn to integrate coordination and communication into their actions. The math problems they find in the chat rooms may be quite different from the drill-and-practice problems they are used to in traditional math textbooks and commercial "educational" software. It may take the group a while to get started in productive problem solving, so the group has to find ways to keep itself together and interacting in the meantime. There may be various forms of socializing, interspersed with attempts to approach the math. As unaccustomed as the math may be, the students always have some knowledge and experience that they can bring to bear. They may apply numerical computations to given values; try to define unknowns and set up equations; graph relationships; put successive cases in a table; use trigonometric relationships or geometric figures; draw graphical representations; or add lines to an existing drawing. Mainly, they put proposals out in the chat stream and respond to the proposals of others. Sometimes the flow of ideas wanders without strong mathematical reflection. Other times, one individual can contribute substantial progress and engage in expository narrative to share her contribution with the group (Stahl, 2006a).

Groupware is never used the way its designers anticipated. The designers of VMT-Chat thought that its referencing tools would immediately clarify references to elements of drawings and transform chat confusion into logical threaded chat. But our studies of the actual use of these designed functions tell a quite different and more interesting story. The shared whiteboard with graphical references from the chat may allow more complex issues to be discussed, but they do not make pointing problem-free. We saw in a previous section how much work ImH and Jas engaged in to clarify for each other what they wanted to focus on. In the excerpt and in the longer chat, they used a variety of textual, drawing, and referencing methods. Through this process, they learned how to use these methods and they taught each other their use. Within a matter of a fraction of a minute, they were able to reach a shared understanding of a topic to work on mathematically. During that brief time, they used dozens of deictic methods, some that would prove more useful than others for the future.

Chat is a highly constrained medium. Participants feel various pressures to get their individual points of view out there. In a system like VMT-Chat, there is a lot to keep track of: new postings, changes to the whiteboard, signs that people are joining, leaving, typing, and drawing. Small details in how something is written, drawn, or referenced may have manifold implications through references to present, past, or future circumstances. Students learn to track these details; apply them creatively; acknowledge to the group that they have been recognized; and check, critique, and repair them. Each group responds to the environment in its own way, giving group meaning to the features of the collaborative world and thereby putting their unique stamp on their group experience.

In the process, they create a group experience that they share. This experience is held together with myriad sorts of references and ties among the chat postings and drawings. Often, what is not said is as significant as what is. Individual postings are fragmentary, wildly ambiguous, and frequently confusing. In lively chats, much of what happens remains confusing for most participants. Clarity comes only through explicit reflections, uptakes, appreciations, or probing. The interactions among postings, at many levels, cohere into a stream of group consciousness, a flow of collaboration, a shared lived temporality, and, with luck, an experience of mathematical group cognition.

The small groups who meet in the VMT-Chat rooms participate in the larger collaborative communities of the VMT project, the Math Forum user community, and the math discourse community at large. In general, interacting small groups mediate between their individual members and the larger communities to which they belong. The discourse within the small group evokes and collects texts, drawings, and actions by different participants, who bring multiple interpretive perspectives to the shared meaning making. Enduring ambiguity, mutual inconsistency, and downright contradiction pervade the resultant group cognition, with its "inter-animation of perspectives" (Bakhtin, 1986; Wegerif, 2006). Whether or not we assume that an individual's thoughts are logically consistent and interpretively determinant, it seems that much of a group chat generally remains a mystery to both participants and researchers. Yet, from out of the shrouds of collective fog, insights are co-constructed that could not otherwise shine forth. The tension arising from conflicting or ungraspable interpretations in place of harmonious shared meaning fuels the creative work of constructing innovative group understanding.

The chat environment as incorporated in the VMT project is essentially different from familiar conversational situations, as we have seen in this paper. In general, there is little known by the participants about each other, except for what appears in the chat text or whiteboard drawings. No one's age, gender, appearance, accent, and ethnicity are known. Even people's real names are replaced in the chat with anonymous login handles. Participants do not observe each other typing and correcting text until it is posted. Nor do they see what people are doing or saying in their lives outside the chat—if they have gone for a snack, are talking on the phone, or are engaged in other, simultaneous online interactions. Normally, a person's history, culture, and personality are conveyed through their vocal intonation and physical appearance (Bourdieu, 1972/1995); these are absent in chat. The 1-hour duration of most VMT chats limits the history that can be established among participants through the available outlets of text and drawing, interaction style, word choice, and use of punctuation. Yet, these drastically restricted means somehow allow incredibly rich, unique, creative, and sophisticated interactions to take place. Insights take place and are shared; meaning is constructed and made sense of by groups. Perspectives and personal voices are established and acknowledged. Like characters in a Beckett play, chat participants learn to survive using radically impoverished discourse within a sensuously desolate landscape, and they sustain surprising forms of interaction for about an hour.

Conclusion

As we have seen in this paper, when students enter into one of our chats, they enter into a complex social world. They typically quickly constitute a working group and begin to engage in activities that configure a group experience. This experience is conditioned by a social, cultural, technological, and pedagogical environment that has been designed for them. Within this environment, they adopt, adapt, and create methods of social practice for interacting together with the other students who they find in the chat environment. Over time, they explore their situation together, create shared meaning, decide what they will do and how they will behave, engage in some form of mathematical discourse, socialize, and eventually decide to end their session.

Then our job as researchers begins: to analyze what has happened and how the software tools we are designing condition, support, and mediate the collaborative experiences that groups construct and sustain. We face the same poverty of knowledge about our subjects that the participants themselves face about each other. But, here too, less can be more. This record is conducive to careful, detailed analysis, without the interpretive complexities of video recording and transcription. We can analyze what happens at the group unit of analysis, with the methods of interaction adopted by the participants, because everything that could have gone into the shared understanding of the participants is available in the persistent record of the chat-room history.

We can study this record at our leisure and make explicit the influences that the group experienced tacitly in the flow of its life. We can observe how several students constitute and sustain their group cognition in the math chat environment we are designing with them. The group cognition persists in its record, indefinitely available for analysis.

We can identify successful and failed math proposals, questions, greetings, and other low-level interactions. We can observe how groups construct, identify, make sense of, and explore mathematical objects. But we can also see how these elementary interactions build up longer sequences of group cognition (Stahl, 2006b) [Investigation 22], intersubjective meaning making (Suthers, 2006) [Investigation 4], and sustained collaborative group experiences.

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Investigation 24. Viewing Learning and Thinking in Groups

Gerry Stahl

Learning without thought is labor lost; thought without learning is perilous.

—Confucius 孔丘 Kong Qiu

Abstract

This is an invited keynote talk that opened the International Conference on Computers in Education (ICCE 2009) on November 30, 2009, in Hong Kong, China. The intent of the talk was to provide a personal view of the field of computer-supported collaborative learning (CSCL) and to relate it to the Asia-Pacific audience. To do this, I tried to describe—in an informal tone—the approach I was taking to analyzing online interaction in small groups. In publishing the talk, I have tried to retain its original tone.

The field of CSCL is particularly interested in the ways small groups can build knowledge together, thanks to communication and support from networking technology. I hope that CSCL environments can be designed to encourage groups to think and learn collaboratively.

In my research, my colleagues and I look at logs of student groups chatting and drawing about mathematics in order to see how they build on each other's utterances to achieve more than they would individually. To answer this important question, we must look carefully at the details of discourse in CSCL groups and develop innovative tools and theories. In this investigation, I outline methods and levels of analysis that have resulted in the findings reported in the Virtual Math Teams research cited in the references.

Keywords

Event · Session · Theme · Discourse move · Adjacency pair · Utterance · Reference

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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Views of Learning and Thinking

About 2600 years ago, Confucius viewed *learning* and *thinking* as belonging together.

The learning sciences of the twenty-first century agree with Confucius on this point. They view learning as involving meaning-making by the learners (Stahl, Koschmann & Suthers, 2006). Students who just passively accept instruction without thinking about it and coming to understand it in their own way of making sense of things will be wasting everyone's time. Why? Because they will not be able to *use* the new knowledge or to *explain* it. Of course, this construction of meaning takes place over time: someone can learn something one day and make sense of it later, when they try to use it in different circumstances and to explain their use to other people and to themselves. But if they never integrate what they have learned into their own thinking and acting—by applying it where appropriate and talking about it clearly—then they will not have really learned anything important.

What sociologists of small groups like Bernstein, as presented in Hasan's overview (1999), know about social interactions and contribute to our understanding of the significance of group cognition is the way participants internalize the resources that evolve within one interactional context and then recontextualize them in the new and radically different contexts they find themselves in later. In this way, the new knowledge that is created, or the new or enhanced knowledge-building skills that are appropriated, can replicate and spread contagiously. It is the magic that, for instance, makes seemingly inconsequential interactions between mothers and children while cleaning the oven play a key role in a child's preparation for schooling (Cloran, 1999). It is precisely because of the tremendous impact the results of these interactions can have going forward that the local sacrifice that may occur in terms of efficiency of the interaction can be viewed as a small price to pay when one considers the long-term cost-benefit ratio, the profound impact of one transformational experience of group cognition.

Vygotsky (1930/1978) made an even stronger argument. He showed for the major forms of human psychological functioning that these individual capabilities were derived from experiences of interactions between people:

> *An inter-personal process is transformed into an intra-personal one*. Every function in the child's cultural development appears twice: first, on the social level and later, on the individual level; first *between* people (*inter-psychological*), and then *inside* the child. This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals. (p. 57)

Although all functions of individual cognition are derived from group cognition, the reverse is not true. As Hutchins (1996) demonstrated with his example of the bridge of a large Navy ship, not all group cognition can be internalized by an individual: "The distribution of knowledge described [in the book] is a property of the navigation team, and there are processes that are enabled by that distribution that can never be internalized by a single individual" (p. 284). Whether or not specific skills and knowledge can be mastered by individuals or only by teams, the learning of those skills or knowledge seems to rely heavily and essentially on group cognition. That is why we try to study and to promote group cognition.

What we, as learning scientists, have learned about learning and thinking in recent decades in the West is influenced by what philosophers before us said. For instance, most Western philosophers until the middle of the 1900s thought that knowledge could be expressed by propositions, sentences, or explicit statements. If that were true, then the learning of knowledge could, indeed, consist simply of students individually hearing or reading the right sentences and remembering them.

However, Ludwig Wittgenstein's book, *Philosophical Investigations*, published in 1953, questioned this view of learning and thinking. It looked at math as a prime example. Mathematical knowledge can be seen as a set of procedures, algorithms, or rules. Wittgenstein asked how one can learn to follow a mathematical rule (Wittgenstein, 1944/1956, Part VI; 1953, §185–243, esp. §201). For instance, if someone shows you how to count by fours by saying "4, 8, 12, 16," how do you know how to go on? Is there a rule for applying the rule of counting by fours (such as "Take the last number and add 4 to it.")? And if so, how do you learn to apply *that* rule? By another rule? Eventually, you need to know how to do something that is not based on following a propositional rule—like counting and naming numbers and recognizing which numbers are larger. The use of explicit rules must be somehow grounded in other kinds of knowledge. Wittgenstein's question brought the logical view of knowledge as explicit propositions into a paradox: if knowledge involves knowing rules, then it must involve knowing how to use rules, which is itself *not* a rule. These other kinds of knowing include the tacit knowledge of how to behave as a human being in our culture: how to speak, count, ask questions, generalize, put different ideas together, apply knowledge from one situation in another context, and so on. *And these are the kinds of things that one initially learns socially, in small groups or in child-parent dyads.* In the theory of group cognition, we identify many of these nonpropositional ways of knowing as practices. We study how groups adopt group practices, which may become personal habits or skills of the group participants [Investigation 16].

Wittgenstein was an unusual philosopher because he said that problems like this one could not be solved by contemplation but rather by looking at how people actually do things. He said, "Don't think, look!" (1953, §66). In studying group cognition, I try to follow Wittgenstein's advice. I try to view how people actually *do* things. Rather than telling you what my *views* or ideas are about learning and thinking in CSCL groups, I want to *show* you how I *view* or observe learning and thinking in CSCL groups.

The term "view" in the title of my talk has this double meaning: it means both viewing by looking at something with my eyes and also viewing in the metaphorical sense of thinking about something from a conceptual perspective. The Greek philosopher, Plato, who lived at about the same time as Confucius, made this metaphor popular in Western thought (Plato, 340 BCE/1941).

Although Wittgenstein himself did not actually look at empirical examples of how people follow rules in math, we can. By carefully setting up a CSCL session, we can produce data that allows us to view small groups of students learning how to follow math rules and thinking about the math rules. This is what I do to view learning and thinking in CSCL groups. It is the basic approach of the science of group cognition (Stahl, 2009) that I want to describe today.

The work of our research team and other colleagues involves looking closely at some rich examples of student groups learning and thinking about math. I would like to share a brief excerpt from one of these examples with you and talk about how we go about viewing the learning and thinking of this group of students. In particular, how do they construct their group cognition through collaborative meaning-making activities?

In this investigation, we will look at the meaning-making work of a group of students, analyzing their language-based interaction at multiple levels:

- The overall *event*
- A specific hour-long *session* of the 2-week event
- A discussion *theme* that arose in the session
- A discourse *move* that triggered that theme
- A pivotal *interchange* that carried out the discourse move
- A single *utterance* that was part of the interchange
- A particular *reference* in the utterance

By looking at the linguistic connections, we can see how the syntax, semantics, and pragmatics weave a network of meaningful references that accomplishes a set of cognitive achievements by the group interaction.

On the one hand, we can see the linguistic elements of a log of discourse and their structure of temporal and hierarchical relationships as accomplishing group cognition by, at each moment, constraining the next utterance as situated in the context of event, session, theme, discourse moves, eliciting adjacency pairs, preceding utterances, and network of references. On the other hand, human actors creatively design accountable responses within the constraining situation defined by these contextual elements. That is, among the constraints on the actors is the requirement that their linguistic actions make sense in the ongoing discourse and that they reveal their meaning and relevance in their linguistic design.

Although people often design their utterances to convey the impression that they are the result of psychological processes (change of mental state, expression of internal reflections), we can analyze the group cognition in terms of the linguistic effects of the observable words and drawing actions, without making any assumptions about individual mental representations. The individual students are active as linguistic processors—interpreting and designing the utterances—but the larger mathematical and cognitive accomplishments are achieved through the group discourse, which exists in the computer displays, observable by the students and, even years later, observable in the logs by analysts. We can see and make explicit how teams become teams in the ways that they manifest the contingencies and accountabilities of their unique situation, using conventional linguistic structures as resources.

The work of the Virtual Math Teams (VMT) research team—which I directed from 2003 to 2014—and collaborating researchers involves looking closely at some rich examples of student groups learning and thinking about math. I would like to share a brief excerpt from one of these examples with you and talk about how we go about viewing the learning and thinking in this group of students.

An Example of Learning and Thinking

I will now describe an illustrative event, session, theme, move, interchange, utterance, and reference from the work of a VMT group of students.

The Event: VMT Spring Fest 2006 Team B

Here, we will be talking about an online event that occurred several years ago. The interaction is preserved in a computer log, which can be replayed by researchers and is partially presented in this investigation. Three students, probably about 16 years old, were assigned to form Team B, and they met with a facilitator in an online chat environment on May 9, 10, 16, and 18, in 2006, for about an hour in the late afternoon each day. The participants were distributed across three time zones in the USA. The event was part of the VMT research project. Neither the students nor we know anything more about each other's personal characteristics or background.

The topic for this event was to explore a pattern of sticks forming a stair-step arrangement of squares (see Fig. 24.1) and then to explore similar patterns chosen by the students themselves. (A subsequent session by the same students is discussed in Investigation 23.)

The VMT online environment consisted primarily of a synchronous chat window and a shared whiteboard. At the end of each session, the students were supposed to post their findings on a wiki, shared with other teams participating in the Spring Fest. Between sessions, the facilitator posted feedback to the students in a textbox on the whiteboard.

The Session: Session 3, May 16, 7:00–8:00 pm

Let's look at an excerpt from the end of the third session. The three students had already solved the original problem of the stair-step pattern of squares. They had also made up their own problem involving three-dimensional pyramids. Now they turned to look at the problem that Team C had described

Session I

1. Draw the pattern for N=4, N=5, and N=6 in the whiteboard. Discuss as a group: How does the graphic pattern grow?

2. Fill in the cells of the table for sticks and squares in rows N=4, N=5, and N=6. Once you agree on these results, post them on the VMT Wiki

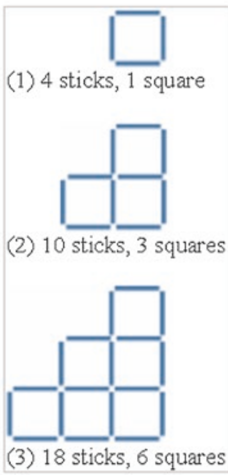
3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the VMT Wiki.

Sessions II and III

1. Discuss the feedback that you received about your previous session.

2. WHAT IF? Mathematicians do not just solve other people's problems—they also explore little worlds of patterns that they define and find interesting. Think about other mathematical problems related to the problem with the sticks. For instance, consider other arrangements of squares in addition to the triangle arrangement (diamond, cross, etc.). What if instead of squares you use other polygons like triangles, hexagons, etc.? Which polygons work well for building patterns like this? How about 3-D figures, like cubes with edges, sides and cubes? What are the different methods (induction, series, recursion, graphing, tables, etc.) you can use to analyze these different patterns?

3. Go to the VMT Wiki and share the most interesting math problems that your group chose to work on.



N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...	...	...
N	?	?

Fig. 24.1 Topic for VMT Spring Fest 2006

on the shared VMT wiki after session 2. Team B is looking at an algebraic expression that the other team of students had derived for a diamond pattern of squares. They start to draw the pattern in their whiteboard (see Fig. 24.2) and chat as a team about the problem of this new pattern.

The Theme: "I have an interesting way to look at this problem"

One of the students, Aznx, begins to make a proposal on how to "look" at their problem. First, he announces, "`I have an interesting way to look at this problem.`" Note that he uses the word "`look`" in the same double meaning of "view" that was mentioned above. As we will see, he means he has a new way to think about the problem mathematically—and that involves a way of observing a visual image of the problem. The group does its thinking both by typing text or algebraic expressions in the chat window and by simultaneously drawing and viewing diagrams or

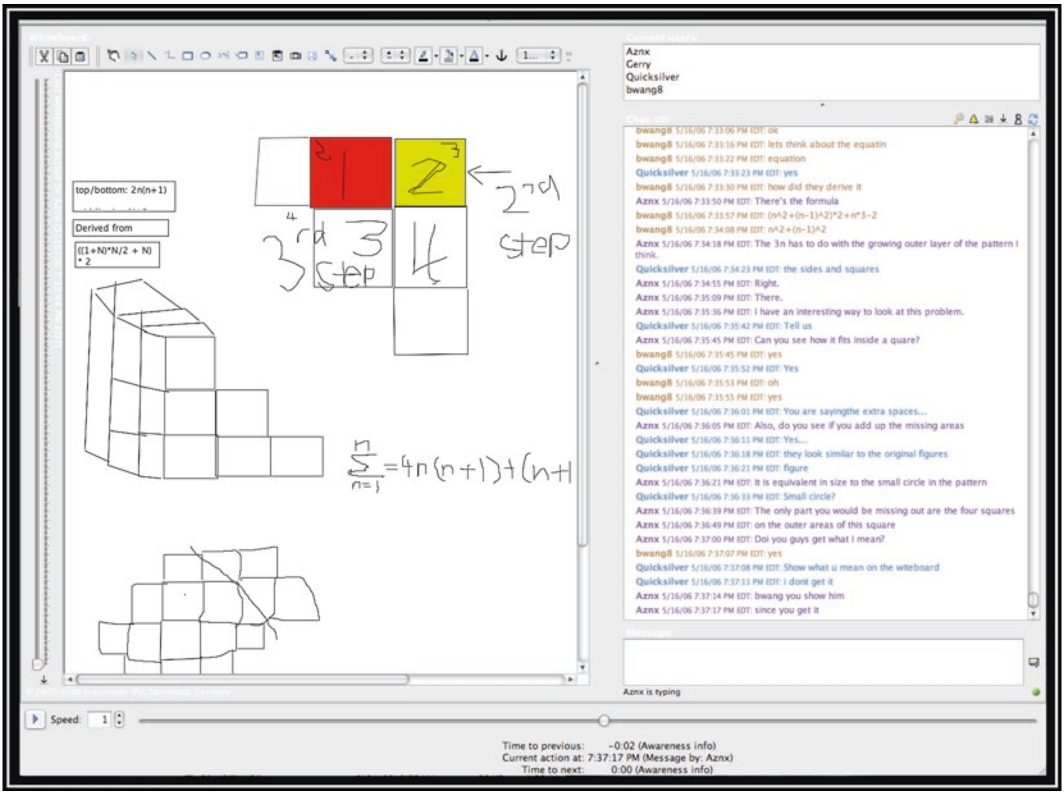


Fig. 24.2 The VMT Replayer showing the VMT online environment

geometric constructions of the problem in the shared whiteboard (see Çakir, Zemel & Stahl, 2009 [Investigation 12], for an analysis of the coordination by the group of their text, symbols, and drawings).

Aznx' announcement opens an opportunity for the group to discuss a way of looking at the problem. In fact, the group takes up the offer that is implicit in Aznx' statement, and the students spend the next 8 minutes trying to each understand it. As it turns out, they will work on this view of the problem for the rest of this session and most of their final session.

A VMT chat session can generally be analyzed as a series of themes or discussion topics. Often, themes come and go, and different themes overlap, with one wrapping up while another gets started. Researchers can identify the boundaries of a theme: when a new theme opens and an old one closes (Zemel, Xhafa & Çakir, 2009).

In this case, the group has been talking about how the diamond pattern grows as a geometric figure for a couple of minutes, and then they discuss Team C's algebraic expression for a couple of minutes. As those themes get played out and there is a pause in the chat, Aznx makes a move to open a new theme for the group.

A Move: Showing How to View the Problem

Aznx' announcement that he has a perspective to share with the group is a way of introducing a new theme, a "pre-announcement" (Schegloff, 2007, pp. 37–44; Terasaki, 2004). Conversations often flow

line	date	start	post	delay		
919	5/16/06	19:35:26	19:35:36	0:00:06	Aznx	I have an interesting way to look at this problem.
920	5/16/06	19:35:41	19:35:42	0:00:03	Quicksilver	Tell us
921	5/16/06	19:35:38	19:35:45	0:00:00	Aznx	Can you see how it fits inside a quare?
922	5/16/06	19:35:45	19:35:45	0:00:07	Bwang	yes
	5/16/06	19:35:49	19:35:52	0:00:00	Bwang	[user erased message]
923	5/16/06	19:35:51	19:35:52	0:00:01	Quicksilver	Yes
924	5/16/06	19:35:52	19:35:53	0:00:02	Bwang	oh
925	5/16/06	19:35:55	19:35:55	0:00:06	Bwang	yes
926	5/16/06	19:35:53	19:36:01	0:00:04	Quicksilver	You are sayingthe extra spaces...
927	5/16/06	19:35:58	19:36:05	0:00:06	Aznx	Also, do you see if you add up the missing areas

Fig. 24.3 The move to introduce Aznx' new way of looking at the group's problem. (This log for analysis encodes the chat stream and associated awareness messages about when people started typing, along with timing data to reflect the flow of discourse)

by new contributions picking up on something that was already being discussed. Online text chat tends to be more open than face-to-face talking; chat does not follow the strict turn-taking rules of conversation. However, it is still common to do some extra work to change themes even in chat. In a sense, Aznx is asking permission from the group to start a new theme. Quicksilver responds encouragingly right away by saying, "`Tell us`" (see Fig. 24.3).

Actually, Aznx already starts typing his proposal before he gets Quicksilver's response, but it is not posted until afterward. The next step in his proposal is: "`Can you see how it fits inside a square?`" Here, he structures his contribution as a question, which elicits a response from the other members of the team. Note that he uses the term "`see`" in his proposal with the same double meaning as the term "`look`" in his prior announcement. As we shall see (in both senses), the group tries to work out and comprehend Aznx' proposal both conceptually and visually.

Both Bwang and Quicksilver respond to Aznx' proposal with "`Yes`." However, both modify this response. Bwang starts to type something else but erases it; then he posts two messages: "`oh`" and "`yes`." This suggests some hesitation in responding to the proposal immediately. Quicksilver follows his initial positive response with "`You are saying the extra spaces` …" He is asking for more clarification of the proposal. While Quicksilver is typing his request for clarification, Aznx is typing an expansion of his initial proposal: "`Also, do you see if you add up the missing areas` …".

The analysis of interaction moves is central to the science of group cognition. This is the level of granularity of many typical group-cognitive actions. Discourse moves are ways in which small online groups get their work done. They often follow conventional patterns—speech genres (Bakhtin, 1986) or member methods (Garfinkel, 1967)—which makes them much easier for participants to understand. Researchers can also look for these patterns to help them understand what the group is doing.

In this case, a new theme is being opened, one that will provide direction for the rest of this group's event together. This move is an example of one way in which a group can establish a shared understanding of a diagram or select a joint problem conceptualization (depending on how we take the terms "`look`" and "`see`"). Other moves that we often see in VMT logs are, for instance, defining shared references, coordinating problem-solving efforts, planning, deducing, designing, describing, solving, explaining, defining, generalizing, representing, remembering, and reflecting as a group.

An Interaction: Question/Response—"Can you see how it fits inside a square?" / "Yes"

Interactions involve two or more people responding to each other. In conversation analysis, one typically looks for well-defined "adjacency pairs" (Duranti, 1998; Sacks, 1965/1995; Schegloff, 2007) as forms that interactions often take. A prototypical adjacency pair is question/answer. Aznx' offering of a question—"`Can you see how it fits inside a square?`"—followed by Bwang and Quicksilver's responses, "`yes`," "`Yes`," illustrates this structure for the simplest ("preferred") case: one person poses a yes/no question, and the others respond with an affirmative answer.

Response structures of interactions are often more complicated than this. Text chat differs from talk in that people can be typing comments at the same time; they do not have to take turns and wait until one person stops talking and relinquishes the floor. They will not miss what the other person is saying, because unlike with talk, the message remains observable for a while. The disadvantage is that one does not observe how people put together their messages, with pauses, restarts, corrections, visual cues, intonations, and personal characteristics. While it is possible to wait when you see that someone else is typing a message,[1] people often type simultaneously, so that the two normal parts of an adjacency pair may be separated by unrelated postings. For example, Quicksilver's question (line 926 in Fig. 24.3) separated Aznx' continuation of his line 921 posting in line 927, because 926 appeared before 927, although 927 was typed without seeing 926. So in chat we might call these "response pairs" rather than "adjacency pairs." While they may be less sequentially *adjacent* than in talk, they are still direct *responses* of one posting to another.

Because the sequencing in online chat texting is less tightly controlled than in face-to-face talk, response pairs are likely to become entangled in the longer sequences of group moves. This may result in the common problem of "chat confusion" (Fuks, Pimentel & Pereira de Lucena, 2006; Herring, 1999). It can also complicate the job of the researcher. In particular, it makes the task of automated analysis more complicated. In convoluted chat logs, it is essential to work out the response structure (threading) before trying to determine the meaning-making. The meaning-making still involves participants interacting through the construction of response pairs, but in chat people have to recreate the ties among these pairs. Realizing this, the group members design their postings to be read in ways that make the response pair or threading structure apparent, as we will see (for more discussion of this, see Zemel & Çakir, 2009).

An Utterance: Question—"Can you see how it fits inside a square?"

In his posting—"`Can you see how it fits inside a square?`"—Aznx is comparing the relatively complicated diamond shape to a simple square. This is a nice strategy for solving the group's problem. The group can easily compute the number of stick squares that fill a large square area. For instance, if there are five little squares across the width of a square area (and therefore five along the height), then there will be five-squared, or 25 little squares in the area. In general, if there are N little squares across the width, there will be N-squared to fill the area. This is a strategy of reducing the problem to a simple or already known situation—and then perhaps having to account for some differences. So Aznx' posting seems to be relevant to thinking about the math problem conceptually.

At the same time, Aznx poses his proposal in visual or graphical terms as one of "`seeing`" how one shape "`fits inside`" of the other. The group has been looking at diagrams of squares in differ-

[1]The VMT environment displays an awareness message under the chat tab when someone is typing. The content being typed is not displayed to other participants until the message is posted to the chat. See Figs. 2 or 5.

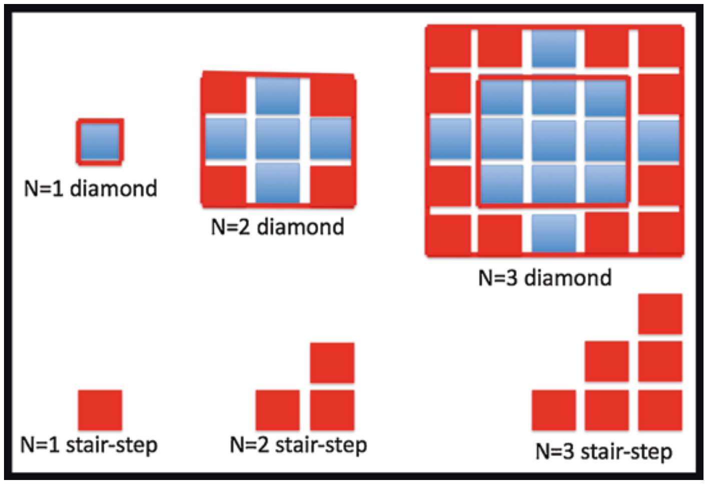


Fig. 24.4 Blue diamond patterns and red stair-step patterns

ent patterns, both a drawing by Team C in their wiki posting and Team B's own drawings in their whiteboard. So Aznx' proposal suggests visualizing a possible modification to one of the diamond drawings, enclosing it in a square figure (see the blue diamond pattern enclosed in the red square in Fig. 24.4). He is asking the others if they can visualize this also, so that the group can use this to simplify and solve their problem with the diamond.

Aznx presents his proposal about rethinking the problem as a question about visualizing the diagram. The group has been working in the VMT environment, going back and forth between text in the chat area and drawings in the whiteboard. They have started with problems presented graphically and have discussed these graphical problems in their text chat. They have shared different ways of viewing the relationships within the drawings, and they have gradually developed symbolic algebraic ways of expressing general relationships about patterns in these drawings, working out these symbolic expressions in the chat, and then storing them more persistently in the whiteboard.

We have been calling Aznx' chat posting a "problem-solving math proposal" (Stahl, 2006a, chap. 21). However, it is presented in the grammatical form of a *question*. Aznx did not simply state a proposal like "I think we should enclose the diamond in a square, calculate the size of the square and then subtract the missing areas." Rather, he first announced that he had "`an interesting way to look at this problem`" and then explained his way of looking by asking if the others could "`see how it fits inside a square`." Presenting a proposal calls on the others to accept the proposal and to start to work on it. Of course, the others can reject the proposal, ask for clarifications about it, make a counterproposal, or ignore the proposal.

But Aznx' utterance is not a full proposal that the others must accept or reject. It is another preliminary step. It asks the others if they can visualize something. It puts this to them as a question. If they say yes, then Aznx can proceed to make his proposal—or perhaps the others will see the implications of his way to look at the problem, what makes it "interesting," and propose the strategy without Aznx having to advocate it, explain it, and defend it. If they say no—that they cannot see how it fits inside a square—then he can explain his view further so they will be better prepared to accept his proposal.

Aznx' chat posting avoids articulating a complete proposal; by starting the conversation about the visualization, it involves the others in articulating the proposal *collaboratively*. In fact, in the subsequent discussion, the others do "see" the strategy that is implicit in Aznx' interesting view of the problem, and they do help to articulate the strategy and then pursue it. By designing his proposal as this preliminary question about viewing the problem, Aznx succeeds in directing the group problem-solving in a certain direction without him having to fully work out a detailed, explicit proposal. Aznx does not seem to be presenting a solution that he has worked out in his head. Rather, he is presenting his "interesting idea" for an approach to solving the problem so that the group will proceed to use the idea and work as a group to try to solve the problem with this approach.

A Reference: "It"

Aznx' question is ambiguous at a purely syntactic level. It asks the others: "`Can you see how it fits inside a square?`" To what does the term "`it`" refer? People use pronouns like "it" rather than lengthy explicit noun phrases when the reference is clear from the context. This situates the utterance in its context—its meaning cannot be gathered from the utterance considered in isolation. Often, "it" will reference something that was recently referred to in a previous contribution that the new utterance is building on. For instance, "`it`" could refer to something mentioned in Aznx' previous utterance: "`I have an interesting way to look at this problem.`" But to say that "`it`" refers to "`this problem`" does not make complete sense. The *problem* does not fit inside a square.

However, a minute earlier, when the group was discussing Team C's equations, Aznx said about part of an equation: "`The 3n has to do with the growing outer layer of the pattern I think.`" He was referencing different aspects of the growth of the diamond pattern, particularly its "outer layer." Therefore, when he announces that he has an interesting way to view the problem, it is reasonable to assume that his new way of looking may be closely related to the observation that he had just reported about the outer layer of the diamond pattern. Because everyone in the group was following the flow of the discussion, Aznx could refer to the topic of the outer layer of the diamond pattern in the shorthand of the pronoun "`it`." When he typed "`Can you see how it fits inside a square?`," he could assume that the readers of this posting would understand that he was referring to how some aspect of the diamond pattern can be seen as fitting inside of some square shape.

Although the reference to some aspect of the diamond pattern is relatively clear, the details are not clear about just what aspect of the diamond is to be visualized or focused on visually, where a square is to be constructed, and how the diamond fits inside the square. At this point, only a rather confusing image of a diamond pattern is visible on the whiteboard (see Fig. 24.2). To *make sense* of "`it`," everyone has to follow the flow of discussion and the way in which the math topic is being developed as part of a "joint problem space," understood and visualized by the whole group.

Bwang and Quicksilver both respond initially to Aznx' question with "`Yes`." However, as we saw, Bwang indicates some hesitancy in his response, and Quicksilver asks for further clarification. Aznx and Quicksilver discuss what they see when they fit a diamond pattern inside a square. Quicksilver notes that the "extra spaces" (colored red in Fig. 24.4) look similar to the stair-step pattern that the team worked on previously. But Aznx goes on to talk about the four squares on the outer areas of the square, confusing Quicksilver. That is, as they each try to work out the details of Aznx' view, they display that they are not *seeing* things quite the same way. They have not yet achieved an adequate shared understanding or shared view.

Quicksilver suggests that Aznx show what he means on the whiteboard, so the ambiguity of his proposal can be resolved. Rather than drawing it himself, Aznx asks Bwang to do a drawing, since Bwang said he could see what Aznx was talking about. Bwang has in the past shown himself to be skilled at making drawings on the whiteboard, while Aznx has not tried to draw much.

Bwang draws a very clear diagram on the whiteboard for the diamond pattern when N = 2 (see Fig. 24.5). As soon as Bwang completes his drawing, he makes explicit the problem-solving proposal that is implicit in Aznx' way of viewing the problem or the pattern: "`We just have to find the`

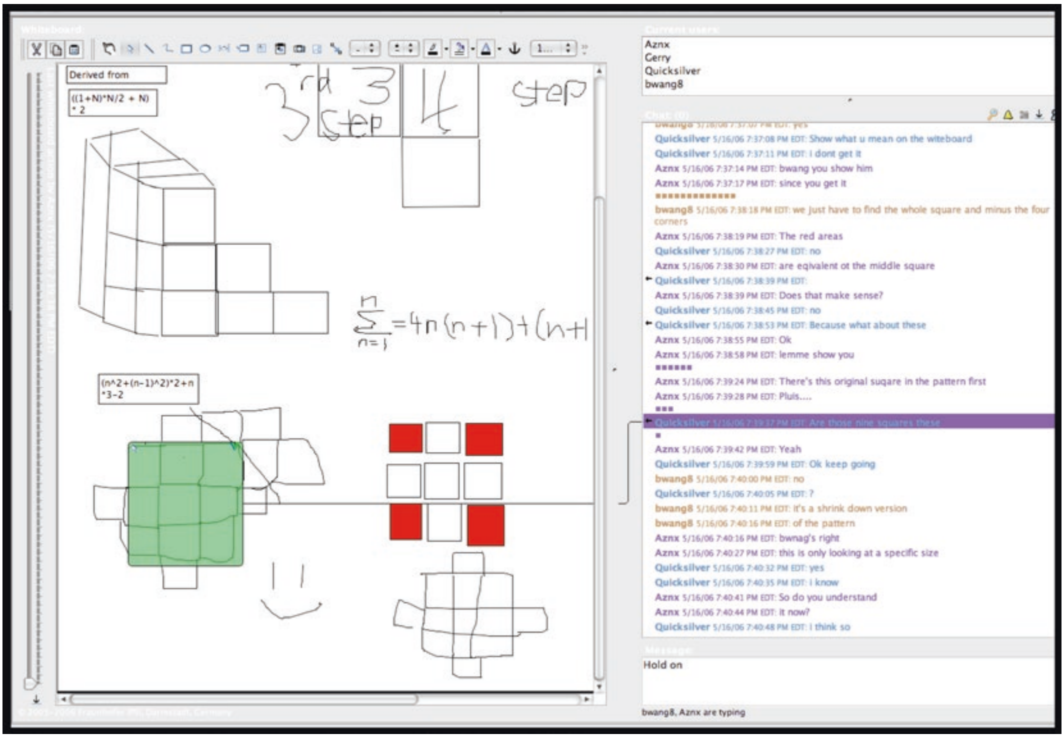


Fig. 24.5 Bwang has drawn the white diamond for N = 2 with red squares filling in the corners of an enclosing square. Quicksilver is pointing to a diamond pattern for N = 3, also re-drawn lower on the whiteboard

`whole square and minus the four corners`." His drawing has made this process very visible. He drew the diamond pattern with white squares and then filled in a large square that the diamond fits into by adding red squares. The red squares fill in symmetrical spaces in the four corners of the diamond pattern. The group can now look at this together in the shared whiteboard, providing a shared view of the matter to the group.

The group then discusses the view of the diamond pattern fitting into an enclosing square. They eventually realize that some of their observations are only true for the diamond pattern at a certain stage, like N = 2.

So Bwang then draws the pattern for N = 3. Here it starts to become visible to the group that the red squares in each corner follow the stair-step pattern (see Fig. 24.6).

The group has realized that viewing a graphical image of a mathematical pattern can be very helpful in thinking about the pattern. They treat the whiteboard as a shared, viewable image of aspects of the joint problem space of their collaborative work. Viewing this image and pointing out elements of it ground their chat discourse.

However, the image drawn by Bwang captures just one particular stage in the pattern, one value of N. They then start to look at images for different values of N or different stages in the growing pattern. They count the number of red squares in a corner as N increases and notice that it goes 0, 1, 3, 6 (see Fig. 24.4). This pattern is familiar to them from their earlier analysis of the stair-step pattern. They call this sequence "triangular numbers," from Pascal's triangle, which is often useful in combinatorics math problems. They know that this sequence can be generated by Gauss' formula for the sum of the consecutive integers from 1 to N: (N + 1)N/2. Unfortunately, at that point, Bwang has to leave the group. But when they return in session 4, they will quickly put together the simple formula for the

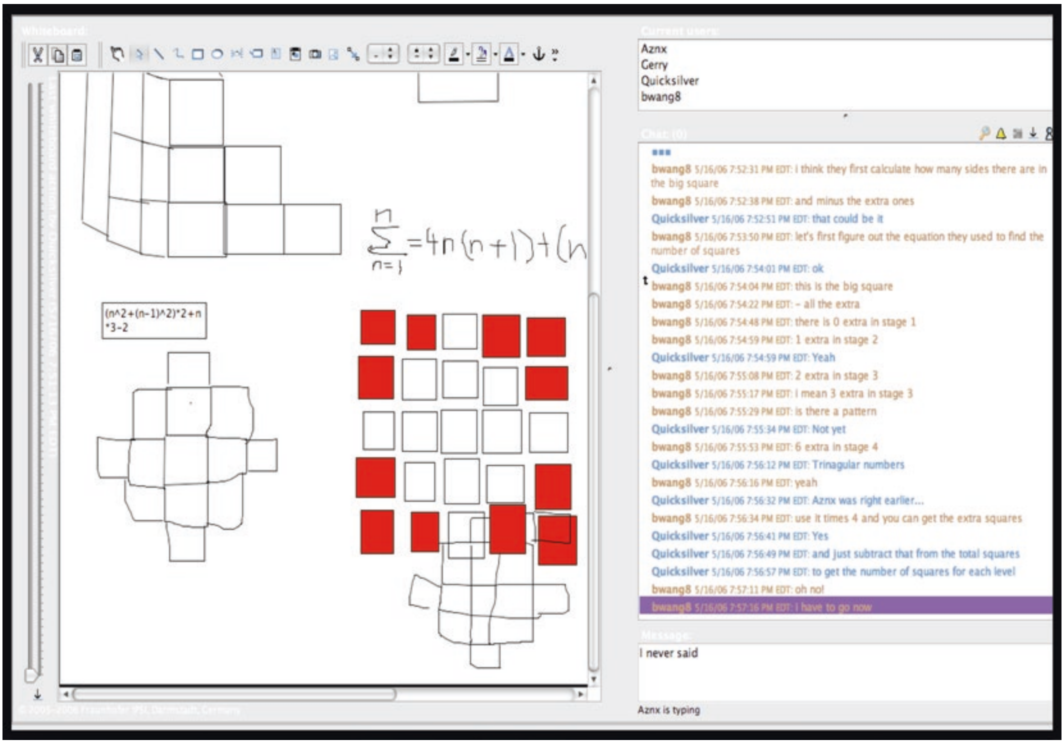


Fig. 24.6 Bwang expanded his drawing to make the diamond for N = 3. Note the red corners are now stair-step patterns

enclosing square minus this formula for the number of squares in each of the four corners to solve their problem.

Viewing the Learning and Thinking

Let us pause now from all these details about the case study of three students in a VMT session and talk about how we view learning and thinking in CSCL groups. I have tried to demonstrate how we view learning and thinking in CSCL groups by *viewing* with you how a group of three students engaged in collaborative thinking and learning processes within an online environment for drawing and chatting.

We went through several levels of analysis of the group discourse (see Fig. 24.7). We started by mentioning the overall context of the *event*. This was an online event in which Team B, consisting of three students, met in the Virtual Math Teams environment to discuss patterns of squares formed by sticks. We then focused on the smaller *session* unit, looking at Team B's third session, in which they considered a pattern that another group, Group C, had analyzed. Within this session, we identified one of several *themes* of discussion in that session, namely, the one involving Aznx' "interesting way to look at this problem."

Aznx introduced the theme by initiating a group problem-solving *move*. Namely, he got the group to view the problem in a certain way, as a diamond enclosed in a square. We saw how the group ended up drawing images in their shared whiteboard of diamond patterns enclosed in squares. Aznx introduced this group move in a subtle way; he did not simply come out and say, "We should analyze this

Event:	VMT Spring Fest 2006, Team B
Session:	session 3, May 16, 7:00-8:00 pm
Theme:	"I have an interesting way to look at this problem"
Move:	Show how to view
Pair:	"Can you see how it fits inside a square?" "Yes"
Utterance:	"Can you see how it fits inside a square?"
Reference:	"it", diamond pattern

Fig. 24.7 Levels of analysis of online group discourse

pattern as partially filling an enclosing square." Rather, he first announced that he had an interesting view, involving the others in his approach to make it a group problem-solving process. Then he asked if the others could view the problem in a certain way. He did this through a question/answer response *pair*: he asked a question, which elicited a yes-or-no response from the others. By eliciting the response, he oriented the others to look at the diagram in the whiteboard in a certain way—namely, in the way that his question implicitly proposed. A set of lines on the whiteboard are not immediately meaningful—they must be seen (interpreted) *as* something (Heidegger, 1927/1996, §32; Wittgenstein, 1953, §II xi).

Aznx' formulation of his question looks like a simple *utterance* in question format, but it entails selection from a number of different ways of picturing the relationships among the diamond pattern, the enclosing square, and the empty corners. To begin with, one must decide what the *reference* to "it" is doing.

Indexical references like the pronoun "it" are ubiquitous in online text chat—and unavoidable according to Garfinkel (1967) [see Investigation 5]. They require the reader to understand or reconstruct the implicit threading or response structure of the chat. The difficulty of doing this often leads to confusions, which require the participants to spend time clarifying the content and structure of their discussion. For instance, in our example of the move of seeing the diamond in the square, the group had to engage in a couple minutes of chatting and drawing to co-construct a shared understanding of the problem.

Issues of shared understanding can be analyzed as linguistic problems of reference. In other words, in order to view learning and thinking in CSCL groups, we do not try to figure out what is going on in the heads of the students; rather, we try to figure out what is going on in their chat postings and their drawing actions. This is what we call the group's *interaction*. In VMT, the interaction of the virtual math team consists of sequences of chat postings and drawing actions.

Our first step in figuring out what is going on in the chat postings and drawing actions is generally to try to analyze the sequencing of these by reconstructing their response structure—what previous action each new action is responding to and what kinds of action it is eliciting, what it is opening up an interaction space for, or what kinds of responses it is making relevant as next postings. Often, this leads to some kind of threading diagram (Çakir, Xhafa & Zhou, 2009), uptake graph (Suthers, Dwyer, Medina & Vatrapu, 2010b), or interaction model (Wee & Looi, 2009). This represents graphically a basic structure of the meaning-making sequencing. Then we try to understand what problem-solving work is being accomplished at each point in the sequence. This involves looking at different levels of granularity, such as the event, session, theme, move, pair, utterance, and reference. Understanding the meaning that the group is co-constructing in their interaction generally involves going back and forth through these different levels and integrating partial interpretations from the different levels in a dialectic of whole and part (Gadamer, 1960/1988).

Through this process, we can gradually view the learning and thinking that takes place in the CSCL group. This learning and thinking is not something that takes place primarily in the minds of the individual participants (although the individuals in the group are each continuously using their linguistic skills to understand what is going on and to respond to it with their postings and drawings). Rather, when there is an intense collaborative process taking place in the online environment, the thinking and learning take place in the visible text and graphical interactions.

According to the theory of group cognition, thinking in a CSCL collaborative interaction does not take place so much the way we usually think of thinking. Thoughts, or cognitive processes, are not characterized in terms of neurons connecting and firing in a brain; they are analyzed in terms of text postings and drawings referring to each other and building on each other, in the spirit of the idea of transactivity. We will look more at how this takes place in a minute. Similarly, learning does not take place the way we learned about learning. It is not viewed as a change in the amount of knowledge stored in a brain. Rather, it is described as a matter of knowledge artifacts being gradually refined through sequences of text postings and graphical drawings that are interrelated and that explicate each other. The knowledge artifacts may be statements about a problem the group is working on, as viewed from a new perspective that the group has developed. The knowledge artifact might be a drawing like Bwang's in Fig. 24.6 or an algebraic formula that sums up the group's analysis of pattern growth.

Unpacking the Group Learning and Thinking

Rather than talking about learning and thinking in the abstract, let us unpack some more how learning and thinking take place in Team B's interaction—in their text chatting and drawing together. Let's go back through the hierarchy of levels of analysis *in the opposite order* to say something about how references, utterances, response pairs, moves, themes, sessions, and events can contribute to learning and thinking in CSCL groups (see Fig. 24.8).

Reference: Network of Meaning, Indexical Ground, Joint Problem Space

When one studies logs of virtual math teams, one sees that they spend a lot of time reaching shared understanding about references in their postings. Elsewhere, I review an example of this from Team B's session 4, where Aznx, Quicksilver, and Bwang get quite confused about references from the chat to different equations written on the whiteboard (Stahl, Zemel & Koschmann, 2009).

The reason that people devote so much time and energy to resolving confusing references is that the network of references that they build up together plays an extremely important role in their group learning and thinking. In the theory of CSCL, there is considerable emphasis on the ideas of "common

Reference:	network of meaning, indexical ground, joint problem space
Utterance:	recipient design for reading's work
Pair:	projection and uptake
Move:	getting the problem-solving work done
Theme:	coherent interactional sequences
Session:	temporal structuring and re-member-ing
Event:	forming groups and co-constructing knowledge objects

Fig. 24.8 Levels of learning and thinking in online group discourse

ground" (Clark & Brennan, 1991) and "joint problem space" (Teasley & Roschelle, 1993). A group establishes common ground largely by reaching a shared understanding of how references work in their discourse. As it interacts over time, a group co-constructs a network of references that can become quite complex (Sarmiento & Stahl, 2008).

This network of references defines the context or situation in which the group discourse continues to take place. Aznx' reference to "it" that we looked at contributed to a network of meaning that the group built up continuously through their interaction. This network included images of sticks in various patterns (like diamonds at stage N = 2 and N = 3), the relationships of the patterns (like a diamond enclosed in a square with stair-step empty corners), concepts referred to by technical terms (like "triangular numbers" or "summation"), and symbols representing mathematical operations (like equations for number of squares in a pattern).

As a group builds up its network of shared references, it can use more shortcut references to point to things without creating confusion. People can use deictic references to point to things in the network, like "this formula," "the second equation," or "it." In linguistic terms, the shared network of references provides a background for referring to things, a so-called indexical ground of deictic reference (Hanks, 1992).

In problem-solving terms, the network of references forms a joint problem space, a shared view of the topic that the group is addressing (Sarmiento & Stahl, 2008). For Team B, the joint problem space starts with the stair-step pattern and the chart of the number of sticks and squares for each stage of this pattern as presented in the topic description for the event. By the middle of session 3, it includes the diamond pattern and the view of "it" enclosed in a square, forming empty corners. It also includes triangular numbers and their associated formula, as well as several other equations from Team C and from Team B's own work. The team's interaction (the text postings and drawings) gradually creates this joint problem space and is situated within it. The work and utterances of the team can only be understood (by the participants and by us as researchers) through an ongoing understanding of the joint problem space as a network of meaningful reference. For Team B, the VMT whiteboard makes their joint problem space visible and persistent as it evolves.

Utterance: Recipient Design for Reading's Work

While both the students who participate in the sessions and the researchers who analyze the logs need to understand the network of references, they understand them in very different ways. The students understand how to respond to what is going on the way they might know how to ride a bike. That is, they are not reasoning about it explicitly, rationally, logically, and consciously. Rather, they are paying attention to what is going on and responding knowingly and intuitively. Quicksilver has not carried out any kind of analysis of Aznx' word "it" the way I did; yet he could respond to it with a sophisticated set of questions. He only had a couple of seconds to respond, whereas I, as a researcher, could spend hours going back and forth over the log reasoning about explicit interpretations.

People are incredibly skilled at using language without thinking about how they do it. In fact, even researchers are only aware of a small percentage of what people take into account almost instantaneously without being aware of it. We say that Aznx "designs" his announcement and proposal so that it will be read by Bwang and Quicksilver in a way that will lead them to understand in a complex way. They will figure out what "it" is referencing but also realize some of the ambiguity of the reference. They will also come to think about the strategy for finding the number of squares in the diamond pattern because of this ambiguity. However, Aznx does not design his statement explicitly through a rational sequence of logical arguments. Rather, as a skilled user of language, he gives voice to a well-designed posting that responds to the current discourse situation. It is somewhat like the way a skilled off-road biker responds to the terrain intuitively as she is speeding down a rough hillside with no time to think about what she is doing—and she somehow designs an optimal path for her journey.

Aznx was successful in designing his question so that it would be read in a certain way within the context of the group's discussion in their joint problem space. This is what ethnomethodology calls the "accountability" of utterances (Garfinkel, 1967). This simply means that utterances are designed to be understood by their recipients, by the audience for whom they are intended. That is, utterances are designed to meet the expectations of their recipients (Garfinkel, 1967). They include an "account" of how they should be read, embedded in the design of their presentation. In chat, postings are designed to be read in a certain way by the other chat readers. We call this "recipient design." This is analogous to utterances in spoken talk, which are designed to be heard and are therefore given subtle vocal emphasis and timing. Chat postings, on the other hand, can incorporate capitalization, abbreviations, symbols, punctuation, emoticons, and special fonts. They can reference previous postings that occurred further back in time because the chat text is persistent, remaining visible or retrievable for longer than speech. In chat, group work takes place as reading; chat postings must be designed to support reading's work of understanding the posted utterances in their discourse context (Livingston, 1995; Zemel & Çakir, 2009).

Response Pair: Projection and Uptake

An important aspect of the design of utterances or postings is how they are designed to fit into what comes before and after them. In general, an utterance performs an uptake or response to something that came before (Suthers, Dwyer, Medina & Vatrapu, 2010a). At the same time, it elicits a follow-up or at least makes relevant certain forms of subsequent utterances by others (Schegloff, 2007). Through its uptake and projection, an utterance provides continuity to the discourse—in fact, it thereby creates a temporal structure (Heidegger, 1927/1996).

The clearest and simplest example of this is the adjacency pair or response pair, such as a question/answer pair. A question elicits an answer. That is, stating a question projects that an answer will be given in response. It opens a conversational space for an answer. It makes it relevant for the next utterance to be an answer responding to the question. In other words, a question is designed to be read as something that should be responded to with an answer. A question worded like "Can you see how it fits inside a square?" is designed to be answered with a "yes" or a "no." The question-and-answer pair forms a unity, a small unit of interaction between people. The "yes" response shows that the posting it is responding to was read as a question and creates the pair as a successful question/answer interaction.

One of my first discoveries in studying virtual math teams was that math discourse is largely driven forward by what I called "math proposal response pairs" (Stahl, 2006a, 2006b). These have the following structure:

- An individual makes a bid for a proposal to the group suggesting how the group should continue to do its mathematical work.
- Another member of the group accepts (or rejects) the proposal on behalf of the group.

This is the simple, default form of the math proposal response pair. If the proposal is accepted, then work begins on the proposal, often in the form of a follow-up proposal.

Of course, there are many variations and complications possible. The bid can be ignored or never responded to. In that case, it does not function as an effective proposal; at best it is a "failed proposal." Before a proposal response is made, there can be other response pairs inserted in the middle of the expected pair—such as a clarification question. It is also possible that someone will propose an amendment to the proposal bid before the original is accepted. Thus, a simple pair can develop a complicated recursive structure of insertions, extensions, repairs, etc.—with each of these being subject to their own insertions, extensions, or repairs. Eventually, each of the intervening pairs may get closed with its anticipated response, and then the original pair may be completed.

Move: Getting the Problem-Solving Work Done

Group problem-solving moves often have the structure of a longer sequence than a simple pair. Such a longer sequence may consist of a complex of response pairs embedded in one another. To identify such a structure, it may be necessary to first conduct a threading analysis to determine what is responding primarily to what. Then, it is often useful to see how this longer response sequence is built up out of simple response pairs (Stahl, 2011).

Together, these intertwining response pairs form a successful move, introducing a new theme for the group. As an example, let's look again at Aznx' move in Fig. 24.9.

We can see four response pairs there:

1. Aznx announces, "`I have an interesting way to look at this problem`," and Quicksilver responds by asking him to "`Tell us`."
2. Aznx asks, "`Can you see how it fits inside a square?`," and first Bwang responds "`yes`." Then Quicksilver responds "`Yes`." Then Bwang responds again, more emphatically, "`oh … yes`."
3. Quicksilver asks a clarification question about the proposal implicit in Aznx' question: "`You are saying the extra spaces …[?]`"
4. Aznx, in parallel with Quicksilver's question, asks a follow-up question, which contains an implicit further proposal about the group's work: "`Also, do you see if you add up the missing areas […?]`"

As the discussion continues, Quicksilver responds to Aznx' question, and the two of them continue to discuss the issues raised in both their questions.

line	start	post		
919	19:35:26	19:35:36	Aznx	I have an interesting way to look at this problem.
920	19:35:41	19:35:42	Quicksilver	Tell us
921	19:35:38	19:35:45	Aznx	Can you see how it fits inside a quare?
922	19:35:45	19:35:45	Bwang	yes
	19:35:49	19:35:52	Bwang	[user erased message]
923	19:35:51	19:35:52	Quicksilver	Yes
924	19:35:52	19:35:53	Bwang	oh
925	19:35:55	19:35:55	Bwang	yes
926	19:35:53	19:36:01	Quicksilver	You are sayingthe extra spaces...
927	19:35:58	19:36:05	Aznx	Also, do you see if you add up the missing areas

Fig. 24.9 The move to introduce Aznx' new way of looking at the group's problem

Theme: Coherent Interactional Sequence

Aznx' *move* introduces the *theme* of the diagonal pattern viewed as enclosed in a square with missing spaces in the four corners. As we have just seen, the move consists of multiple response pairs that drive the work of the group to consider this theme.

As the theme evolves, the group draws and discusses some increasingly elaborate drawings to view the patterns that the theme involves. The group considers different stages of the pattern (N = 1, 2, 3, 4) and how the number of missing spaces changes as the diamond pattern grows.

This leads them right to the point where they can formulate an equation to summarize their analysis of the pattern growth. Unfortunately, Bwang has to leave the session and they do not complete this work. During the fourth session 2 days later, the group picks up this theme and discusses it repeatedly, eventually deriving the equations for number of squares and sticks in the diamond pattern at all stages (Stahl, 2011). This theme is the basis for the equation for number of squares, which simply subtracts the number of missing spaces in the four corners of a square that encloses the diamond pattern.

Session: Temporal Structuring and Re-member-ing

After Bwang left the third session, Aznx and Quicksilver try to review the group's accomplishments. They become confused about various equations and unsure of their ability to explain what the group has figured out. They end the session with Quicksilver saying, "`then let's pick it up next time when Bwang can explain it`." This ends one session and projects what will happen in a future session.

When the group meets for the fourth session, Aznx and Quicksilver do eventually get Bwang to review the derivation of the equation based on the view of the problem that Aznx introduced in the theme we just considered. The discussion in session 4 refers back to the group's work in session 3 and also to Team C's work in session 2. But it does this in ways that are situated in Team B's session 4 context (Sarmiento-Klapper, 2009). The team members and the memories they bring with them from the past are reconstituted in the new situation, made relevant to the current themes, problem space, and available resources. The group remembering process makes the individual students who are present in the new sessions members of the group: it is a re-member-ing process, necessary at the start of many sessions, especially where the group membership has changed.

Event: Forming Groups and Co-constructing Knowledge Artifacts

At the beginning of session one, the students were not part of a particularly effective group or team. They did not build much on each other's contributions and were hesitant to make proposals, ask each other to undertake tasks, produce permanent drawings, or manipulate mathematical symbols. That all changed dramatically during their four-session event. By the end, they had many graphical, narrative, and symbolic representations or expressions related to their mathematical topic. They worked effectively together and solved their problems well. Problem-solving methods that one person introduced were later proposed and used by the other group members. Effective collaboration comes with interaction practice.

You may be wondering if each of the students learned mathematics. The interesting thing about looking closely at what really went on in this event is that what we traditionally consider to be the math content actually plays a relatively minor role in the group's problem-solving. Yes, content is brought in: the students talk about triangular numbers, and they apply the formula for summing consecutive integers, for instance. Often, this math content is brought in quickly through proposals by individuals. It is then discussed through responses to the proposal that check that everyone understands the math content and agrees on its applicability. However, the bulk of the hard work is not accessing the traditional math content but selecting, adapting, integrating, visualizing, sharing, explaining, testing, refining, building on, and summarizing sequences of group response pairs. These proposals and discussions reference not only math content but also various related resources that the group has co-constructed.

The learning and thinking of the group takes place through the group's discourse, as a temporally unfolding multilevel structure of response pairs interwoven into larger sequences of group moves, problem-solving themes, and sessions of events. The group learns about the mathematics of its topic by building and exploring an increasingly rich joint problem space. It thinks about the mathematical relationships and patterns by following sequences of proposals, raising and responding to various kinds of questions, and engaging in other sorts of interactional moves. Some of this gets summarized in persistent knowledge artifacts like drawings, concepts, equations, solution statements, and textual arguments. The building of the joint problem space generally requires a lot of work to resolve references and to co-construct a shared network of meaning (Stahl, Zhou, Çakir & Sarmiento-Klapper, 2011).

The math skills—like following certain procedures to do long division or to transform symbols—are not where the deep learning takes place and real knowledge is involved. Rather, the ability to sustain progressive inquiry through methods of group interaction is the real goal. This ability makes use of the math skills as resources for answering questions and coming up with new proposals.

If you wonder how to view learning and thinking in CSCL groups, follow Wittgenstein's advice: "Don't think, look!" My colleagues and I have tried to do this by looking at the work of virtual math teams in the way I have just described. We have been amazed to discover that collaborative learning and group cognition are a lot different than people thought.

CSCL as a New Approach to Computers in Education

Reading is learning, but applying is also learning and the more important kind of learning at that…. It is often not a matter of first learning and then doing, but of doing and then learning, for doing is itself learning.

—Chairman Mao 毛泽东 (1936)

Computers in education bring many advantages, even as seen within a traditional view of education:

- They give students and teachers access to all the information on the Web.
- They provide the ability to access lectures anywhere/anytime/on large scales.
- They can support testing, tutoring, and scripting of learning processes.
- They offer simulations, educational gaming, virtual reality, and artificial intelligence.

But networked computers in education—using CSCL software environments like VMT—also open opportunities for a radically new view of learning and thinking:

- Networking of students can let them get together with others interested in similar topics around the world.
- Effective collaborative-learning experiences help students learn how to work, think, and learn in groups. Group work is a new force of production in the world, and students need to learn how to produce knowledge in teams.
- CSCL events can give students first-hand, hands-on experience in knowledge building.
- Discussing mathematics in peer groups teaches students how to do math, how to talk about math, how to make math connections, how to learn math, and how to think mathematically.

In this second view of computers in education, book learning of facts and rote procedures has a place, but the more important kind of learning comes through doing. CSCL groups can provide effective learning experiences in which teams of students actually do mathematics by exploring rich problem spaces and discussing them—the way that Aznx, Quicksilver, and Bwang did.

There are *two* popular approaches to CSCL theory:

- Collaborative learning can be seen as an *extension* of traditional *individual* learning. Individuals possess knowledge that they can state in sentences and can communicate to other individuals. Our commonsense concepts can describe this, and we can measure what individuals know at different times. Learning in this traditional view is an increase in individual knowledge.
- Collaborative learning can be viewed as being *qualitatively* different from traditional individual learning, and we need to *discover* the nature of collaborative learning and its relation to individual learning by exploratory research. We need to *rethink* our ideas about learning, collaboration, education, computer support, research methodology, and cognitive theory (Stahl, 2006a). We need to look carefully at data from real CSCL sessions to see what *actually* takes place there, without imposing our commonsense views.

It should be clear by now that *I view* learning and thinking in CSCL groups as a mystery to be investigated, not as something well understood to be measured. It is a new form of human existence with great potential. We must observe it to learn how it works. My colleagues and I have begun to do this, as have other researchers in CSCL. I have tried to indicate to you here how you can go about observing learning and thinking in CSCL groups.

It may be easier to understand issues of technology design and of traditional instruction when studying computers in education than to understand this new view of learning and thinking. However, I believe that if we hope to get the most benefit from computers in education and to understand how groups learn and think in CSCL groups, then we will have to closely observe the discourse and interaction in ways similar to what I have presented here.

Afterword: Notes on Group Cognition

When one studies logs of virtual math teams, one sees that the teams spend a lot of time and effort constructing *shared understanding* about references in their postings. The reason that teams and other small groups devote so much time and energy to resolving confusing references is that the network of references that they build up together plays an essential role in their group learning and thinking. In the theory of CSCL, there is considerable emphasis on the idea of "common ground" (Clark & Brennan, 1991) and "joint problem space" (Teasley & Roschelle, 1993). A group establishes common ground largely by reaching a shared understanding of how references work in their discourse. As it interacts over time, a group co-constructs a network of references that can become quite complex.

The "shared understanding" that is built up is akin to the notion of *co-orientation*, which refers to the mutual orientation of individuals in a group toward an object (knowledge, belief, attitude), and can be traced back to the interactionist social psychology of John Dewey and George Herbert Mead. Psycho-linguistic metaphors of comparing stored mental representations are unnecessary and can be misleading, reducing all knowledge to individual mental possessions. Team members share a world centered on their task; they orient as a group to the objects that populate that world, such as Aznx' proposals, Bwang's drawings, and Quicksilver's queries. *Because they share a common world*—which they co-constitute largely through their discourse, mediated by the larger common social, cultural, and historical horizons of their world—*they can co-construct a shared understanding*.

The shared network of references defines the context or *situation* in which the group discourse continues to take place (Heidegger, 1927/1996, §18). Aznx' reference to "it" that we looked at contributed to a network of meaning that the group built up continuously through their interaction. This network included images of sticks in various patterns (like diamonds at stage N = 2 and N = 3), the relationships of the patterns (like a diamond enclosed in a square with stair-step empty corners), concepts referred to by technical terms (like "triangular numbers" or "summation") and symbols representing mathematical operations (like equations for number of squares in a pattern).

The co-construction of shared understanding by a small group is what I refer to as "group cognition."

This investigation represents a disciplinary perspective from Computer-Supported Collaborative Learning (CSCL), an interdisciplinary field concerned with leveraging technology for education and with analyzing cognitive processes like learning and meaning-making in small groups of students (Stahl et al., 2006). *Group cognition* is a theory developed to support CSCL research by describing how collaborative groups of students could achieve cognitive accomplishments together and how that could benefit the individual learning of the participants (Stahl, 2006a).

It may well be that a group of students working together manages to solve problems faster than any of the individual students may have been able to do alone—particularly when the problem is challenging for them. However, the most important benefits of group cognition are the potential for genuinely innovative solutions that go beyond the expertise of any individual in the group. It is the deeper understanding that is achieved through the interaction as part of that creative process—and the lasting impact of that deep understanding that the students take with them when they move on from that interaction—which they may then carry with them as new resources into subsequent group problem-solving scenarios. Group cognition can then be seen as what transforms groups into factories for the creation of new knowledge.

The types of problems that have been the focus of exploration within the group-cognition paradigm have not been routine, well-structured problems where every participant can know exactly what their piece of the puzzle is up-front in such a way that the team can divide up the work, *cooperate*, and function as a well-oiled machine. Many critical group tasks do not fit into well-known and practiced protocols—for example, low-resource circumstances that may occur in disaster situations, where standard solutions are not an option. In acknowledgment of this, the focus within the group-cognition research has been on problems that offer groups the opportunity to explore creatively how those problems can be approached from a variety of perspectives, where the groups are encouraged to *collaborate* and explore unique perspectives.

The processes that are the concern of group-cognition research have not primarily been those that are related to efficiency of problem-solving. Rather, the focus has been on the pivotal moments where a creative spark or a process of collaborative knowledge building occurs through interaction. Our fascination has been with identifying the conditions under which these moments of group inspiration are triggered, with the goal of facilitating this process of team innovation and collaborative knowledge creation.

The field of CSCL has explored what makes group discussions productive for learning under different names, such as *transactivity* (Azmitia & Montgomery, 1993; Berkowitz & Gibbs, 1983; di Lisi & Golbeck, 1999; Teasley, 1997), *uptake* (Suthers, 2006), *social modes of co-construction* (Weinberger & Fischer, 2006), or *productive agency* (Schwartz, 1998). Despite differences in orientation between the subcommunities where these frameworks have originated, the conversational behaviors that have been identified as valuable are quite similar. Specifically, these different frameworks universally value explicit articulation of reasoning and making connections between instances of articulated reasoning. For example, Schwartz and colleagues (1998) and de Lisi and Golbeck (1999) make very similar arguments for the significance of these behaviors from the Vygotskian and Piagetian theoretical frameworks, respectively. The idea of transactivity as a property of a conversational contribution originates from a Piagetian framework and requires that a contribution contain an explicit reasoning display and encode an acknowledgment of a previous explicit reasoning display. However, note that when Schwartz describes from a Vygotskian framework the kind of mental scaffolding that collaborating peers offer one another, he describes it in terms of one student using words that serve as a starting place for the other student's reasoning and construction of knowledge. This implies explicit displays of reasoning, so that the reasoning can be known by the partner and then built upon by that partner. Thus, the process is very similar to what we describe for the production of transactive contributions. In both cases, a transactive analysis would say that mental models are articulated, shared, mutually examined, and potentially integrated.

Group cognition is a post-cognitive theory [Investigation 15]. Post-cognitivism is a tradition characterized by situated, non-dualistic, practice-based approaches. Cognitivism—which retains theoretical remnants of the Cartesian dualism of the mental and physical worlds—originally arose through the critique of behaviorism, with the argument that human responses to stimuli in the world are mediated by cognitive activity in the mind of the human agent. This argument was particularly strong in considerations of linguistic behavior (Chomsky, 1959). More recently, post-cognitivist theories have argued that cognitive activity can span multiple people (as well as artifacts), such as when knowledge develops through a sequence of utterances by different people and the emergent knowledge cannot be attributed to any one person or assumed to be an expression of any individual's prior mental representations (e.g., Bereiter, 2002, p. 283).

Group-cognition theory explicitly focuses on these interpersonal phenomena and investigates data in which one can observe the development of cognitive achievements in the interactions of small groups of people, often in online collaborative settings, where interactions can be automatically logged. By interaction, we mean the discourse that takes place in the group. Group cognition is fundamentally a linguistic (speech or text) process, rather than a psychological (mental) one. Thus, unlike the theory of transactivity described above, this post-cognitive approach does not assume cognitive constructs such as mental models, internal representations, or retrievable stores of personal knowledge. In the online setting of VMT, cognition is analyzed by looking closely at the ways in which meaning is built up through the interplay of text postings, graphical constructions, and algebraic formulations (Çakir, Zemel, et al., 2009) [Investigation 12].

There is a tension between the human sciences and the natural sciences, between *understanding* team cognition (e.g., with micro-analysis of situated case studies) and *explaining* it (e.g., modeling, confirming general hypotheses, formulating laws, and specifying predictive causal relations). Group cognition in online teams involves both humans and computers—both highly situated collaborative interactions and programmed computer support. Thus, the analysis of group cognition must integrate the identification of characteristic patterns with the recognition of irreducible uniqueness of cases.

In our research, our colleagues and we look at logs of student groups chatting and drawing about mathematics in order to see if they build on each other's ideas to achieve more than they would individually. How do they understand each other and build shared language and a joint problem focus?

What kinds of problems of understanding do they run into and how do they overcome those? How do they accomplish intersubjective meaning-making, interpersonal trains of thought, shared understandings of diagrams, joint problem conceptualizations, common references, and coordination of problem-solving efforts: planning, deducing, designing, describing, problem-solving, explaining, defining, generalizing, representing, remembering, and reflecting as a group? What can we say about the general methods that small groups use to learn and think as groups? How can we support and encourage this better with software support for social awareness, social networking, simulations, visualizations, and communication, with intelligent software agents, with pedagogical scaffolds and guidance, with training and mentoring, with access to digital resources, and with new theories of learning and thinking? To answer these complex questions, we must look carefully at the details of discourse in CSCL groups and develop innovative tools (both analytic and automated) and theories (of cognition by individuals, small groups, and discourse communities).

The field of CSCL is particularly interested in the ways small groups can build knowledge together, thanks to communication and support from the networking technology. We hope that CSCL environments can be designed to encourage groups to think and learn collaboratively.

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Investigation 25. Structuring Problem-Solving

Gerry Stahl

Abstract

To develop a science of small-group interaction in collaboration software, we need a method for analyzing the structure of computer-mediated discourse that complements our theory of group cognition. We need an approach to understanding the structure of interaction during group sessions of mathematical problem-solving and similar group-cognitive activities. Conversation analysis offers an analysis of conversational talk in terms of a fine structure of adjacency pairs and offers some suggestions about longer sequences built on these pairs.

This investigation presents a case study of students solving a math problem in an online chat environment. It shows that their problem-solving discourse consists of a sequence of exchanges, each built on a base adjacency pair and each contributing a move in the longer sequences of the solution process.

Keywords

Adjacency pair · Longer sequence · Conversation analysis · Discourse · Problem-solving

Structuring Group Cognition at Multiple Levels

Information, people, and technology converge in a practical way in online collaborative problem-solving. My colleagues and I have been pursuing a research agenda aimed at investigating how to support online collaborative problem-solving. We have focused on the domain of school mathematics—especially beginning algebra and geometry—where students learn formal techniques and tacit practices of solving abstract problems. This is perhaps the most perspicuous occasion for observing the development of abstract thinking, including systematic problem-solving. In a collaborative context, students have to demonstrate to each other what they are doing and why. As researchers studying such interactions, we find that mechanisms of group problem-solving can become visible in this context.

G. Stahl (✉)
Chatham, MA, USA
e-mail: Gerry@gerrystahl.net

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Our research—such as that reported here—confirms that there are distinctive processes of information use in problem-solving at the small-group unit of analysis. These processes should not be reduced to either the individual psychological level or the larger social community level—despite the fact that groups are physically composed of individuals and that they are embedded in sociohistorical contexts. A small group of young students does not solve a problem the way that an individual adult does or the way a mathematical algorithm would indicate. Group cognition is distinct from both individual and social cognition. While an approach methodologically focused on the group unit of analysis is in line with current post-cognitive theories, it is rarely carried out consistently at that level.

We developed the Virtual Math Teams (VMT) environment and invited students to work in online groups for up to 8 hour-long sessions. We presented challenging problems for them to explore together and encouraged them to pursue their own questions. The environment was instrumented to capture a complete and accurate record at the group unit of analysis—i.e., all text-chat postings, all drawing actions, and all social awareness messages that were displayed to the group. As researchers, we can replay the group interaction and view it as it appeared to the group or browse it in as much detail as needed for analysis.

Because we are pursuing design-based research to improve the VMT environment, we are not oriented toward theoretical hypotheses, statistical generalizations, individual mental representations, or sociocultural influences—except to the extent that they manifest themselves within the group interaction. Rather, we try to understand the situated processes that take place at the group level of description in actual case studies. In particular, we look at the ways in which groups of math students use information and solve problems in our environment so that we can design improved sociotechnical supports for their collaborative online problem-solving.

We have tried a variety of research approaches in the VMT Project, including coding, statistical comparison, modeling, uptake analysis, conversation analysis, critical ethnography, and discourse analysis. In general, we have found the most insightful approach to involve adapting ethnomethodologically inspired conversation analysis (CA) to our context of online text chat by math students.

In Investigation 24, (Stahl, 2009a), I claimed that the discourse of group cognition has a hierarchical structure, typically including the following levels:

- **Group event**: E.g., Team B's participation in the VMT Spring Fest 2006
- **Temporal session**: Session 3 of Team B on the afternoon of May 16, 2006
- **Conversational topic**: Determining the number of sticks in a diamond pattern
- **Discourse move**: A stage in the sequence of moves to accomplish discussing the conversational topic
- **Adjacency pair**: The base interaction involving two or three utterances, which drives a discourse move
- **Textual utterance**: A text chat posting by an individual participant, which may contribute to an adjacency pair
- **Indexical reference**: An element of a textual utterance that points to a relevant resource

The multilayered structure corresponds to the multiplicity of constraints imposed on small-group discourse—from the character of the life-world and of culture (which mediate macro-structure) to the semantic, syntactic, and pragmatic rules of language (which govern the fine structure of utterances). A theory of group cognition must concern itself primarily with the analysis of mid-level phenomena—such as how small groups accomplish collaborative problem-solving and other conversational topics.

The study of mid-level group-cognition phenomena is a realm of analysis that is currently underdeveloped in the research literature. For instance, many CSCL studies focus on coding individual (micro-level) utterances or assessing learning outcomes (macro-level), without analyzing the group processes (mid-level). Similarly, conversation analysis (CA) centers on micro-level adjacency pairs, while sociocultural discourse analysis is concerned with macro-level identity and power, without characterizing the interaction patterns that build such macro phenomena out of micro-elements. Understanding these mid-level phenomena is crucial to analyzing collaborative learning, for it is this level that largely mediates between the interpretations of individuals and the sociocultural factors of communities.

In the current investigation, we will see how a small group of students collaborating online constructed a coherent longer sequence, through which they solved the problem that they had posed for themselves. In particular, we will look at the final conversational topic in Session 4 of the same virtual math team whose Session 3 is analyzed in Investigation 24.

Methodologically, it is important to note that the definition of the longer sequence—like that of the other levels of structure listed above—is oriented to by the discourse of the students and is not simply a construct of the researcher.

An Analytic Method

I have tried to apply our approach based on CA in a systematic way to the analysis of VMT chat logs. Schegloff's (2007) book on *Sequence Organization in Interaction: A Primer in Conversation Analysis* represents the culmination of decades of CA. As indicated by its subtitle, it provides a useful primer in CA. My goal here is to extend the CA approach based on short sequences of utterances to analyze the larger-scale interactions of group problem-solving in VMT.

Schegloff's presentation highlights the central role of the adjacency pair as the primary unit of sequence construction according to CA. An adjacency pair is composed of two turns by two different people, with an interactional order, such as a question followed by an answer to the question. The simple two-turn pair can be extended with secondary adjacency pairs that precede, are inserted between, or follow up on the base pair, potentially recursively. This yields "extensive stretches of talk which nonetheless must be understood as built on the armature of a single adjacency pair, and therefore needing to be understood as extensions of it" (p. 12).

These "extensive stretches of talk" are still focused on a single interaction of meaning-making, and not a larger cognitive achievement like problem-solving, involving multiple steps. However, both Sacks and Schegloff provide only vague suggestions about the analysis of longer sequences. These suggestions have not been extensively developed within CA. This essay is an attempt to explore them in an online text-chat context.

Schegloff (2007) briefly takes up "larger sequence structures to which adjacency pairs can give rise and of which they may be building blocks … such as sequences of sequences" (p. 12). One way in which a sequence (an extended adjacency pair) may be related to, yet separate from, a previous, completed adjacency pair "is that it implements a next step or stage in a course of action, for which the just-closed sequence implemented a prior stage" (p. 213). Note the two-way reference, with the second stage having the character of a next but also the first stage having the character of a prior. This is analogous to the two parts of a simple adjacency pair according to Schegloff:

> Adjacency pair organization has (in addition to the backwards import just described) a powerful prospective operation. A first pair part projects a prospective relevance, and not only a retrospective understanding. It makes relevant a limited set of possible second pair parts, and thereby sets some of the terms by which a next turn will be understood—as, for example, being responsive to the constraints of the first pair part or not. (p. 16)

The adjacency-pair structure was first discussed extensively by Sacks (1965/1995, II 521–569). In these seminal lectures, he also briefly discussed long sequences. Here, his main point was to state that little is known about the structure of long sequences, that the analytic problem is in principle harder, and that, in particular, it is wrong to assume that an analysis at the level of adjacency pairs will be useful to understanding the co-construction of long sequences:

> It turns out that one central problem in building big packages is that the ways the utterances that turn out to compose the package get dealt with as single utterances or pairs of utterances or triplets of utterances, etc., may have almost no bearing on how they're to be dealt with when an attempt is made to build the larger package. (II p. 354)

The analyses provided by CA come primarily from the study of American adults conducting face-to-face, verbal, informal, social conversation, although some of the early data came from distance conversations by telephone and the field has broadened its sources considerably more recently. However, we must be careful when applying CA methods to online, text-based, learning-related discourse about mathematics by students. Along these lines, Schegloff (2007) warns about his presentation:

> Note that this discussion is focused on conversation in particular. Because different organizations of turn-taking can characterize different speech-exchange systems (Sacks, Schegloff, & Jefferson, 1974, n. 11 729–731), anything that is grounded in turn-taking organization may vary with differences in the turn-taking organization. It is a matter for empirical inquiry, therefore, how the matters taken up in the text are appropriately described in non-conversational settings. (p. 15n)

As we have frequently argued (e.g., Stahl, 2006, 2009c; Stahl, Koschmann, & Suthers, 2006), we believe that adapting CA to computer-mediated communication offers the best prospects for analysis of interaction in sociotechnical environments like VMT. The preceding review of the topics of adjacency pairs and long sequences indicates that it is an empirical question how well this proposed adaptation might work in specific cases. We designed and conducted the VMT Project from 2003 to 2015 in order to produce a corpus of data that could be analyzed in as much detail as needed to determine the structure of group cognition, that is, of collaborative knowledge building through interaction at the group unit of analysis.

In looking at the VMT data corpus, the VMT research team has clearly seen the differences between online text chat and verbal conversation. The system of turn-taking so important in CA (Sacks et al., 1974) does not apply in chat. Instead, chat participants engage in reading's work (Zemel & Çakir, 2009), in which "readers connect objects through reading's work to create a 'thread of meaning' from the various postings available for inspection" (p. 274f). The first and second parts of an adjacency pair may no longer be literally temporally adjacent to each other, but they still occur as mutually relevant, anticipatory, and responsive. The task of reading's work—for both participants and analysts—typically includes reconstructing the threading of the underlying adjacency-pair response structure (Stahl, 2009b).

In CA, adjacency pairs are related to both issues of timing (turn-taking) and of sequentiality (response). In chat, they retain their importance solely as sequential, in order to maintain interaction in the absence of turn-taking. We have tried to explore the larger sequential structure of problem-solving chat by using the CA notion of openings and closings (Schegloff & Sacks, 1973). VMT researchers looked at several math chats from 2004, which used a simple chat tool from AOL. We coded and statistically analyzed the fine-structure threading of adjacency pairs (Çakir, Xhafa, & Zhou, 2009). In addition, we defined long sequences based on when opening and closing adjacency pairs achieved changes in topic (Zemel, Xhafa, & Çakir, 2009). These long sequences were graphed to show their roles in constituting the chat sessions, but their internal sequential structures were not investigated at that time.

My colleagues and I have subsequently conducted numerous case studies from the VMT corpus. We have been particularly drawn to the records of Team B and Team C in the VMT Spring Fest 2006. These were particularly rich sessions of online mathematical knowledge building because these teams of students met for over 4 hours together and engaged in rich explorations of interesting mathematical phenomena. However, partially because of the richness of the interactions, it was often hard for analysts to determine a clear structure to the student interactions. Despite access to everything that the students knew about each other (team members were spread across the USA) and about the group interaction, it proved hard to unambiguously specify the group-cognition processes at work (Medina, Suthers, & Vatrapu, 2009; Stahl, 2009b; Stahl, Zemel, & Koschmann, 2009).

Therefore, in the following case study, I have selected a segment of Team B's final session, in which the structure of the interaction seems to be clearer. The interaction is simpler than in earlier segments partially because two of the four people in the chat room leave. Thus, the response structure is more direct and less interrupted. In addition, the students have already been together for over 4 hours, so they know how to interact in the software environment and with each other. Furthermore, they set themselves a straightforward and well-understood mathematical task. The analysis of this relatively simple segment of VMT interaction can then provide a model for subsequently looking at the more complex data and seeing if it may follow a similar pattern.

The Case Study

Three anonymous students (Aznx, Bwang, Quicksilver) from US high schools met online as Team B of the VMT Spring Fest 2006 contest to compete to be "the most collaborative virtual math team." They met for 4 hour-long sessions during a 2-week period in May 2006. A facilitator was present in the chat room to help with technical issues, but not to instruct in mathematics.

In their first session, they solved a given combinatorics problem, finding a mathematical formula for the growth pattern of the number of squares and the number of sticks making up a stair-step figure. They determined the number of sticks by drawing just the horizontal sticks together and then just the vertical ones (see Fig. 25.1). They noticed that both the horizontals and the verticals formed the same pattern of `1 + 2 + 3 + … + n + n` sticks at the `n`th stage of the growth pattern. They then applied the well-known Gaussian formula for the sum of consecutive integers, added the extra `n`, and multiplied by `2` to account for both the horizontal and vertical sets of sticks.

In the second session, they explored problems that they came up with themselves, related to the stair-step problem, including 3-D pyramids. Here they ran into problems drawing and analyzing 3-D structures. However, they managed to approach the problem from a number of perspectives, including decomposing the structure into horizontal and vertical sticks.

In the third session, Team B was attracted to a diamond-shaped variation of the stair-step figure, as explored by Team C in the Spring Fest. They tried to understand how the other team had derived its solution. They counted the number of squares by simplifying the problem through filling in the four corners surrounding the diamond to make a large square; the corners turned out to follow the stair-step pattern from their original problem.

In the fourth session, they discovered that the other team's formula for the number of sticks was wrong. In the following, we join them an hour and 17 min into the fourth session, when one of the three students as well as the facilitator had to leave.

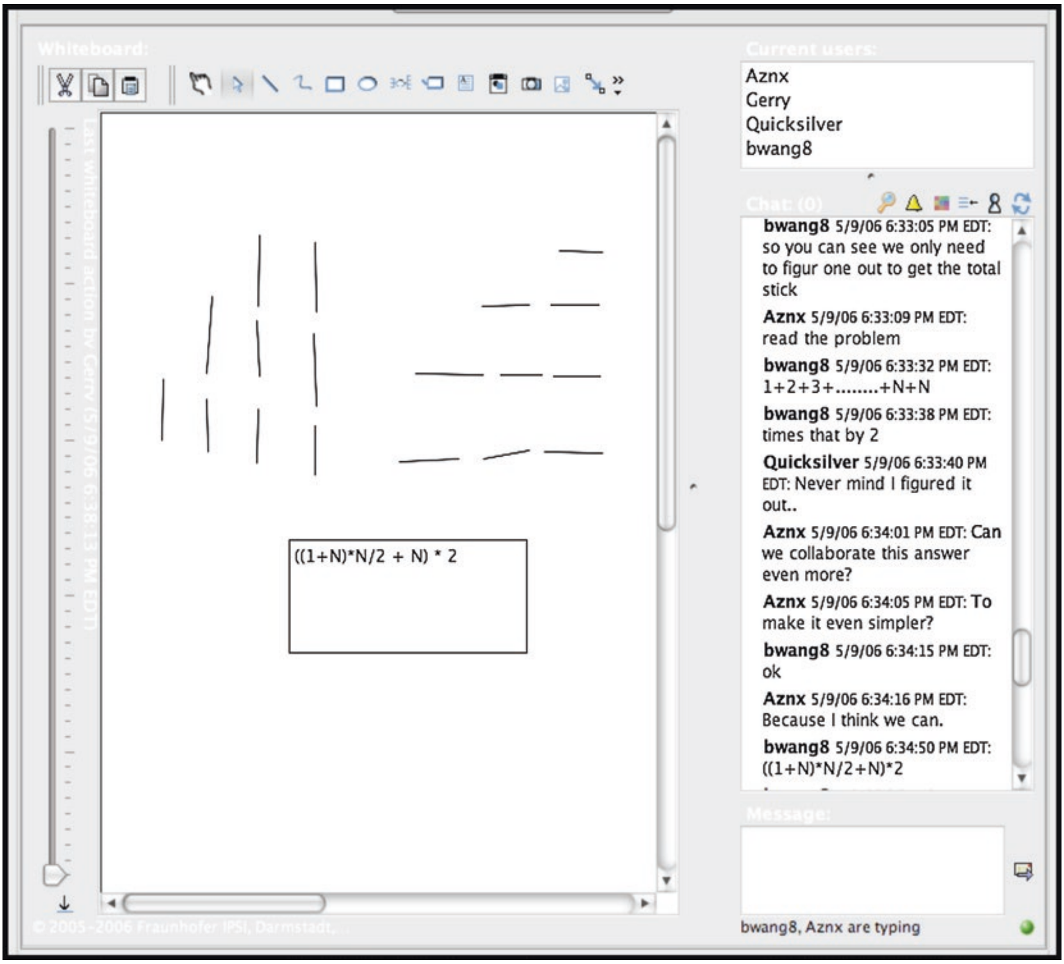

Fig. 25.1 Screenshot of the VMT environment showing the pattern of horizontal and vertical sticks in the stair-step figure

Problem-Solving Moves

In this section, the interaction will be analyzed as a sequence of moves in the problem-solving interaction between Bwang and Aznx, the two remaining students. Each move is seen to include a base adjacency pair (changed to **bold** face in the logs), which provides the central interaction of the move and accomplishes the focal problem-solving activity. The captions given by the researchers to the log excerpts indicate the aim of the move, according to the analysis.

In line 1734 of Log 25.1, Bwang states that the team is close to being able to solve the problem of the number of sticks in the nth stage of the diamond pattern, suggesting that they might stay and finish it. Note that this is the end of the last of the scheduled four sessions for the contest, despite some arrangements underway to allow the team to continue to meet.

Log 25.1. Open a Topic

Line	Time	Author	Text of chat posting
1734	08.17.20	bwang8	i think we are very close to solving the problem here
1735	08.17.35	Quicksilver	Oh great...I have to leave
1736	08.17.39	Aznx	**We can solve on that topic.**
1737	08.17.42	Quicksilver	Sorry guys
1738	08.17.45	bwang8	oh
1739	08.17.46	Aznx	It shouldn't take much time.
1740	08.17.47	bwang8	**ok**
1741	08.17.50	Aznx	k, bye Quicksilver
1742	08.17.52	Quicksilver	Just tell me the name of the room
1743	08.17.52	bwang8	bye
1744	08.18.14	Gerry	The new room is in the lobby under Open Rooms
1745	08.18.44	Gerry	It is under The Grid World. It has your names on it
1746	08.18.49	Quicksilver	[leaves the room]
1747	08.19.00	Aznx	Alright found it.
1748	08.19.04	Aznx	Thanks.

Aznx responds in line 1736, indicating—and implicitly endorsing the suggestion—that the team could indeed continue to work on the current topic. This opens the topic for the group.

Quicksilver apologetically stresses that he must leave immediately. He just wants to know the location of the new chat room that the facilitator is setting up for the team to continue its math explorations on a future date. The facilitator supplies this information and everyone says goodbye to Quicksilver. We ignore this other activity in our current analysis and focus on the problem-solving interactions.

Aznx expresses uncertainty about how to proceed now that Quicksilver has gone and the facilitator has arranged things for the future. He questions whether he and Bwang need to go as well (Log 25.2). Bwang then reiterates his suggestion that they could stay and finish solving the problem. He argues that it should not take much longer. Bwang directly asks Aznx if he wants to solve the problem now.

Log 25.2. Decide to Start

1749	08.19.12	Aznx	I guess we should leave then.
1750	**08.19.34**	**bwang8**	**well do you want to solve the problem**
1751	08.19.36	bwang8	i mean
1752	08.19.39	bwang8	we are close
1753	**08.19.48**	**Aznx**	**Alright.**
1754	08.19.51	bwang8	i don't want to wait til tomorrow
1755	08.19.53	bwang8	ok

Aznx agrees by responding to Bwang's question in the affirmative. This effects a decision by the pair of students to start working on the problem right away. Bwang continues to argue for starting on the problem now—posting line 1754 just 3 seconds after Aznx' agreement, probably just sending what he had already typed before reading Aznx' response. Bwang then acknowledges the response.

Once a decision has been made to solve the problem, the question of how to approach the problem is raised in line 1756 (Log 25.3). Bwang immediately lays out his approach in lines 1757, 1759, 1764, and 1765. The approach is the same as they used in the first session: visualize just the vertical or just the horizontal sticks. The two sets follow the same pattern. In fact, the diamond is also symmetric left/right and top/bottom, so the vertical sticks can be divided left/right into two identical sets, and the horizontal sticks can be divided top/bottom. This produces four identical sets of sticks (color-coded in Fig. 25.2), each having rows of `1, 3, 5, 7,` … sticks, up to `(2n-1)` for the `n`th stage of the diamond pattern.

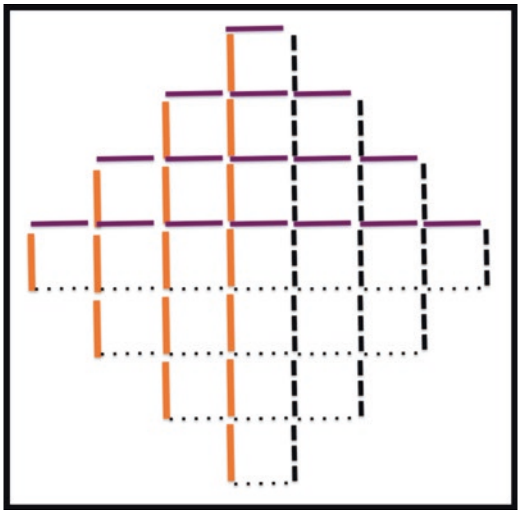

Fig. 25.2 A representation (not from the data) of the diamond figure at stage n = 4, color-coding the sticks in four identical (symmetric) sets

Log 25.3. Pick an Approach

1756	08.19.55	Aznx	**How do you want to approach it?**
1757	08.20.14	bwang8	**1st level have 1*4**
1758	08.20.20	Gerry	You can put something on the wiki to summarize what you found today
1759	08.20.29	bwang8	2st level have (1 + 3)*4
1760	08.20.32	Aznx	bwang you put it.
1761	08.20.35	Aznx	for the wiki
1762	08.20.37	bwang8	ok
1763	08.20.42	Aznx	we actually did quite a lot today
1764	08.20.53	bwang8	3rd level have (1 + 3 + 5)*4
1765	08.21.05	bwang8	4th level have (1 + 3 + 5 + 7)*4
1766	08.21.10	Gerry	This is a nice way to solve it

Interspersed with this defining of the approach is a reminder from the facilitator to summarize the team's work on the Spring Fest wiki for other teams to see, motivating this with a word of encouragement about the team's work.

Aznx has previously been oriented toward finding patterns of growth in the mathematical objects the group has been exploring. Often, someone will create a graphical representation of the object in such a way that it makes the pattern visible. Aznx will then formulate a textual description of the pattern. Then the group will work on a symbolic representation to capture the pattern in a mathematical formula. (See (Çakir, Zemel, & Stahl, 2009) [Interaction 12] for an analysis of the intertwining of graphical/visual, textual/narrative and symbolic/mathematical modes of interaction within the work of Team C.)

Here, in line 1767 (Log 25.4), Aznx describes the pattern as involving adding numbers that successively increase by `2`. The number of sticks in a given stage of the diamond shape is a sum of numbers that start at `1` and increase successively by `2`. When going from one stage to the next, one simply adds another number to this sum that is `2` more than the highest previous one.

Log 25.4. Identify the Pattern

1767	08.21.12	Aznx	**So it's a pattern of +2s?**
1768	08.21.15	Aznx	Ah ha!
1769	08.21.15	bwang8	**yes**
1770	08.21.20	Aznx	There's the pattern!

Aznx presented his description as a question, and Bwang affirmed it at the same time as Aznx posted line 1768. Aznx then emphasized that they had discovered the pattern.

Bwang indicates that the next step in their work is to "find an equation that describes the pattern" (line 1771, Log 25.5). Aznx asks Bwang to let him state the equation, implicitly agreeing that this is the next step by trying to produce the equation.

Log 25.5. Seek the Equation

1771	08.21.39	bwang8	now we have to find a equation that describe that pattern
1772	08.21.49	Aznx	Hold on.
1773	08.21.51	Aznx	I know it.
1774	**08.21.57**	**bwang8**	**what is it**
1775	08.21.58	Aznx	But I'm trying to remember it. =P
1776	08.22.04	Aznx	and explain it as well.
1777	08.22.17	Aznx	try and think of it
1778	08.22.53	Gerry	Maybe Quicksilver can come back here tomorrow or next week to finish it with you
1779	08.23.01	Gerry	I have to go now
1780	08.23.05	Gerry	Bye!
1781	08.23.06	bwang8	ok
1782	08.23.07	bwang8	bye
1783	08.23.23	Gerry	[leaves the room]
1784	08.23.29	bwang8	ok
1785	08.23.32	bwang8	so
1786	08.23.37	bwang8	i think it is this
1787	08.23.53	Aznx	ok
1788	08.23.55	Aznx	i found it
1789	**08.24.00**	**Aznx**	**n^2**
1790	08.24.01	bwang8	(2*n)*n/2
1791	08.24.09	Aznx	or (n/2)^2

Bwang asks Aznx to state the equation, and Aznx expresses difficulty in formulating an adequate and accountable answer. After a half minute of silence with still no formulation from Aznx, the facilitator suggests that Aznx and Bwang might want to wait until a future time when the whole group can work together to finish the problem. The facilitator then says goodbye and leaves the chat room.

After more than a minute since Aznx posted anything, Bwang starts to preface the presentation of his own formulation. Eventually, Aznx joins back in. Simultaneously, Aznx and Bwang post their formulae. For Aznx, it is either `n`^{2} or `(n/2)`^{2}. For Bwang, it is `2n(n/2)`.

Aznx has not given any indication of how he got his proposed formula. The format of Bwang's formula suggests the use of Gauss' summation, which the students have used repeatedly in the past. According to this summation of an arithmetic sequence of integers, the result is the sum of the first and last member of the sequence times half the number of members. For a sequence of `n` members, `1 + 3 + 5 + … + (2n-1)`, the sum would be `[1 + (2n-1)]*(n/2)`. Adding the `1` and the `-1` yields Bwang's formula: `2n(n/2)`. Note that the `n`th odd integer can be represented by `(2n-1)`.

It is likely that Aznx used a similar method, working on his own during his prolonged silence, but got confused about the result when he simplified his expression. As Aznx shows next, Aznx's first answer is equivalent to Bwang's answer, once Aznx simplifies it (in Log 25.6). His second answer is related to part of Bwang's unsimplified answer.

Log 25.6. Negotiate the Solution

1792	08.24.14	Aznx	I'm simplifying
1793	08.24.30	Aznx	if u simplify urs
1794	**08.24.35**	**Aznx**	**its n^2**
1795	08.24.59	Aznx	bwang
1796	08.25.01	Aznx	you there?
1797	**08.25.03**	**bwang8**	**so that's wrong**
1798	08.25.07	bwang8	yeah
1799	08.25.08	bwang8	i am here

Aznx simplifies Bwang's formula: $2n(n/2) = n^2$. This is the same as one of Aznx' proposed formulae. When Bwang does not respond to this posting, Aznx wonders if Bwang is still present online.

Bwang was apparently already typing "so that is wrong" when he received Aznx' question concerning his presence. This message in effect confirmed that Aznx' second formula, (n/2)2, is wrong and his first one, which agrees with Bwang's, is correct.

Going along with this, Aznx then multiplies their agreed upon formula by 4 because there were 4 sets of horizontal or vertical sticks, each numbering 1 + 3 + ... In lines 1800–1802 (Log 25.7), Aznx poses his message as a question, soliciting confirmation from Bwang. By offering this next step in the symbolic representation, Aznx demonstrates that he understands where Bwang's formula came from, and he understands the larger strategy of approaching the problem that Bwang had proposed. In other words, Aznx demonstrates a level of mathematical competence and of shared understanding that he did not always display in the previous sessions.

Log 25.7. Check Cases

1800	08.25.11	Aznx	so
1801	08.25.13	Aznx	the formula
1802	**08.25.22**	**Aznx**	**would be 4n^2?**
1803	08.25.28	bwang8	let's check
1804	08.25.55	bwang8	Yes
1805	**08.26.00**	**bwang8**	**it actually is**
1806	08.26.02	Aznx	So we got it!

Before being ready to answer whether $4n^2$ is actually the correct formula for the number of sticks, Bwang suggests that they first check if the formula works by testing it for a number of values of n and counting the sticks in drawings of diamonds at the corresponding nth stage. A half minute later, Bwang concludes that the formula does check out. He therefore answers Aznx' question with a confident "Yes," perhaps expressed with a touch of surprise.

Aznx concludes that they got the solution for the number of sticks in the diamond pattern—a problem that Team C had posed for itself, but for which they had derived the wrong formula, without, however, realizing it. Team B had been shocked earlier to discover that the formula they had been struggling to understand from Team C had been wrong: it did not check out for any values of n.

Their surprise and excitement at correctly solving this elusive problem is almost uncontrollable. In Log 25.8, they use every chat technique they know to express their joy. Their postings intertwine like a frenzied dance.

Log 25.8. Confirm the Solution

1807	08.26.02	bwang8	omg
1808	08.26.04	Aznx	yay!
1809	**08.26.08**	**bwang8**	**i think we got it!!!!!!!!!!!!**
1810	**08.26.12**	**Aznx**	**WE DID IT!!!!!!**
1811	08.26.12	bwang8	and it is so simple
1812	08.26.14	Aznx	YAY!!!!
1813	08.26.16	Aznx	i know
1814	08.26.17	bwang8	lol
1815	08.26.18	Aznx	lol

Once the mathematical exploration is done, it is time to write up a report of one's findings. They plan their report in Log 25.9.

Log 25.9. Present a Formal Solution

1816	08.26.34	Aznx	So you're putting it in the wiki, right?
1817	08.26.37	bwang8	yes
1818	08.26.41	Aznx	Alright then.
1819	08.26.43	bwang8	ok
1820	08.26.53	Aznx	Give an email to Gery, telling him that we got it. =)
1821	08.26.57	bwang8	ok
1822	08.26.59	Aznx	I meant Gerry
1823	08.27.04	bwang8	**are you going to do it**
1824	08.27.07	bwang8	or am i
1825	08.27.12	Aznx	**You do it.**
1826	08.27.14	bwang8	ok
1827	08.27.19	Aznx	Tell him that we both derived n^2
1828	08.27.29	Aznx	And then we saw that pattern
1829	08.27.37	Aznx	and we got the formula

Professional mathematicians would do this in the form of a proof. When a group of mathematicians recently conducted an online collaborative analysis of a mathematical problem, it took them longer to write the publishable proof than it did to figure out the approach and solve it (Gowers & Nielsen, 2010; Polymath, 2010).

Sometime after the chat session, Bwang posted the narrative shown in Fig. 25.3 to the Spring Fest wiki.

Finally, Aznx and Bwang wrap up the conversational topic by exchanging email addresses and agreeing to meet again online with Quicksilver and pursue further mathematical adventures together (Log 25.10).

Log 25.10. Close the Topic

1830	08.27.44	Aznx	when should we meet again?
1831	08.27.49	Aznx	what's your email?
1832	**08.27.52**	**Aznx**	**we should keep in touch**
1833	**08.27.57**	**bwang8**	**yeah**

```
We then move on to understand Team C's formula for summing up the
total # of sticks in n-level diamond. We first tried to used the big
square and then minus the extra corners, but the corners turns out to
be to hard to calculate. Then we tried to simplify Team C's equation
to help as find a lead, but we found out that their stick equation is
wrong. We then decide to find out a whole new equation and tried to
divide the sticks up into vertical and horizontal groups like we did
before with all the other problems. The groups can be further divided
into 2 equal parts. We found a pattern.

1st level: 1
2nd level: 1+3
3rd level: 1+3+5
4th level: 1+3+5+7
5th level: 1+3+5+7+9
nth level: (2*n)*n/2

We then found out that each of these can be by calculated by (2*n)*n/2
which simplified into n^2. n^2 can then be multiplied by 4 and get the
total of sticks in a nth leveled diamond. The final equation is
4(n^2).
```

Fig. 25.3 Wiki posting by Group B after session 4

The Sequence of Pairs

Within each of the preceding log excerpts, we have identified a base adjacency pair by means of which the work of a specific move in the problem-solving effort of the small group is interactively accomplished. In most cases, a question is posed and a response is then given to it.

As Schegloff (2007) argues, an adjacency pair is itself a sequence. It embodies a temporal structure, with the first element of the pair projecting the opportunity and expectation of a response in the interactional immediate future. The second element constitutes an uptake of a first element that it implicitly references as in the interactional immediate past (Suthers, Dwyer, Medina, & Vatrapu, 2010). In engaging in the exchange of an adjacency pair, the participants in the interaction effectively co-construct an elementary temporal structure in which future and past are constituted.

In talk-in-interaction, as analyzed by conversation analysis, the immediacy of response is intimately related to the turn-taking structure of vocal conversation (Sacks et al., 1974). As mentioned above, the completion of the adjacency pair is often postponed by insertion sequences, such as repairs of misunderstandings or clarification exchanges. The base adjacency pair can also be preceded by introductory exchanges, such as announcements of what is coming, or succeeded by follow-up exchanges or confirmations.

In chat-in-interaction, as seen in the preceding log extracts, adjacency pairs can be delayed by a more complicated response structure, in which multiple participants can be typing simultaneously and postings do not always directly follow the message to which they are responding. Thus, in Log 25.1, Quicksilver or Gerry can be initiating other topics in the midst of an interaction between Aznx and Bwang. Also, Aznx and Bwang can be typing to each other simultaneously as in Log 25.6, particularly if there has been an extended period of inactivity. This often makes textual chat harder to follow and to analyze than verbal conversation.

Nevertheless, it is generally possible to identify base adjacency pairs carrying the discourse along. In the previous section, we identified ten pairs. The discourse moves in the log excerpts (each including one of these base adjacency pairs) formed a problem-solving sequence:

- Log 25.1. Open the topic
- Log 25.2. Decide to start
- Log 25.3. Pick an approach
- Log 25.4. Identify the pattern
- Log 25.5. Seek the equation
- Log 25.6. Negotiate the solution
- Log 25.7. Check cases
- Log 25.8. Confirm the solution
- Log 25.9. Present a formal solution
- Log 25.10. Close the topic

The integrity of each of the ten moves is constructed by the discourse of the participants. Each move contains its single base adjacency pair, which drives the interaction. In addition, there may be several utterances of secondary structural importance, which introduce, interrupt, or extend the base pair; there may also be some peripheral utterances by other participants.

The analysis of this essay is an attempt to make explicit the structure of adjacency pairs and a problem-solving longer sequence that is experienced by the participants and is implicit in the formulation of their contributions to the discourse. This is in contrast to analytic approaches that to some degree impose a set of coding categories based on the analyst's research interests or on an a priori theoretical framework, rather than on the perspective of the participants as evidenced in their discourse.

Lines 1795 and 1796, for instance, show the power *for the participants* of the adjacency pairings. Here, Aznx has addressed a mathematical proposal to Bwang: "`If you simplify yours` [expression]`, it is n`^{2}." After 24 seconds of inaction, Aznx cannot understand why Bwang has not replied, expressing agreement or disagreement with the first part of the proposal, for which Aznx expects a response. Because it is not a preferred move at this point for Aznx to reprimand Bwang for not responding, Aznx inquires if Bwang has disappeared, perhaps due to a technical software problem, which would not be anyone's fault. Two seconds later, we see that Bwang was typing a more involved response that implicitly accepted Aznx' proposal. Bwang then immediately explicitly accepts the proposal in line 1798, allowing Aznx to continue with the start of a new move with line 1802. Here we see Aznx and Bwang clearly orienting to the adjacency-pair structure of their discourse, in terms of their expectations and responses.

Aznx and Bwang co-constructed the longer (ten-move) problem-solving sequence by engaging in the successive exchange of adjacency pairs. Sometimes one of the students would initiate the pair, sometimes the other. As soon as they completed one pair, they would start the next. This longer sequence also has a temporal structure. It is grounded in their present situation, trying to find a formula for the number of sticks in the diamond figure. It makes considerable use of resources from their shared (co-experienced) past during the previous 4 hours of online sessions. It is strongly driven forward into the future by the practices they have learned for engaging in problem-solving, culminating teleologically in the presentation of a solution.

The problem-solving sequence analyzed in this essay—covering 100 lines of chat during 10 minutes—is not selected arbitrarily or imposed in accordance with criteria external to the interaction but is grounded in the discourse as structured by the participants. The excerpted sequence is defined as a coherent conversational topic by the discourse of Aznx and Bwang. They explicitly open (jointly decide upon) this topic with their interaction in Log 25.1, and they close it (wrap it up and move on) with the discourse move in Log 25.10 (Schegloff & Sacks, 1973).

This case study provides an unusually clear and simple example of group cognition in a virtual math team. In earlier sessions, the students encountered many difficulties, although they also achieved a variety of successes and learned much about both collaboration and mathematics. At the beginning of their first session, they did not know how to behave together and showed rather poor collaboration skills. Bwang said very little in English, often simply producing drawings or mathematical expressions. Aznx, at the other extreme, tried hard to engage the others but seemed to display a weak mathematical understanding of what the others were discussing. At various points in the sessions, misunderstandings caused major detours and breakdowns in the group work. Moreover, from an analyst's perspective, the interaction was often almost impossible to parse or interpret (Stahl, 2009b). By contrast, in the final segment that is here reviewed, the interaction is focused on two participants; they work well together; they seem to follow each other well; and their work goes quite smoothly. The structure of the interaction is also relatively easy to follow.

It seems that Aznx and Bwang have substantially increased their skills in online collaborative mathematics. The level of their excitement—especially in the excerpt of Log 25.8—shows they are highly motivated. Log 25.10 indicates that they would like to continue this kind of experience in the future.

Collaborative Mathematical Meaning-Making

Shared meaning is co-constructed as the discourse moves (the log excerpts based around adjacency pairs) build on each other to form the longer sequence of the discourse topic. This is a key level of analysis for understanding the workings of group cognition. Because these discourse moves are founded upon adjacency pairs, they essentially involve more than one participant and therefore lend themselves to being vehicles for cognitive phenomena at the group unit of analysis. Through their sequential positioning and subtle forms of mutual referencing, they contribute to problem-solving and other cognitive accomplishments. As an example, we can see how Team B solved its mathematical problem across Logs 25.5, 25.6, and 25.7.

In Log 25.5, we see that collaborative problem-solving of a math topic—like most group meaning-making—is an intricate intertwining of individual interpretation and shared meaning (Stahl, 2009b). Bwang (line 1771) states the goal for the dyad of finding an equation to describe the pattern of twos. Aznx immediately announces that he knows the equation (1773) and wants to provide it (1772), to which Bwang acquiesces (1774). However, Aznx has trouble coming up with an equation: remembering it, explaining it, thinking of it, or finding it. After a while, Bwang gradually announces that he will provide the equation (1784–1786). Then they both propose equations. Throughout the online session, mathematical proposals originate from the understanding of individual students. In this excerpt, they negotiate about who is to make the proposal and end up both doing so.

Then it is necessary in Log 25.6 to decide whose proposal will be adopted by the group as a basis for future work. Interestingly, Aznx reconciles their proposals by algebraically transforming Bwang's equation to be the same as one of Aznx' own (1792–1794). This circumvents the possibility that Bwang will reject Aznx' proposal, which he in fact does (1797). It also establishes a group solution whose meaning (derivation, use, form) is likely to be mutually understood since the solution was proposed by both.

Finally, in Log 25.7, Aznx takes a further mathematical step, multiplying the n^2 by 4 to account for the four symmetrical sets of sticks. However, he presents this final formula in question format (1800–1802), soliciting Bwang's agreement in order to establish the formula within their joint problem space. Bwang implicitly accepts Aznx's step and reinterprets the question as requiring a next step of checking the formula for values of n. Bwang presumably checks several values and concludes that the formula works (1804–1805). Aznx summarizes, "So we got it!" Note his use of the pronoun, "we," attributing the solving to the group.

The formula, $4n^2$, is a particularly meaningful expression in this chat, the triumphal culmination of 4 hours of mathematical exploration. It is a highly meaningful expression for the group, summarizing their analysis of the diamond pattern of sticks at every level of n. The students understand its meaning as a consequence of their participation in the group processes of drawing and discussing together a rich set of related mathematical phenomena. The shared meaning of the math expression is publicly available in the discourse and through its traces in the log; it was co-constructed through the contributions of individuals and is interpreted by those individuals—and later by analysts.

The Structure of Group Cognition

The analysis of the case study in this essay provides a first analysis of the long-sequence-of-moves structure of collaborative mathematical problem-solving in a virtual math team. This is a paradigmatic example of group cognition. The small group—here reduced to a dyad—solves a math problem whose solution had until then eluded them (and had escaped Team C as well).

The students accomplish the problem-solving by successively completing a sequence of ten moves. Each of the moves seems almost trivial, but each takes place through an interaction that involves both students in its achievement. The moves are commonplace, taken-for-granted practices of mathematical problem-solving. They are familiar from individual and classroom problem-solving in algebra classrooms. They have also been encountered repeatedly by Team B in their previous 4 hours of collaborative problem-solving (Medina et al., 2009).

Reviewing the sequence of the group's ten moves presented in this essay, we can follow the mathematical solution process. After opening the topic of the sticks problem (Log 25.1) and deciding to work on it together (Log 2), the team picked an approach of looking at the number of sticks as being countable with the series (1+3+5+7+…)*4 (Log 25.3). This series is generated by counting the sticks in a visual representation of the diamond pattern at different values of n (Fig. 25.2). This uses the approach from previous sessions of separating the horizontal and vertical sticks (Fig. 25.1) and then dividing each of those groups into two symmetrical groups (Fig. 25.3). The group then articulates a verbal description of this visual series as being "a pattern of +2s" (Log 25.4). Both students try to symbolize the pattern of the verbal description as an equation (Log 25.5) and they come to agreement on the formula as n^2 (Log 25.6), presumably based on the formula for summing integer series, familiar to them from previous sessions. They then check that their equation works for a number of stages of the diamond pattern (Bwang does this offline during Log 25.7). Having solved the mathematical challenge as a group, they celebrate the group achievement: "WE DID IT!!!!!!" (Log 25.8), decide to present their solution publicly (Log 25.9), and close the discourse topic (Log 25.10).

It is this sequence of moves that accomplishes the problem-solving. The sequence has an inner logic, with each move requiring the previous moves to have already been successfully completed (taking it up) and each move preparing the way for (anticipating, projecting) the following ones. Of course, in working on a problem, problem-solvers—even professionals (Gowers & Nielsen, 2010; Polymath, 2010)—often make mistakes and explore dead ends. Team B's wiki posting (Fig. 25.4) documents that some of this had happened prior to the excerpt analyzed in this essay. Part of what contributes to the unusual clarity of our example is the simplicity of the sequence followed in the final segment.

The common assumption about mathematical problem-solving is that information in the form of math facts and manipulations is what is most important. In our analysis of problem-solving in a group context, math content and other information is simply, unproblematically included in individual postings. In fact, more often than not, it is implicitly used and understood "between the lines" of the text chat. Of course, this is only possible because the group had already co-constructed a joint problem space (Medina et al., 2009; Sarmiento & Stahl, 2008; Teasley & Roschelle, 1993) that included this math content as already meaningful for the group.

Rather, the important aspects of discourse engaged in collaborative math problem-solving are matters of coordination, communication, explanation, decision-making, and perspective shifting (e.g., moving between visual, verbal, and symbolic modes (Çakir, Zemel et al., 2009) [Interaction 12]). To some extent, these are interactional moves required by most group activities; to some extent, these are adapted to the nature of mathematical discourse.

In conclusion, the group-cognitive achievement of the solution to the group's final problem was accomplished by a sequence of moves. Each move was mundane when considered by itself. The moves and their sequencing were common practices of mathematical problem-solving. The group had adopted—implicitly or explicitly—the math practices as group practices [Interaction 16]. Each move was interactively achieved through the exchange of base adjacency pairs situated in the ongoing discourse. The problem-solving was an act of group cognition structured as a sequence of these interactive moves.

While we cannot generalize from the analysis in this essay, it seems that this case study can serve as a perhaps unusually clear and simple model of the structure of group cognition in mathematical problem-solving by a virtual math team. It shows the group cognition taking place through the co-construction of a temporal sequence of problem-solving moves. Each move is conducted on the basis of an interactional adjacency pair of chat utterances. While the fine structure adheres to the adjacency-pair system of interactional exchange, the larger problem-solving structure builds on these elements through a sequence defined by the topical moves of mathematical deduction.

More generally, this suggests a multilayered hierarchical structure to discourse in virtual math teams, which we explored in Investigation 24. Each layer is oriented to by the participant activities:

(a) **Group event**: E.g., Team B's participation in the VMT Spring Fest 2006. The team meets together and gradually starts to act as a collaborative group.
(b) **Temporal session**: Session 4 of Team B on the afternoon of May 18, 2006. The participants agree when to break up a session and when to meet next and then show up at the same time.
(c) **Conversational topic**: Determining the number of sticks in a diamond pattern (lines 1734 to 1833 of Session 4). We saw how Bwang and Aznx open the topic and later close it.
(d) **Discourse move**: A stage in the sequence of moves to accomplish discussing the conversational topic (e.g., lines 1767 to 1770). The team steps through the sequence of moves.

(e) **Adjacency pair**: The base interaction involving two or three utterances, which drives a discourse move (lines 1767 and 1769). Each initial utterance elicits a response.
(f) **Textual utterance**: A text chat posting by an individual participant, which may contribute to an adjacency pair (line 1767). The group members format their separate postings.
(g) **Indexical reference**: An element of a textual utterance that points to a relevant resource. In VMT, actions and objects in the shared whiteboard are often referenced. Mathematical content and other resources from the joint problem space and from shared past experience are also brought into the discourse by explicit or implicit reference in an utterance.

The preceding analysis illustrates the applicability of the notion of a long sequence as suggested by both Sacks (1965/1995) and Schegloff (2007). The sequence consists of a coherent series of shorter sequences built on adjacency pairs. This multilayered sequential structure is adapted from CA to the essentially different, but analogous, context of groupware-supported communication and group cognition. Having seen that this kind of sequential structure exists in the relatively simple case we analyzed, we can now look for longer sequences in the traces of other acts of groupware-mediated group cognition.

Addendum: Coding Scheme for Sequential Discourse

We have developed a coding scheme for the multilayered hierarchical structure we have found in discourse in virtual math teams. The coding scheme was developed based on the analysis of adjacency pairs according to Schegloff (2007). It was applied to the entire log of Session 4 of Team B, conducted during VMT Spring Fest 2006.

The basic idea is that discourse is built up hierarchically: from (g) various indexical references (e.g., "that") in (f) textual utterances (e.g., chat postings) contributing to (e) adjacency pairs (e.g., question/answer). Sequences of adjacency pairs (including extensions and recursive embeddings) form (d) discourse moves. The moves contribute to (c) conversational topics (that are opened and closed). Topics are included in larger (b) group events, which make up (a) the entire session (e.g., Session 4 of Team B).

In Table 25.1, examples of (c) through (f) are included under those headings. Schegloff's symbols are listed for use in coding utterances in adjacency pairs. For each symbol, its meaning is given. The list contains some common FPPs (first pair parts) of adjacency pairs, with their corresponding SPPs (second pair parts).

In Table 25.2, the excerpt (lines 1734–1829), which was analyzed in this investigation, is coded in accordance with the coding scheme. The coding process involved considerable back-and-forth influence between the coding of the threading, the code, the utterance category, the adjacency pair, and the discourse move.

Table 25.1 Coding scheme

(c) Conversational topic	(d) Discourse move	(e) Adjacency pair	(f) Textual utterance	(g) Indexical reference		(b) Group event	(a) Temporal session
transition	anticipate	announcement	announce; acknowledge; follow up				
opening	close	compliment	compliment; acknowledge	Schegloff symbols	meaning of symbol	FPP	SPP
technical	open	explanation	explain; acknowledge; follow up	F, Fbase	first pair part (base FPP)	question/ask	answer
feedback	return to	greeting	greet; return greeting; farewell; return farewell	S, Sbase	second pair part (base SPP)	request	grant
select	introduce new approach	joke	joke; laugh; respond to joke; return laughter	Fpre	pre-sequence FPP	offer *	reject
review	terminate use of approach	proposal	propose; acknowledge; ratify; reject; follow up	Spre	pre-sequence SPP	invite *	accept
wiki		question	question; answer; agree; disagree; follow up	Fins	insert sequence FPP	announce	decline
equation		request	request; acknowledge; accept; reject; follow up	Sins	insert sequence SPP	greet	agree
indexing		suggestion	suggest; acknowledge; ratify; reject; follow up	SCT	sequence closing third	farewell	disagree
compare		directive	direct; acknowledge; receive; reject; follow up; report	Fpost	post sequence FPP	notice *	acknowledge
strategy		evaluation	evaluate; acknowledge; agree; disagree	Spost	post sequence SPP	promise *	contest
wrong		commentary	comment; acknowledge; agree; disagree	+S	preferred SPP	tell *	tease
celebrate		clarification	clarify; acknowledge	PCM	post completion musing	complain *	finess
facilitator		repair	self-correct; question; clarify; acknowledge			propose	comply
follow-up		failed X escalated X		ni	non-interactive or system message	suggest	perform
closing		+ (continuation)	+ (continue)	+	continuation	request	ratify
Construction						direct	follow up
narrative						joke	receive
reflection						laugh	report

						Compliment	assess
						explain	return
						clarify	clarify
						repair	
						evaluate	
						comment	

Table 25.2 Coding of an excerpt from Spring Fest 2013

Line #	Time posting	Bwang8	Aznx	Quicksilver	Gerry	Threading	Code	Utterance category	Adjacency pair	Dis-course move	Conversational topic
1734	20:17:20	i think we are very close to solving the problem here				1709	Fb	proposal	proposal	open topic	sticks
1735	20:17:35			Oh great...I have to leave		--	Fpre	announce	announcement	open topic	sticks
1736	20:17:39		We can solve on that topic.			1734	Sb	ratify		open topic	sticks
1737	20:17:42			Sorry guys		1735	+	+		open topic	sticks
1738	20:17:45	oh				1735	Spre	acknowledge		open topic	sticks
1739	20:17:46		It shouldn't take much time.			1736	+	+		open topic	sticks
1740	20:17:47	ok				1738	SCT	acknowledge		open topic	sticks
1741	20:17:50		k, bye aditya			1737	F	farewell	farewell	open topic	sticks
1742	20:17:52			Just tell me the name of the room		1737	Fpost	question	question	open topic	sticks
1743	20:17:52	bye				1737	F	farewell	farewell	open topic	sticks
1744	20:18:14				The new room is in the lobby under Open Rooms	1742	Spost	answer		open topic	sticks

1745	20:18:44				It is under The Grid World. It has your names on it	1744	+	+		open topic	sticks
1746	20:18:49			leaves the room			ni			open topic	sticks
1747	20:19:00		Alright found it.			1745	SCT	acknowledge		open topic	sticks
1748	20:19:04		Thanks.			1747	+	+		open topic	sticks
1749	20:19:12		I guess we should leave then.			1748	F	question	question	decide to start	sticks
1750	20:19:34	well do you want to solve the problem				1749	Fb	question	question	decide to start	sticks
1751	20:19:36	i mean				1750	+	+		decide to start	sticks
1752	20:19:39	we are close				1751	+	+		decide to start	sticks
1753	20:19:48		Alright.			1752	Sb	agree		decide to start	sticks
1754	20:19:51	i don't want to wait til tomorrow				1752	+	+		decide to start	sticks
1755	20:19:53	ok				1753	SCT	agree		decide to start	sticks
1756	20:19:55		How do you want to approach it?			1755	Fb	question	question	pick an approach	sticks
1757	20:20:14	1st level have 1*4				1756	Sb	follow up		pick an approach	sticks

(continued)

Table 25.2 (continued)

Line #	Time posting	Bwang8	Aznx	Quicksilver	Gerry	Threading	Code	Utterance category	Adjacency pair	Dis-course move	Conversational topic
1758	20:20:20				You can put something on the wiki to summarize what you found today	1757	F	direct	directive	pick an approach	sticks
1759	20:20:29	2st level have (1+3)*4				1757	+	+	proposal	pick an approach	sticks
1760	20:20:32		bwang you put it.			1758	F	direct	directive	pick an approach	sticks
1761	20:20:35		for the wiki			1760	+	+		pick an approach	sticks
1762	20:20:37	ok				1761	S	agree		pick an approach	sticks
1763	20:20:42		we actually did quite a lot today			1761	F	proposal	proposal	pick an approach	sticks
1764	20:20:53	3rd level have (1+3+5)*4				1759	+	+		pick an approach	sticks
1765	20:21:05	4th level have (1+3+5+7)*4				1764	+	+		pick an approach	sticks
1766	20:21:10				This is a nice way to solve it	1764	F	compliment	compliment	pick an approach	sticks
1767	20:21:12		So it's a pattern of +2s?			1765	Fb	question	question	identify pattern	sticks
1768	20:21:15		Ah ha!			1767	+	+		identify pattern	sticks
1769	20:21:15	yes				1767	Sb	agree		identify pattern	sticks
1770	20:21:20		There's the pattern!			1769	Fpost	proposal	proposal	identify pattern	sticks

1771	20:21:39	now we have to find a equation that describe that pattern				1770	F	proposal	proposal	seek equation	sticks
1772	20:21:49		Hold on.			1771	Fpre	request	request	seek equation	sticks
1773	20:21:51		I know it.			1772	+	+		seek equation	sticks
1774	20:21:57	what is it				1773	Fb	question	question	seek equation	sticks
1775	20:21:58		But I'm trying to remember it. =P			1773	+	+		seek equation	sticks
1776	20:22:04		and explain it as well.			1775	+	+		seek equation	sticks
1777	20:22:17		try and think of it			1776	+	+		seek equation	sticks
1778	20:22:53				Maybe Quicksilver can come back here tomorrow or next week to finish it with you	1777	F	proposal	failed proposal	seek equation	sticks
1779	20:23:01				I have to go now	1778	Fpre	announce	announcement	seek equation	sticks
1780	20:23:05				Bye!	1779	F	farewell	farewell	seek equation	sticks
1781	20:23:06	ok				1780	Spre	acknowledge		seek equation	sticks
1782	20:23:07	bye				1781	S	farewell		seek equation	sticks

(continued)

Table 25.2 (continued)

Line #	Time posting	Bwang8	Aznx	Quicksilver	Gerry	Threading	Code	Utterance category	Adjacency pair	Dis-course move	Conversational topic
1783	20:23:23				leaves the room		ni			seek equation	sticks
1784	20:23:29	ok				1771	SCT	acknowledge		seek equation	sticks
1785	20:23:32	so				1784	+	+		seek equation	sticks
1786	20:23:37	i think it is this				1785	Fpre	proposal	proposal	seek equation	sticks
1787	20:23:53		ok			1786	SCT	announce		seek equation	sticks
1788	20:23:55		i found it			1787	Fpre	announce	announcement	seek equation	sticks
1789	20:24:00		n^2			1788	Sb	answer		seek equation	sticks
1790	20:24:01	(2*n)*n/2				1786	F	proposal	proposal	seek equation	sticks
1791	20:24:09		or (n/2)^2			1789	+	+		seek equation	sticks
1792	20:24:14		I'm simplifying			1791	Fpre	explain		negotiate solution	sticks
1793	20:24:30		if u simplify urs			1790	+	+		negotiate solution	sticks
1794	20:24:35		its n^2			1793	Fb	proposal	proposal	negotiate solution	sticks
1795	20:24:59		bwang			1794	F	question	question	negotiate solution	sticks
1796	20:25:01		you there?			1795	+	+		negotiate solution	sticks
1797	20:25:03	so that's wrong				1796	Sb	reject		negotiate solution	sticks
1798	20:25:07	yeah				1796	S	answer		negotiate solution	sticks

1799	20:25:08	i am here				1798	+	+		negotiate solution	sticks
1800	20:25:11		so			1799	Fpre	announce	announcement	check cases	sticks
1801	20:25:13		the formula			1800	+	+		check cases	sticks
1802	20:25:22		would be 4n^2?			1801	Fb	question	question	check cases	sticks
1803	20:25:28	let's check				1802	S	follow up		check cases	sticks
1804	20:25:55	yes				1803	Spre	agree		check cases	sticks
1805	20:26:00	it actually is				1804	Sb	answer		check cases	sticks
1806	20:26:02		So we got it!			1804	SCT	ratify		check cases	sticks
1807	20:26:02	omg					F	laugh	joke	celebrate	sticks
1808	20:26:04		yay!			1807	S	laugh		celebrate	sticks
1809	20:26:08	i think we got it!!!!!!!!!!!!				1806	Fb	announce	announcement	celebrate	sticks
1810	20:26:12		WE DID IT!!!!!!			1809	Sb	ratify		celebrate	sticks
1811	20:26:12	and it is so simple				1809	Fpost	proposal	proposal	celebrate	sticks
1812	20:26:14		YAY!!!!			1812	S	laugh		celebrate	sticks
1813	20:26:16		i know			1811	Spost	agree		celebrate	sticks
1814	20:26:17	lol				1813	S	laugh		celebrate	sticks
1815	20:26:18		lol			1814	S	laugh		celebrate	sticks
1816	20:26:34		So you're putting it in the wiki, right?			1815	Fb	question	question	present solution	sticks
1817	20:26:37	yes				1816	Sb	agree		present solution	sticks

(continued)

Table 25.2 (continued)

Line #	Time posting	Bwang8	Aznx	Quicksilver	Gerry	Threading	Code	Utterance category	Adjacency pair	Dis-course move	Conversational topic
1818	20:26:41		Alright then.			1817	SCT	follow up		present solution	sticks
1819	20:26:43	ok				1817	SCT	agree		present solution	sticks
1820	20:26:53		Give an email to Gery, telling him that we got it. =)			1819	F	direct	directive	present solution	sticks
1821	20:26:57	ok				1820	S	agree		present solution	sticks
1822	20:26:59		I meant Gerry			1820	S	repair		present solution	sticks
1823	20:27:04	are you going to do it				1820	F	question	question	present solution	sticks
1824	20:27:07	or am i				1823	+	+		present solution	sticks
1825	20:27:12		You do it.			1824	S	answer		present solution	sticks
1826	20:27:14	ok				1825	S	agree		present solution	sticks
1827	20:27:19		Tell him that we both derived n^2			1826	F	direct	directive	present solution	sticks
1828	20:27:29		And then we saw that pattern			1827	+	+		present solution	sticks
1829	20:27:37		and we got the formula			1828	+	+		present solution	sticks

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Appendices

Notes on the Investigations

Introduction

Written for this volume in 2017.

Investigation 1
Written for this volume in 2017.

Investigation 2
Written for this volume in 2017 with ideas and excerpts from the following *ijCSCL* editorial introductions:

- Conceptualizing the intersubjective group (Stahl, 2015b)
- Ethnomethodologically informed (Stahl, 2012b)
- Cognizing mediating: Unpacking the entanglement of artifacts with collective minds (Stahl, 2012a)
- Traversing planes of learning (Stahl, 2012c)
- Learning across levels (Stahl, 2013)

Investigation 3
Reprint of Jones, Dirckinck-Holmfeld, and Lindstrom (2006).

Investigation 4
Reprint of Suthers (2006).

Investigation 5
Reprint of Zemel and Koschmann (2013).

Investigation 6
Reprint of Overdijk, van Diggelen, Andriessen, and Kirschner (2014).

Investigation 7
Reprint of Ritella and Hakkarainen (2012).

Investigation 8
Reprint of Stahl (2008).

G. Stahl (ed.), *Theoretical Investigations*, Computer-Supported Collaborative Learning Series 18,
https://doi.org/10.1007/978-3-030-49157-4

Investigation 9
Reprint of Öner (2016).

Investigation 10
Reprint of Reimann (2009).

Investigation 11
Reprint of Damsa (2014).

Investigation 12
Reprint of Çakir, Zemel, and Stahl (2009).

Investigation 13
Reprint of Looi, So, Toh, and Chen (2011).

Investigation 14
Reprint of Chan (2011).

Investigation 15
Edited and extended version of Stahl (2016b).

Investigation 16
Edited and extended version of Stahl (2017).

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Investigation 17
Edited and extended version of Stahl, Zhou, Çakir, and Sarmiento-Klapper (2011).

Investigation 18
Edited and extended version of Stahl (2016a).

Investigation 19
Edited and extended version of constitution (Stahl, 2014).

Investigation 20
Edited and extended version of Stahl (2005).

Investigation 21
Edited and extended version of Stahl (2015a).

Investigation 22
Edited and extended version of Stahl (2006a).

Investigation 23
Edited and extended version of Stahl (2006b).

An earlier version of the first part of this paper won a Best Paper Award at ICCE 2005 in Singapore (Stahl, 2005). The Virtual Math Teams Project is a collaborative effort at Drexel University. The Principal Investigators are Gerry Stahl, Stephen Weimar, and Wesley Shumar. A number of Math Forum staff work on the project, especially Stephen Weimar, Annie Fetter, and Ian Underwood. The graduate research assistants are Murat Çakir, Johann Sarmiento, Ramon Toledo, and Nan Zhou. Alan Zemel is the post-doc; he facilitates weekly conversation analysis data sessions. The following visiting researchers have spent 3 to 6 months on the project: Jan-Willem Strijbos (Netherlands), Fatos Xhafa (Spain), Stefan Trausan-Matu (Romania), Martin Wessner (Germany), and Elizabeth Charles (Canada). The VMT-Chat software was developed in collaboration with Martin Wessner, Martin Mühlpfordt, and colleagues at the Fraunhofer Institute IPSI in Darmstadt, Germany. The VMT project is supported by grants from the NSDL, IERI, and SoL programs of the US National Science Foundation.

Investigation 24

Edited and extended version of Stahl (2011c).

Investigation 25

Edited and extended version of Stahl (2011a, b).

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