Chapter 5
Computer-Supported Collaborative Learning

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Digitization of Society

In the knowledge society, the development of new infrastructures for information and communication is intertwined with people's everyday, professional and public lives as our societies gradually become more digitized. These developments also change the conditions for human learning and communication. How this plays out is the topic of this chapter. These developments create questions that are important and urgent: How and what do people learn when using new technologies? How and what can be learned in collaborative efforts? The collaborative dimension is important since many societal and institutional problems require collaborative and interdisciplinary problem solving. Collaboration also involves social, emotional, and cognitive mechanisms on which learning is dependent. Collaborative learning is both a means to an end and a process that is important for learning and development in and of itself. Social interaction and collaboration create resources for which people gain the capacities to explore and solve problems together. In human development it is individual, joint and collective intentionality that creates the conditions for cumulative human learning (e.g., Tomasello, 2014).

The computer-supported collaborative learning (CSCL) field is part of the overall development of technology, culture, and society. More specifically, CSCL provides new learning designs that support collaboration and learning in multiple domains and rigorous analyses of emerging social practices supported by digital technology. How knowledge is inscribed and represented in tools changes with new developments in computer science. In this sense, researchers working within the CSCL field merge social, cultural, psychological, and technological developments into a phenomenon we need to investigate to understand how individuals, groups,

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institutions, and society are transformed. The designs and practices used in CSCL contribute to change primarily at the interactional and individual layers of human development. Since the early 1990s, CSCL has been established as an interdisciplinary field for scholars around the globe (Stahl, 2015). For different overviews, see Stahl, Koschman, and Suthers (2014) (the first of our selected papers) and Ludvigsen and Mørch (2010) (the second selected paper). For other overviews of CSCL, see Jeong, Hmelo-Silver, and Yu (2014) and Tang, Tsai, and Lin (2014).

Computer-supported collaborative learning builds on different scientific disciplines and fields, such as the learning sciences, communication studies, computer science (e.g., human computer interaction, computational linguistics) and some branches of the social sciences. Methodologies from a number of fields are part of the repertoire of CSCL researchers. More concretely, methods from experimental psychology, analysis of social interaction, design studies, and field studies are used in the CL part of the CSCL field, while in the CS part, methods are connected to the development of hardware, software and interfaces, and the use of formalism (e.g., Tchounikine, Mørch, & Bannon, 2009). We emphasize that the defining features of CSCL are the interdisciplinary interdependencies between theories of learning, collaboration and computer science.

CSCL Research: The Phenomenon

Since the 1990s, CSCL research has developed together and in parallel with design-based research in the educational and learning sciences. The conceptual frameworks and practices of designing learning environments constitute one important building block of CSCL. The design of a learning environment can have different origins. Generally, careful analysis of learning activities combined with detailed descriptions of technological affordances constitute the starting point. Furthermore, computer support implies that computational tools are involved. Tools, such as scripts (which provide students with predefined roles and sequences of actions they should follow) or prompts as well as content-based scaffolds can offer support that enhances collaborative processes (de Jong et al., 2012; Fischer, Kollar, Stegmann, & Wecker, 2013). In many studies in the domain of science education, simulations and visualizations have been used to enhance students' conceptual understanding (e.g., Donnelly, Linn, & Ludvigsen, 2014).

Several empirical CSCL studies build on learning research that has identified students' learning challenges within a specific domain, such as mathematics or science (Arnseth & Säljö, 2007; Stahl, 2009). Advanced technologies, such as simulations or dynamic visualizations, make conceptual features and relations in a domain visible and others invisible. For instance, in a curriculum unit in the Web-based Inquiry Science Environment (WISE), exothermic reactions are presented and the students can start, stop, reset, and replay a simulation in order to increase their understanding of the reactions. As part of the WISE design of this simulation, a number of questions related to molecules are posed; this implies that students need to engage with the content (Linn & Eylon, 2011).

The meanings of representations always need to be inferred, and research demonstrates that making sense of these tools can be challenging for students. In the same vein, several studies show that it can be fruitful for students to make meaning of these tools in dyads or small groups supported by a teacher. The implication is that students and teachers together must unpack knowledge inscribed into these tools in order to learn the content and be able to use it for inquiry and problem solving. Complex representations constitute meaning potentials that students must work with to develop a deeper understanding.

Learning challenges can, for example, be related to conceptual issues in specific domains, such as learning about protein synthesis in biology, or learning specific procedures, such as performing an experiment in chemistry using virtual labs. Collaborative learning, small group interaction, and the characteristics and functions of social interaction have been important and classical themes in educational psychology, educational research, and the social sciences for many years. What is unique to CSCL concerns how collaborative learning becomes intertwined with computer support; this uniqueness, however, also creates conceptual challenges for the field. Questions related to what constitutes the appropriate unit of analysis and level of description lead to other questions about how to analyze, describe, and measure the learning that takes place in CSCL environments.

The following are key questions in CSCL: (1) How is collaboration and computer support conceptualized? (2) How and what do people learn in collaboration, and how and what do people learn as individuals participating in collaborative encounters? As pointed out in the introduction, joint intentionality cannot be understood only from an individual perspective. As a field, CSCL also needs studies that emphasize how different layers in socio-technical settings influence how collaborative learning is played out.

Conceptualization of CSCL Research

In CSCL research, we find important contributions from three main theoretical perspectives on learning and cognition: cognitive, socio-cognitive, and socio-cultural. These three perspectives are foundational within the learning sciences (Greeno, 2006). Collaborative knowledge building (Scardamalia & Bereiter, 1994, 2014; Stahl, 2009) is a design-based approach that builds on both socio-cognitive and socio-cultural perspectives. In the original work by Scardamalia and Bereiter (1994), knowledge building was based on studies of how experts develop their competences and how scientific communities make progress. However, the social mechanisms that support individual development or scientific progress was not explicitly addressed. In more recent studies by authors who apply knowledge building as their framework, the individual student's progress is still used as the unit of analysis, while others, such as Stahl, use the group as the unit of analysis and the interactional and social dimensions of knowledge building are explicitly addressed (e.g., Stahl, 2009).

A question we might ask ourselves is whether the fact that CSCL is based on different perspectives should be seen as a weakness of the field. We would argue that the opposite is the case. Within the broad area of learning sciences, interdisciplinarity could also be seen as a strength since complex problems can benefit from being framed by different assumptions. Collaboration as a concept is connected to psychology and social sciences, while the modelling of human actions is connected to computer science. This means that the two main building blocks of CSCL research are interdependent. Over time, the accumulation of knowledge from both areas can become more robust, particularly when different research designs lead to the same, or similar, conclusions. In the CSCL field, we see this very clearly in the design of environments such as knowledge building systems, inquiry in science (e.g., Web-based Inquiry Science Environment (WISE) (Linn & Eylon, 2011) and Science Created by YOU (de Jong et al., 2012)) virtual labs, and simulations, where knowledge from different perspectives become translated into the design of new computational tools, including scaffolds that support both social and individual meaning making (de Jong et al., 2012).

In Arnseth and Ludvigsen (2006), we proposed that CSCL research comprises two different orientations and practices: systemic and dialogical. This categorization cuts across the perspectives we have described and gives a nuanced analytic account of the kinds of results produced in different studies. The systemic orientation is grounded in the idea of testing hypotheses based on variables, while the dialogical orientation analyses collaboration and learning as it emerges in situ across different time scales.[1] The systemic orientation can be connected to the factoring assumption (Greeno & Engeström, 2014), which implies that different variables are tested to measure which of the designed features seem to enhance the student's conceptual understanding most efficiently. In studies based on this assumption, the individual's learning outcomes is often the most important measure of success. This orientation provides an explicit model of how one can design features in CSCL environments that improve individual learning outcomes.

In a dialogic approach, one conducts studies that consider how interaction emerges over specific stretches of time, analyzing in detail samples of specific interaction sequences. Here the learning outcome is often endogenous to the activity itself. These studies are inspired by dialogic and cultural approaches in Russian psychology (e.g., Arnseth & Säljö, 2007; Bahktin, 1986; Furberg, Kluge, & Ludvigsen, 2013; Vygotsky, 1978, 1986) and approaches emerging from American pragmatism, such as ethnomethodology (Medina & Suthers, 2013; Stahl, 2009). In addition, the dialogic approach makes use of concepts like argumentation and

[1]In their chapter in the second edition of the *Cambridge Handbook of the Learning Sciences*, Nathan and Sawyer (2014) chose to use the term *elemental* when we use *systemic*, and when they use *systemic* we use *dialogic*. In this chapter, we use the concepts that we introduced in 2006.

communication. Here, psycholinguistics is often used as an analytic resource (for a recent excellent overview, see Baker, Andriessen, & Jävelä, 2013). When collaboration with tools is analyzed as an emerging phenomenon, analysis often demonstrates how students' learning and conceptual development are situationally contingent on cultural tools, joint meaning making, and settings of activity. In such studies, the level of description can vary. The level of description refers to aspects that are included in the work, such as gestures, linguistic details, content, interactional moves, episodic events, and types of sequences (Linell, 1998).

CSCL Research: Orientations and Multiple Layers

As mentioned previously, in CSCL research one can identify influential studies based on the cognitive, socio-cognitive or the socio-cultural perspective. From the cognitive perspective, Roschelle's (1992) article (the third of our selected papers) discusses how students work together to solve problems in physics; the article analyzes how two students interact. It is based on the idea of the students' gradual development of a shared problem space, which in this study means a conceptual convergence between the students. A high number of contributions from socio-cognitive studies focus on motivation, metacognition, and self- and co-regulation (e.g., Hadwin, Järvelä, & Miller, 2011). Studies from the socio-cognitive perspective mostly contribute to the systemic orientation (but one can also find important studies based on a dialogic orientation) that investigates social regulation and perspective taking. In contrast, almost all studies based on the socio-cultural stance are dialogical in their orientations. These studies focus on emerging interactions in domains such as mathematics, science, social science, and art (e.g., Arnseth & Säljö, 2007; Stahl, 2009). These different orientations in CSCL imply that their analytic attentions are directed toward different aspects of learning and human cognition. The most important difference is how collaboration is accounted for. Within the cognitive and socio-cognitive perspective, individual contributions in collaboration and outcome measures are normally assessed. The socio-cultural studies have mostly been concerned with the investigation of emerging interactions and social practices. The studies are conducted in CSCL environments (Stahl, 2009) or in school environments where CSCL tools are used to scaffold specific forms of collaboration and activate resources within a knowledge domain (e.g., Furberg et al., 2013).

While the cognitive and socio-cognitive approaches use a unit of analysis that mainly focus on the individual within settings and environments, the socio-cultural perspective provides us with an analytic stance that encompasses three interdependent layers (social interaction, the individual, and social practices), all of which are needed in order to understand and explain learning, human cognition, and development (Ludvigsen, 2012; Valsiner & Van der Veer, 2000).

The socio-cultural perspectives on learning start with an analysis of micro-interaction. Learning outcomes can be assessed by examining specific forms of arguing or knowledge construction that occur during learner interactions or by measuring the relative contribution of different collaborative features to students' thinking and problem solving (Enyedy & Stevens, 2014). The study of micro-interaction implies a detailed analysis (or measurement) of how students engage in reasoning, arguing, and problem solving in specific knowledge domains or in themes that cross areas of disciplinary knowledge. Collaboration as a specific form of social interaction is crucial because it is here that history, tools, and human action come together and mutually shape one another (Valsiner & Van der Veer, 2000; Vygotsky, 1978). Collaboration with a specific tool, such as a simulation about climate change, creates emerging conditions for learning (Donnelly et al., 2014). This is the first layer in the analysis. The second layer focuses explicitly on how individuals participate in tasks, situations, and activities. Students make their cognitive, social, and emotional competences relevant through a series of actions in collaboration with others. This layer gives insight into how students manage collaboration and their assignments and their mastery of specific forms of knowledge (e.g., knowledge about climate change).

The third layer focuses on the institutional and historical dimensions that create affordances and constraints for students' actions—the social practices. One way to explain what this third layer implies is that institutions, such as schools, come with specific histories and a domain, such as mathematics, that emphasize certain historical norms, values, and ways of organizing knowledge. This could be the use of definitions or ways of arguing about mathematical ideas. Institutions like schools create conditions for ways of participating, and students bring with them different norms for the participation and different experiences of how their contributions are recognized. This orientation emphasizes that we need to account for how institutional settings influence collaborative learning through their histories, their domains, and how their students see themselves in the future. The influence is bidirectional, which means that institutions are produced and reproduced through participants' efforts. The three layers are nested within each other, meaning that all three layers are in principle visible and analyzable in micro-interactions. However, an understanding of micro-interaction often requires a broader historical and institutional analysis using a variety of methods, both quantitative and qualitative.

The processes and outcomes of collaboration can be analyzed based on different methods, such as interaction analysis, observations, log analysis, institutional analysis, and task and artefact analysis and pre- and post-tests. By using different analytic techniques, we understand how the three layers interact to create emerging opportunities for students' learning in collaboration with other actors and the tools involved. The students' learning processes can be conceptualized as intersecting trajectories of participation that include both the temporal and spatial dimensions of learning (Ludvigsen, Rasmussen, Krange, Moen, & Middleton, 2011).

We need more studies that can differentiate analytically between the layers and explain how they can be connected. Some such studies do exist. In Dolonen and Ludvigsen (2012), we investigated how students worked to learn concepts in the domain of geometry. They were exposed to 2D and 3D models and worked in teams of two in a specific environment and with the support of a teacher that engaged with them as he moved through the classroom. Here we combine the individual and interactional layers, while less emphasis is placed on the social practices. In a study of how students use categories in the domain of science, we combined the analyses of the interactional and socio-practices layers (Ludvigsen, 2012). The socio-cultural stance makes it possible to work with different types of analysis rather than with only one analytic layer. Based on the socio-cultural stance, one can use research designs that aim to understand each student's individual progress and to analyze how students collaborate with computer support in an institutional and historical setting. Here the concern is how one conceptualizes the phenomena and that learning and collaboration cannot be reduced to one of the described layers. We argue that the CSCL field needs to recognize that multiple layers influence collaborative learning and perform studies that can contribute to new understandings and explanations about how humans learn together with new computational tools.

CSCL and Scaffolds

Scaffolding is perhaps the most important mechanism in technology-enhanced learning and in CSCL (for a recent overview, see Reiser & Tabak, 2014). In a seminal work by Wood, Bruner, and Ross (1978), the authors describe how scaffolds can function to promote the students' capacity to perform more complex tasks than they could have done otherwise. Another concept that often is associated with scaffolding is the "zone of proximal development" (ZPD) (Vygotsky, 1978, 1986). The ZPD represents a unit of socially mediated interactions and provides a unit for describing the character and direction of conceptual change. It refers to an interactive cognitive system (one or more minds together) working successfully on problems that at least one participant could not solve alone (Newman, Griffin, & Cole, 1989).

In the learning process, scaffolding implies a cognitive division of labor between the students and the tool(s). The overall idea is that the scaffolding should help the students bridge their prior knowledge to tasks and to a future practice. Students can get support to collaborate in more productive ways, and the knowledge represented can be displayed in different ways that can facilitate cognitive development. The knowledge is displayed dependent on what the students choose to do and is adapted to their needs and level of expertise. In some cases, the students can learn so that the scaffolding can be reduced or taken away, while under other conditions, the tools and artefacts become part of the distribution of the cognitive processes involved (Hutchins, 2005). This means that to take away the tool would make the sequence of actions impossible. In CSCL environments, both ideas of scaffolding are used.

In the learning sciences and CSCL, scaffolding is part of designs that aim to cultivate students' advanced skills and participation in different social practices. The idea is not to decompose the scaffolding to a minimal component but to utilize it to support the work with complex problems. The design of CSCL environments and, more broadly, inquiry-learning environments provide us with many of the same features. Here we emphasize four features that are based on a recent review (Donnelly et al., 2014).

The first feature is the exploration of a specific context. We know that tasks and the task structure are important for students to develop the capacities to engage in complex problem solving. To enhance such knowledge, it is important for the tasks to be meaningful. Meaningful tasks for students are often based on a specific part of a practice from science, industry, or an everyday problem. The task and the problem in which the task is embedded create a relevance structure for the students. The context for the tasks can be related to a problem, such as climate change or gene technology, or to engage in mathematical problem solving.

The second feature is the use of simulations and dynamic visualizations. Simulations create affordances in which students can test hypotheses and manipulate parameters. Visualization is often used to model complex phenomena in chemistry, physics, or biology and complex datasets. Visualization can also involve creating models of phenomena that we cannot observe directly with the human eye. In mathematics, visualization can involve features in which students can observe how their actions create differences in a representation (e.g., 2D or 3D environments in geometry).

The third feature is to encourage students to collaborate in their work. To ask students to work together can be done in a number of different ways in dyads or groups or by software that structures student's work together based on a set of criteria. Based on findings from a high number of empirical CSCL studies, one can conclude that students' collaborations do not automatically activate advanced cognitive activities (Fischer et al., 2013; see also Littleton & Mercer, 2013). One of the most influential design approaches is the idea of scripting collaboration, which means that students work based on their internal scripts as well as on the designed external scripts. This approach is described in the fourth of our selected papers (Fischer et al., 2013). These external scripts could consist of components like plays, scenes, and roles. Such components could give students who lack internal scripts for regulation external support so that they can perform epistemic actions. The internal scripts can be seen as closely related to prior knowledge that needs to be activated and made relevant in a CSCL practice.

The fourth feature involves developing students' own goals, distinguishing between ideas and concepts, and linking their ways of reasoning into more complex arguments. The use of metacognitive strategies and students' capacity to self- and co-regulate themselves in socio-cultural environments and to contribute with epistemic actions cannot be taken for granted. Such a repertoire of actions must be cultivated over time. In addition, we emphasize that recent CSCL environments include design of technological features, such as learning analytics. Based on the learning analytics, we can trace what students do (Baker & Siemens, 2014). This information can be used for redesign to improve students' learning processes and outcomes.

CSCL: Impact and Future Challenges

In fields that address questions related to learning and collaboration, the issue of impact on social practice is important. The development of the CSCL field takes advantage of the cumulative growth of knowledge in its own context as well as in the contexts of learning science and computer science. The question becomes whether advanced CSCL environments and tools can be used in all types of educational institutions and in more informal settings (see the work of Math Forum [Stahl, 2009] as one example). CSCL is also used in higher education (Strijbos, Kirschner, & Martens, 2004), and new studies in the mentioned areas continue to be performed (Lindwall, Häkkinen, Koschman, Tchounikine, & Ludvigsen, 2015). We also find new types of CSCL studies in the mobile learning community (see Chap. 8).

We can find success stories, such as the WISE project (Linn & Eylon, 2011), which is used in many U.S. schools and in some European countries, the collaborative knowledge-building approach used in Hong Kong (Chan, 2011), and the work based on knowledge building and knowledge creation (Knowledge Forum) that is used in selected schools and classrooms in many countries (Scardamalia & Bereiter, 2014). We can model practice that represents new ways of designing environments for teaching and learning, and we can demonstrate how CSCL tools can be used. The CSCL field can create impact on social practices through modelling how in-depth learning can take place. To create change on a large scale involves much more than scientific studies and developmental work; local and national politics are often part of large-scale changes as the research on reforms of school systems has shown. However, in Hong Kong and Singapore, research teams have influenced educational policy and make and use CSCL as part of the overall framework for improving the educational system and the performance of teachers and students (Chan, 2011; Law, 2010; Looi, So, Toh, & Chen, 2011).

We think that CSCL design-based research tested in naturalistic environments has provided the research community and practitioners with very important knowledge about how to make use of new technologies in schools. Such studies make the cultures of schooling visible. While the CSCL design often emphasizes that students' work should be modelled based on (parts of) scientific practices, many schools and classrooms are based on other social and cultural conventions. This means that CSCL designs can create tensions and discontinuities in the practices in which students and teachers are involved. Such tensions and discontinuities can be important for creating "seeds for change" for new practices that are based on state-of-the-art learning principles. A strong sign of policy impact is the new study performed by the Organisation for Economic Co-operation and Development (OECD), which includes peer collaboration with tools in their new assessment of 21st-century skills (OECD, 2015).

Most CSCL studies are conducted with relatively low numbers of participants (although see Chap. 6 for a new account of mass collaboration). This means that CSCL studies are often based on either small-scale experiments, quasi-experimental designs, or design-based studies in natural contexts. In experimental studies, specific hypotheses are tested, while in design-based and explorative studies, one investigates what and how students can learn under specific conditions. All these types of studies should be seen as part of the research designs that can bring novel contributions to CSCL. When we ask questions that cut across the different studies, specific patterns emerge that show how we can design for in-depth learning. Different research designs, assumptions, and perspectives then do not need to be fused but rather can be seen as incremental steps toward a more advanced understanding of how and what students learn in collaboration with new technological tools in designed environments that are built on the generalized knowledge from the CSCL field. It is through variation in research design that we see how the different perspectives contribute to CSCL.

We, as a community, must recognize that students need to learn in many different ways. We also need to consider impacts other than those on the systemic, national, or regional levels. We need to see the impact as part of inspiring teachers to make use of the micro-analyses of collaboration with tools, which the CSCL field has contributed. Teachers can then advance their designs for learning and create better tasks for their students.

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