Mary Kay Stein
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Instructional Explanations in the Disciplines

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This book is dedicated to
Gaea Leinhardt
whose research and scholarship related to teaching
has inspired and will continue to inspire
all those for whom
education is a compelling enterprise.

Preface

With the implementation of recent testing and accountability schemes, the nation has become painfully aware of the wide variation that exists with respect to student achievement across schools and classrooms. As a result, policymakers have "discovered" the importance of teachers and teaching as the proximal cause of student learning. Unfortunately, their attention has focused on "teacher quality" – defined as the presence or absence of credentials. It can be argued that this unrelenting focus on teacher quality has redirected researchers' attention away from what we know is the most important determiner of what students learn: the processes of teaching itself, that is, the tasks with which teachers and students engage and the classroom discussion surrounding those tasks.

One of the most significant contributors to research on teaching has been Gaea Leinhardt. Across three decades, her work has focused attention on the heart of instruction – a place where subject matter meets the everyday acts of teaching. Cited by Lee Shulman in 1986 as one of two researchers in the country actively engaged in subject-matter-specific investigations of classroom teaching, Leinhardt was a pioneer in recognizing the importance of and developing methods for analyzing the subject matter content of instructional episodes. Through close examination of carefully chosen episodes of instruction, Leinhardt has done more than perhaps any other scholar to advance the discussion of how "the uniqueness of epistemology, language, task, constraints, and affordances of different subjects transform and mold the commonplaces of the instructional landscapes" (Schwab, 1978). In a recent article by Grossman and McDonald (2008), Leinhardt's work with instructional explanations was cited as an important example of the kind of analysis of teaching components that is critical for the advancement of the field and that cuts across subject matter and grade level.

Her singular contribution to this line of work has been the identification of the *instructional explanation* as a key research location for identifying what is common and what varies within an instructional system. Classroom researchers, Leinhardt argues, must be able to make sense of what they see by "looking closely and over a long period of time at some specific portion of the teaching and learning enterprise" (Leinhardt, 2001, p. 354). She goes on to make a convincing case for the instructional explanation as a researchable moment because it offers both a sense of universality (she calls it the *commonplace* of teaching because it is ubiquitous and recognizable) and a sense of richly textured variability. Instructional explanations bring a sense of the familiar while, at the same time, provide an opportunity to showcase the ways in which the epistemologies and organizing ideas of different disciplines shape the very essence of what we know and how we know it.

In contrast to everyday or disciplinary explanations, "instructional explanations are designed to explicitly teach – to communicate some portion of the subject matter to others, the learners" (Leinhardt, 2001, p. 340). However, unlike the commonly evoked image of explanations delivered lecture style by a single teacher at the front of the room, Leinhardt's conception of instructional explanations is much more complex and nuanced. Not only can instructional explanations be developed jointly by teachers and students, but they can also be given by a textbook or a computer – either alone or in interactive dialogue with students and/or teachers. Emphasis is placed on *what* is talked about and how, rather than on *who* is doing the talking.

The construct of instructional explanation promotes coherence across various school subjects while, at the same time, providing space for uncovering the subtleties of subject-matter-specific teaching and learning. Research on instructional explanations highlights what the various disciplines can explain, the nature of explanatory resources within each discipline (e.g., concepts and methods), how disciplinary-specific explanations are generated, and how they work. At the same time, this body of research, building on Leinhardt's model, identifies similarities across explanations, the critical features of which include examples, representations, and devices that limit the explanation (through identification of errors, principles, and conditions of use).

The present volume is a collection of chapters that interrogate and illuminate the notion of instructional explanations from a variety of perspectives. The authors of the chapters gathered at the University of Pittsburgh in the spring of 2008 to honor Gaea Leinhardt on the occasion of her retirement.

The first chapter in this volume is an introduction by Gaea, Explaining Instructional Explanations, that provides both a subjective and a more objective account of her interest in instructional explanations. The chapters that follow are organized into three parts, which focus on instructional explanations in the teaching and learning of science, mathematics, and the humanities.

Part I: Instructional Explanations in the Teaching and Learning of Science

The first chapter in this part is Chapter 2 by Richard Lehrer and Leona Schauble. They argue that modeling is a fundamental epistemology of science and illustrate the cognitive challenges that classroom-based modeling raises for students.

Chapter 3 by Jorge Larreamendy-Joems and Tatiana Munoz reports on a study that investigated the verbal interactions between experts and apprentices in the context of joint scientific practices during biology fieldwork, and how those interactions support learning and identity formation.

Chapter 4 by David Yaron and his colleagues describes an approach to the development of college chemistry courses that foreground instructional explanations in ways that convey why and how chemistry knowledge is useful.

Chapter 5 by Kyung Youn Kim and Kevin Crowley explores an interactive science exhibit in a children's museum as a context in which families can begin practicing scientific thinking.

Part II: Instructional Explanations in the Teaching and Learning of Mathematics

The first chapter in Part II is Chapter 6 by Carla van de Sande and James Greeno. Using examples from tutoring exchanges in an open, online, calculus help forum, this chapter reframes the focus of instruction from explaining *to* to explaining *with* students.

Chapter 7 by Alan Schoenfeld, presents and exemplifies a theoretical framework that characterizes the relationship between teachers' knowledge, goals, and orientations and their explanations and elaborations of mathematical ideas.

Chapter 8 by Orit Zaslavsky, focuses on ways in which experienced teachers select, adapt, and generate examples in and for the mathematics classroom and highlights the explanatory features of examples that support learning.

The final chapter in this part, Chapter 9 by Magadalene Lampert and her colleagues, reports on recent development work in pre-service teacher preparation. The authors discuss the preparation of novices to engage in instructional dialogues as a means of enacting classroom explanations that are respectful of disciplinary knowledge and purposeful toward students acquiring such knowledge.

Part III: Instructional Explanations in the Teaching and Learning of the Humanities

The first chapter in Part III is Chapter 10 by Mariana Achugar and Catherine Stainton. The authors present an analysis of a unit on Reconstruction in US history that focuses on explicating the text analysis tools and the role of language for constructing an historical explanation with particular attention to the needs of English Language Learners.

Chapter 11 by Kevin Ashley and Collin Lynch, describes a program that the authors designed to help law students understand hypothetical reasoning. Then, the authors evaluate whether students' responses can be used to diagnose the extent of their understanding of important aspects of legal argument.

Chapter 12 by Karen Knutson and Kevin Crowley, explores the conversations that took place among family members about a large-scale narrative painting and a decorative French bed in two different museum settings (family room and gallery) for the purpose of understanding how both setting and art object influence talk.

The final chapter in Part III, Chapter 13 by Kwangsu Cho and Christian Schunn, describes SWoRD, a Web-based reciprocal peer review technology and how it supports students' acquisition of writing skills through peer review activities with appropriate content and accountability structures.

We believe that the diversity this volume encompasses in terms of disciplinary domains and instructional contexts attests to the power of instructional explanation as a construct for thinking about teaching in robust ways. As former students and current colleagues of Gaea Leinhardt, we are honored to present this book to those who teach and study teaching.

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Chapter 1
Introduction: Explaining Instructional Explanations

Gaea Leinhardt

> T: . . .I would like you to think about how you would explain where that X is on the screen. Suppose you were trying to explain it to somebody who couldn't see the screen.
>
> T: . . .(Continuing three days later) Where is the origin on the graph I have up there?
>
> S1: Um, its like, um 17, um, I think it's 20, There's and 21 divided by 2 is 10 and a half, so you go that way 10 and a half. And 18, so you go 9 that way.
>
> S2: I, since you're only, since you're only seeing one fourth thinking of where the zeroes are in the middle – you would think that is the whole paper if the zeroes are in the corner.
>
> S3: Well you said the origin is by zero zero. Ali thinks that would be the origin. But Tara thinks that the origin is in the middle.
>
> (from Leinhardt and Steele 2005, pp. 102, 116)
>
> .

I am of two minds as I start to write this short account of explanations. Should I try to share the clean straightforward account of what explanations are and why they are an important part of understanding teaching and learning? Or should I share my own more personal reasons for worrying so much about this one limited aspect of teaching? I have decided to do both. The reader who wishes only the clean relatively clear account can ignore the italicized commentary. The explanatory fragment above comes from a portion of an explanation about functions and their graphs that took place in Magdelene Lampert's classroom. Over the ten days in which the explanation evolved there were many examples of smaller nested explanations offered by students alone, students in concert with Lampert, and Lampert alone.

The explanatory fragment above comes from an extended classroom discussion in mathematics. The discussion had descriptions, posed problems, supported debates, and it also contained explanations. Explanations are particularly powerful moments in teaching, and while each explanatory moment is unique, constrained by classroom histories, subject matter conventions, and instructional goals, there are some core features present in effective instructional explanations that tend to be absent in less effective ones. Much of my work has been concerned with the

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patterns and forms associated with effective explanations in different subject areas. Instructional explanations are important because they "carry" the overall pedagogical messages of the classroom through both style and stance and because they contain critical elements of legitimacy, modality, and function from the discipline whether that discipline is history, mathematics, physics, or poetry. Instructional Explanations, whether delivered by the teacher alone or through the process of focused discussion, are a central deliberate act of teaching.

Instructional Explanations rest at the intersection of two trajectories of activity. One trajectory consists of the family of explanations in general: common, self, instructional, and disciplinary. Another trajectory consists of the family of pedagogical moves that engage a group of students and teachers in deep thoughtful activities connected to subject matter learning: presentation, demonstration, problem selection and posing, case building, explanation, and argument. Within the trajectory of explanations in general there are markers that relate to audience (face to face or not), formality of language (formal disciplinary language or informal personal language), time (synchronous or slightly asynchronous or vastly – centuries – asynchronous), and location (in a shared space or in a shared text) to mention just four; within the trajectory of pedagogical moves there are markers of audience (one's self or small group, a larger student group, a teacher, and examiner), ownership (the disciplinary authority, the teacher, the student, the community), perspective (shared, introduced, or negotiated), and participation pattern (jointly constructed or given). The particular combination of markers gives the particular sense of an explanation as it unfolds and reflects different values and assumptions about teaching and learning.

I chose to start to study instructional explanations as a result of my interest in what goes on in classrooms. I have sat in on or taught classes from grades 1–16 for over forty years and have observed hundreds of hours of instructional activity both live and on video. When I first enter a teaching environment I am always overwhelmed by the "stuff" that exists – there are technological doodads, there are geographical arrangements (from small cozy library corners, to careful desk groupings to huge lecture amphitheatres), there are all variety of interactions – the issue if one wants to understand learning in these settings is what to look at and how. Early on I decided that I should keep track of the common everyday repeat activities that serve as the hallmarks of climate and educational philosophy in any class. That work lead to my thinking about "routines." Routines happen all the time, they serve many functions, and they tend not to be anchored in subject matter content (although disciplinary practices of conversation do enter in). At the other end of the pedagogical continuum, if you will, are the pedagogical features that are inextricably linked to the content being learned, that are unique, and happen either briefly or far less frequently than routines. Explanations are one such feature. Explanations require engaged thought; while they can be planned they must, to be effective, be responsive both to the learning goals at hand and the learning issues that arise.

Philosophically, explanations exist as answers to some sort of actual or implied query. These queries can range from the common ones such as, "why have they set up a detour here?" to more profound and arcane ones such as, "how do planets form?" The nature of the explanatory answers (as opposed to the question itself) to these queries is what determines whether an explanation is a common, self, instructional, or disciplinary one. Common explanations occur all of the time in everyday face-to-face conversation, there is an implicit coordination in the discussion that suggests the level of detail and content required in the answer. Thus, the expected answer to the question of “why have they set up a detour here?” is not an exegesis on the nature of detours in general nor a discussion of the political ramifications of sending traffic one way or another but a more localized description of the logic (or illogic) of the choice. At the other end of the trajectory, disciplinary explanations require reference to agreed-upon discussions to date, an adherence to the rules and formalisms of the discussion in the discipline, and coordinated use of formal and informal representations. Disciplinary explanations answer questions that are of value and salience to the discipline. At another point on the continuum, self-explanations occur when an individual experiences an interruption in some aspect of comprehension. By definition, self-explanations are constructed to serve the needs of the self; thus language can be internal, fragmentary, and colloquial as well as fuzzy. Usually, the goal of a self-explanation is to link a current piece of information (in a text, figure, or speech) with an understood self-defined learning goal.

Instructional explanations as distinct from these other types of explanations are aimed at teaching and sharing with others. They must coordinate informal colloquial familiar forms of language and understanding with more formal disciplinary ones in the interests of improving learning. The implicit assumptions need to be made explicit, connections between ideas need to be justified, representations need to be explicitly mapped, and the central query that guides the explanatory discussion must be identified. In the fragment above the teacher’s questions are introductions to instructional explanations constructed by the group. They are within the discipline but a mature mathematician would already know the answer although he or she would see the value in asking the question. The answers sought must somehow coordinate with one another – hence the importance of the last comment.

I realized that instructional explanations belonged to a family of explanations when I started to research the entire idea of focusing on explanations as a key moment in the activities of classrooms. I saw teachers presenting new material, discussing new material, giving various demonstrations of ideas but only rarely actually explaining; sometimes I saw students explaining but often it was a justification for a particular move – but occasionally I would see an explanation either given by the teacher or by the class and teacher together that seemed to “stick.” So I began to search out ideas that surrounded explanation in a broader sense. Since explanation is a central idea in philosophy I went there and discovered that the “examples” had little to do with learning something new but rather something far more abstract. I decided to read explanations in disciplinary texts – history and mathematics – what I came across were explanations interwoven with justifications and arguments that had the flavor of the discipline but not the flavor of instruction. This led me to realize that instructional explanations were a particular form and that it might be worthwhile to try to specify both what such an explanation consisted of and what features seemed to be characteristic of particularly effective explanations.

Instructional explanations can be described as a network of goals, actions, and knowledge assumptions. At the heart of the goal system of explanations is the posing of a powerful and important question. In an effective instructional explanation, the query or problem itself must be carefully unpacked and examined, not just stated – this means identifying features in the query that are problematic and summoning effective and important examples. The knowledge system that supports the framing of a significant query is a combination of deep disciplinary knowledge and solid pedagogical understanding – when Lampert asks (in reference to graphs), “Where is the origin?” it appears to be a simple question but as things unfolded it took 2 days to tease out the answer – its close tie to mathematical history is in part why it was both an important question and a fruitful one. When the history teacher, Sterling, asks, “What do you think the purpose of the Emancipation Proclamation really was?” it is significant because the answer is not the one assumed, namely, to free the slaves, rather the answer entails understanding that the document limited the set of who would and would not be freed, and that it overturned a field order issued months before that had, in fact, freed all slaves. When Lehrer and Schauble report a teacher asking, “How should we measure the growth?” it again appears to be a simple question but the answering of it captures critical features of scientific thought. In all three cases, the students need to come to see both what the object of the query is and why it is salient as they engage in an explanation.

A second significant goal in an instructional explanation is the completion and interconnections of the discussion. This goal implies making connections to prior knowledge and examples, showing the principles of use and limits of use of the concept or procedure, and displaying how errors are connected to the misapplication of principles or actions. In completing an explanation in this way, there needs to be an understanding of the historical culture of the classroom, the range of possible disciplinary situations that apply to the explanation or are covered by it, and finally a rich array of examples needs to be accessible. From a teaching perspective this means keeping track of all of the little questions and examples that have come out over the course of a discussion and pulling them back into the activity of explaining.

A third significant goal in an instructional explanation is the systematic and careful development of examples and representations. These are the analogical instructional tools, if you will. The tools can be developed by the students or in conjunction with the teacher and students. However, the examples and representations (pictures, formalisms, diagrams) must be appropriate to the situation, and they must be unpacked and carefully mapped or flagged to the salient aspects of the answer to the query. The orchestration of representations and examples in the service of an instructional goal is challenging and complex. In the opening explanatory fragment, the questions in combination are both central to the discipline and, in the case of the origin, central to the representation that is being used to introduce functions.

In studying the practice of teaching what I have found is that many teachers design instructional settings that meet some of these goals but in many cases some critical goals – such as establishing a central query that the explanation is in the service of –are left out. The new teacher, for example, over-focuses on the activity (the worked example or representation) and forgets to have the students grapple with the central question. Other teachers often assume that the example is the explanation or that a representation is self-evident.

The details of how the goals and actions work in an instructional explanation have changed since I first began thinking about this with Jim Greeno. The particular formalism of a planning net which I have used to capture the larger set of goals and actions appeals to me because it suggests a lack of order for many of the goals and is agnostic with respect to ownership of the goal states or authorship of actions. Students or teachers can take the lead. I find it interesting that many of the changes in our beliefs about excellence in teaching and learning can be discussed in terms of the ordering and authorship of ideas within an explanation. For example, direct instruction would suggest that the sense of query must come first followed by a clear unpacking of critically chosen examples, followed by a wrap up that meets the completion goals. Constructivist instruction might start with an example that is problematic, a review of prior knowledge (from the completion goal), identification of unique features and a drawing out of the sense of query, ending with a new array of examples. Who asks and does what when seems to capture the distinctions of pedagogical values more than the presence or absence of particular explanatory features (Leinhardt, 2001).

Explanations are by no means the only thing that goes on in a classroom that is of instructional value. However, explanations combined with routines seem to span some of the interesting classroom activities. Research that has been carried out examining explanations has shown that the construct is valid – students do learn more, as measured in a variety of ways, when explanations include most of the critical features. The explanatory fragment that opened this short essay is just a fragment. Many of the goals that need to be met in order for an instructional explanation to support learning are not included – although they were during other parts of the lesson.

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Part I
Instructional Explanations in the Teaching and Learning of Science

Chapter 2
What Kind of Explanation is a Model?

Richard Lehrer and Leona Schauble

Why Is Modeling an Important Form of Explanation?

Modeling is a form of explanation that is characteristic – even defining – of science (Gierre, 1988). Nersessian (2008) refers to model-based reasoning practices as the *signature* of research in the sciences, both in the discovery of new scientific ideas and in the application of more familiar ones. Models are analogies in which objects and relations in one system, the model system, are used as stand-ins to represent, predict, and elaborate those in the natural world. Familiar examples include billiard ball models of the behavior of gases and solar system models of atoms. Although familiar, these examples are somewhat misleading in that they suggest a ready-made model structure mapped onto nature. In practice and in history, models and worlds are more typically co-constituted (Nersessian, 2008).

Contemporary depictions of science have shifted from an emphasis on experimentation to the development, test, and revision of models, but by and large, school science has not followed this trend (Windschtl, Thompson, & Braaten, 2007. Instead, to the extent that models occupy a place in school science, they are typically used as illustrative devices for explaining concepts to students, rather than as scientific theory-building tools and practices. Perhaps educators misinterpret the National Science Education Standards (1996), which emphasize inquiry as the organizing principle of science. Teachers tend to associate inquiry with understanding and employing the methods of science; modeling and inquiry are often regarded as totally distinct enterprises (Windscht & Thompson, 2006).

These misunderstandings about the nature of science and its implications for school science may be partly responsible for the general lack of attention to modeling in science education, in spite of its centrality in professional science. Yet there are also other reasons why model-based reasoning does not have a more prominent role. As we will argue, modeling is a form of reasoning that is difficult for novices to grasp. Understanding the challenges of modeling entails understanding

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the developmental roots and progressions of this form of reasoning, especially in contexts of instruction (Lehrer & Schauble, 2006. Accordingly, our research program seeks to identify young children's early resources for becoming engaged in what Hestenes (1992) calls the "modeling game." We also are trying to better understand what makes this form of reasoning demanding and what forms of instruction best support its long-term development. To investigate these issues, it is necessary to both support and study teaching and student learning, because one cannot investigate the development of a phenomenon if the conditions for its development are absent. Therefore, we work directly in participating classrooms to help teachers understand modeling and focus their mathematics and science instruction around it. Simultaneously, we study the development of student learning in grades K through 6. We have had the opportunity to follow a number of students across several years of instruction. As our findings emerge, they are employed to retune instruction, so that the learning studies and the instructional design inform each other in closely interlocking cycles of revision.

Currently we are conducting this research in two contrasting school districts. One is a district that has been taken over by the State for failing to make adequate yearly progress on NCLB benchmarks. Approximately 70% of the children in these schools are eligible for free or reduced lunch, and the district is populated by high percentages of minority children. This district has a long tradition of top-down decision-making about instruction. In contrast, the other is a well-performing but fast-growing district with a large bilingual population and a tradition of decentralized decision-making and teacher professionalism. In these two very different districts, we are working to create, replicate, and revise the forms of instruction that assist students in their first entry into modeling so that we can begin to understand the relationships between development and learning of this kind of reasoning. In addition, we are trying to understand what it takes to make these forms of teaching and learning take hold in these disparate institutional settings.

Development of Representational Repertoire

Because our interest is in development rather than in full-fledged professional practice, we focus on a wide gamut of representational forms that are plausible precursors to modeling and that are components of models. These representations are inscribed as drawings, diagrams, maps, physical replicas, mathematical functions, and simulations. We emphasize these representational forms in instruction, because we consider their invention and use to be critical steps toward modeling and because they are a language of expression for modeling. We study changes in the qualities and uses of representations over time, favoring and continually pressing for increase in their scope and precision.

Initial inscriptions (e.g., drawings, physical replicas) generally capitalize on resemblance between the representing and represented worlds. We have found that young students and novices seem to find it easier to accept a representation as "standing for" a phenomenon if it bears some feature resemblance to that phenomenon. For example, kindergarten students seeking to track changes in the length of plant roots chose to cut lengths of string to represent root length because, to the children, the strings looked like roots. This superficial resemblance seemed to help children construct and maintain coordination between the represented and representing worlds. These 4- and 5-year olds needed to take a mental step away from the plant roots to focus on the *attribute* of length. This necessarily entailed ignoring some of what they had already noticed, such as the color, number, and thickness of the roots. At the same time, as they considered and compared changes in the attribute of length, students needed to relate these qualities back to the plants, the original focus of interest.

The reliance on resemblance lessens as students' knowledge and goals evolve, especially if alternative representational forms are recognized as having particular advantages over the early ones. For example, shifting from strings to paper strips made it easier for the kindergartners to record change over time by supporting more precise measures of the amount of change from one measurement to the next. In general, succeeding inscriptions tend to select (meaning that they leave out information), emphasize (highlight relevant information), and fix functional relations (that is, stabilize processes or conditions that are undergoing change – see Latour, 1990 and Olson, 1994 for further analyses of the functions that representations support). Our perspective on the development of representational forms is that later representations do not "replace" those that developed earlier. Instead, multiple inscriptional forms remain cognitively active, with earlier-forming representations lending meaning and preserving coherence and reference with those that are later developing, so that representational systems "circulate" (Latour, 1999) to enrich the reach and grasp of the models that they instantiate (Lehrer & Schauble, 2008).

As in the history of science, representational re-description of the world changes what students observe, and therefore the questions they choose to pursue (Kline, 1980). Plotting changes in the heights of Wisconsin Fast Plants™ on a coordinate graph made it possible for third graders to notice that the rates of change were not constant. Instead, as one child explained, "First it grew slow and then it speeded up. Then it slowed down again." Because they had a sound understanding of measurement, these third graders proceeded to quantify rates of growth for different intervals of the piecewise linear graphs they had created. "The plant grew 9 mm in 3 days during this period. That's 3 mm per day." Investigations of the changing rates provoked additional questions about whether all the plants followed the same pattern and, if so, the reasons for and nature of these changes. Over several weeks, the children proposed alternative ways to graphically describe the changes in the heights of all 23 class plants, explored whether changes in the volumes of the canopies would "tell" the same story as the coordinate graphs, investigated how changes in growth factors (such as crowdedness) changed the pattern of growth, and sought to learn whether other organisms grow in a similar pattern (Lehrer, Schauble, Carpenter, & Penner, 2000).

Fifth-grade children who first developed the mathematics of weight and volume measure, as well as linear function, went on to "find" that the ratio of weight to volume was invariant, no matter the shape and form of the unknown substance. The mathematics of measure and ratio helped students envision how different packings of the same structured space, the volume, might account for commonplace behaviors of materials, such as whether or not they float or sink, or might predict how a composite of materials, including air, would behave. Quantification supported reasoning about qualities, and thinking about qualities, such as the nature of volume, supported reasoning about prospectively sensible forms of quantification (Lehrer, Schauble, Strom, & Pligge, 2001).

Mathematics is a powerful language of modeling, and as these examples suggest, we regard mathematics as an essential resource for pursuing modeling investigations and explanations in science. Although this perspective appears to contradict the typical preferred emphasis in science education for qualitative over quantitative analysis, we are not proponents for the role of mindless computation. Rather, we have found that students who have a broad and powerful vocabulary for mathematizing the world can deploy mathematics to make sense of situations, so that qualitative and quantitative approaches are less distinct than they are sometimes portrayed. A repertoire of mathematics that equips a student to makes sense of the world extends well beyond the usual focus on arithmetic in elementary school. Accordingly, students in our classrooms are participating in a mathematics education that includes appropriate instruction in space and geometry, measurement, data, and uncertainty. These ideas have their own integrity and structure and require thoughtful development in their own right, so we are not advancing the simple "integration" of mathematics and science. However, we are convinced that these mathematical resources are vital if we expect students to call their own theories and beliefs to account. For example, there is no point in arguing about the importance of evidence without considering the forms of evidence that students are equipped to analyze and interpret.

What Makes Modeling a Challenging Form of Explanation?

Our studies of modeling in classrooms support the observation that modeling is a rather indirect and unfamiliar genre of reasoning – and not just for children. Indeed, some of the well-documented difficulties that older students have with domains like physics are due to the indirectness of this kind of thinking (Hestenes, 1992). In high school and university science classes, instructors presume that modeling and its benefits are self-evident, even though there has been very little in earlier schooling that would generate that understanding. Our observations suggest that modeling is far from self-explanatory. Consider for a moment: Why would anyone represent bodies as point-masses? What does an inclined plane have to do with objects that fall? You may agree that this is a rather strange form of epistemology: namely, trying to understand the world by arranging a simplified version of it and then studying the model, rather than directly investigating the phenomenon of interest.

Modeling evolved only gradually in the history of science. Bazerman (1988) explains that early scientific articles tended to be narrative-like accounts of the general form, "This is the interesting phenomenon I observed, and if you go over there, you will see it, too." Yet seeing, of course, is not necessarily believing. Inevitably, disputes arose as readers began to contest what was seen and, especially, what it meant. In response, researchers eventually began to include in their reports more precise specification – not only of the phenomena of interest but also of the *conditions of seeing* under which that phenomenon could be observed. Only relatively recently did the model become a favored way of arranging these *conditions of seeing*. Model-based reasoning entails deliberately turning attention away from the object of study to construct a representation that stands in for that phenomenon by encapsulating and enhancing its theoretically important objects and relations. Instead of directly studying the world, one studies the model – the simplified, stripped-down analog. Bazerman credits Newton with pushing this trend toward the evolution of a scientific report into a form of argument. By attempting to foresee and address in advance all potential alternative interpretations that a reader might raise, Newton moved quite far from the sequential retelling that characterized earlier accounts. It is no surprise why people would find this specialized form of argument somewhat puzzling. For instance, even graduate students often mention that they find it unsettling that a multi-experiment research article may report studies not in the chronological order in which they were conducted but in the order that is most logically persuasive. This upset Newton's contemporaries as well (Bazerman, 1988).

Introducing Novices to the "Modeling Game"

Modeling, then, is a rather specialized way of thinking and its indirectness poses unique instructional challenges. How can models be introduced in ways that allow students to participate in their invention and revision?

Arranging the conditions for seeing. One challenge that is characteristically sidestepped in school science is the construction of the conditions for seeing via materials, comparisons, observational schemes, experiments, and/or instruments. Rarely do school students receive much opportunity to participate in this critical phase. Science kits, which are increasingly widely used in elementary science education, adroitly avoid these struggles. Most of the kits are quite prescriptive, specifying the question(s) to be pursued and step-by-step instructions for carrying out the "investigation." It may be that the intent is to make scientific inquiry "fail-safe" because teachers feel uncomfortable negotiating student failure. Similarly, in many university courses, limitations of time and materials, coupled with a concern that students "discover" a particular predetermined relationship or finding, restrict students to recipe-like laboratories with fixed questions and known "right" answers.

Although it stems from understandable motivations, the scripting of inquiry fundamentally distorts it. Pickering (1995) points out that constructing situations, machines, and materials to investigate the world is a defining element of scientific practice. Pickering refers to this activity as achieving a "mechanic grip on the world," a phrase that evokes the struggle that ensues when scientists try to wrestle the natural world into a position where they can effectively study it. Scientists harness machines and related forms of material to pursue avenues of inquiry. Moreover, when one develops a material system for investigation, nature presses back in ways that investigators often find surprising and that result in adjustments of human intentions and understandings. For example, when our sixth graders studied aquatic ecosystems by creating models of a healthy pond system in a one-gallon jar, they were surprised (and dismayed) when many of the jars became eutrophic and eventually crashed, resulting in the smelly death of many of the inhabitants (and the proliferation of others, largely unseen). These system failures, in turn, provoked a great deal of learning, as students struggled to adjust their earlier simple views of aquatic systems to incorporate the role of previously unconsidered entities such as bacteria, dissolved oxygen, and algae (Lehrer, Schauble, & Lucas, 2008).

Pickering describes science as a process of interactive stabilization, one that forms a dialectic of resistance (by nature) and accommodation (by humans). The outcome of this dialectic cannot be determined a priori. Unfortunately, school science at every level resists engaging with this intersection of the conceptual and material worlds. Instead, students are provided with apparatus, and their experiences are preordained in laboratory exercises. Everyone knows what one is supposed to "see." Machines and material are relegated to secondary status as mere tools and the history of interactive stabilization is obliterated, so that the machines and materials are positioned as routine and transparent. Perhaps for this reason, little is known about youngsters' capability to engage in formulating the questions and conditions for inquiry. Almost all of what we have learned from research about students' scientific reasoning focuses exclusively on what happens after these issues are resolved (almost always by the curriculum designer), even though these critical activities are key in shaping the design of research, interpretation of data, and conclusions that are ultimately drawn.

Inventing measures. In contrast, and consistent with the focus on modeling, we expect students in our participating classrooms to ask questions, build and revise systems for investigation, construct data representations that are convincing to other investigators, and decide which conclusions are warranted and how much trust they should be given. A corollary is that we expect students to invent measures that capture what is of interest. Measures and qualities of a system are co-determined: inventing measures requires reconceptualizing the qualities being measured, and developing measures makes it possible to specify relationships among qualities. For example, the sixth graders struggled with the problem of how to capture their notion of a "healthy" aquatic system. Many initially believed that a "healthy" system was simply one in which the organisms stayed alive. What would signal a healthy system? How might expectations about the color of plants and the relative turbidity of water be encapsulated as measures that could show change? Over time these questions inspired a menu of inventive measures, many of which were picked up by other student investigators and adopted as classroom conventions. One boy developed a small window cut out of cardboard for estimating the number of daphnia (small water crustaceans) swimming in a jar. He found that by counting the number of daphnia visible in the (standard-sized) window, he could estimate the relative density of daphnia with reasonable accuracy. Another child developed a "greenness index," operationalized in a set of paint chips, to categorize the health of the water plants. A third student proposed a "branching index" to describe the growth of elodea plants. Composite measures (for example, to assess the "health" of a jar) required deciding which component measures to include, how to combine them, and whether and how to assign them relative weight so that the final measure aligned with and produced more precise indices of students' intuitive assessment of the jars' health (Lucas, Broderick, Lehrer, & Bohanan, 2005).

Developing representational competence. In addition to struggling with the challenges of material and measures, learners also must confront representational challenges. By this, we mean they must either accept (if the goal is to understand) or communicate (if the goal is to construct) the representational validity of the model. Is X an adequate, persuasive, or informative stand-in for Y? For which purposes? These questions are at play at all ages and experience levels but may be especially difficult for younger students. Like Bazerman's early scientists, young children tend to assume that seeing is believing. They do not find it obvious why someone would construct a representation or model as a way of learning more about something that you could very well observe directly. Moreover, it is always unclear just what needs to be represented.

Consider, for example, the kindergarteners who grew flowering bulbs of different species: hyacinth, amaryllis, and paperwhite narcissus. The growth patterns of these bulbs are characteristically different, and teachers sought to focus the children on patterns of change. However, with their unassisted eyes, the children saw plants, not patterns. They lovingly drew detailed pictures of the plants in their journals, devoting care to achieving the right nuances in changes of color, texture, number of leaves, and the like. It was not easy for them to abstract the attribute of "height" from their rich, personal histories with the plants. To turn their attention to changing patterns of height, the teacher worked with them to first record and then display these changes. As the plants grew, children cut lengths of string to record the heights of the growing plants at several days of observation and later mounted the strings on paper strips. For these youngsters, the correspondence between the strings, the strips, and plant heights was not immediately evident. Many of the children recalled stages in the plants' development but could not coordinate them with the patterns of growth that were represented by the strips. The children's struggles illustrate the heart of the representational challenge: Can a piece of string stand in for something about a plant? If so, which attributes are important to focus on? What does the representation tell us and why don't we just look at the plants? The displays captured patterns of growth that children were otherwise unable to notice, but noticing had to be carefully cultivated and did not just spontaneously occur.

Part of the representational challenge involves relinquishing the assumption that *represent* means *copy*. At first the kindergartners were presenting *plants*; only over time and discussion did they come to represent *plant heights*. Preserving similarity between the representation and the represented world can enhance the likelihood that children will accept the representation as a legitimate stand-in for the target phenomenon. For example, in our early work with David Penner we found that first graders who were asked to use hardware junk to make something that “works like their elbow” insisted on including Styrofoam balls and popsicle sticks to indicate fingers and the “bump where your elbow is,” even though neither of these features had anything to do with the motion of the elbow joint (Penner, Giles, Lehrer, & Schauble, 1997). As this example illustrates, although similarity helps with the representational challenge, it also has a dark side. It can provoke children’s reluctance to leave information out, even if that information is useless or distracting with respect to the current purpose. In instruction, one can easily err, either by too quickly abandoning similarity or by failing ever to nudge children beyond it. A helpful first record of plant growth might be a display made by pressing, sequentially arranging, and then Xeroxing plants at each day of growth. This display records changes in the plant heights but anchors them to other recognizable features, like the number of leaves and buds. However, plant volume, color, and mass are not represented in the pressed plant display and these omissions are frequently resisted by students. However, as students coordinate the pressed plant display with conventional coordinate graph descriptions of changing rates of growth, they can understand better the value of omission. The pressed plant displays support coordination between change in growth rates (i.e., the growth spurt) and morphological change, which often sparks new questions about biological function. What is the advantage to the plant of a period of accelerated growth? Moreover, as we noted earlier, rather than replacement, the challenge for succeeding representations is to enter into relation with predecessors, so that a phenomenon comes to be understood via the “circulation” of reference (Latour, 1999).

Children sometimes find it disconcerting to entertain the possibility that there is no one “right” representation. A good representational solution for one kind of problem may not work well for another. Yet in school, students are accustomed to pursuing “right answers” and readily suppose that solutions should have eternal verity. One’s evaluation of representations and models depends entirely on what one is trying to learn or communicate with them. For this reason, our collaborating teachers do not follow the usual instructional practice of introducing canonical forms of representation (such as pie graphs, tables, and the like) along with rules that specify the circumstances under which they should be used. We prefer to focus attention instead on the perceived problem and the way the various solutions work to resolve it, rather than on a so-called “correct” representation. One way to introduce these issues in a classroom is to pose tasks that evoke a variety of representational forms. In one series of studies, all the students in a class measured the width of their teacher’s outspread arms. As one might expect, there was some variability in the measurements, with most measures clustered around the center of the measures. After displaying all the measurements, the teacher challenged students to invent a data display that would reveal a “trend or pattern” in the data. Researchers observed a variety of representational solutions to this problem that included both ordered and unordered lists, frequency graphs featuring different-sized intervals, pie charts, and other inventions (Lehrer & Schauble, 2007).

Once students have produced variable solutions to a representational problem, it can be helpful as a next step to ask students to critique and evaluate their own and their peers' representations with respect to what their displays "show and hide." The message conveyed is that all representations involve trade-offs and that design choices should be governed by one's purpose and audience. Teachers invite students to trade their invented representations so that a student who was *not* involved in the creation of a representation is asked to communicate to the rest of the class what she thinks it implies with respect to the question at hand. When students regularly compare and critique representations, both their representational sense and their representational repertoire expand.

Developing an epistemology of modeling. Models are analogies and hence represent reality without making claims about direct correspondence between components in the model and components in a natural system: "works like," not "is a." As a consequence, models can be evaluated only in light of contest from competing models. Consequently, instruction must be designed so that students have the opportunity to invent and revise models, or otherwise engage in what Lesh and Doerr (2003) call a cycle of modeling. The instructional emphasis on variability of representational means and solutions supports this fundamental quality of modeling. It provides students a practical forum to regard their own knowledge or ideas as potentially disconfirmable and as contingent upon evidence. Young students often assume instead that others see the world as they do and that differences of opinion are easy to resolve if only individuals agree to look in the "right" way (Driver, Leach, Millar, & Scott, 1995). The very idea of evidence presumes that the observer is prepared to "bracket" his theory or interpretation apart from the evidence that supports or disconfirms it and to evaluate the relationships between belief and evidence. Thus, evidence is taken as bearing on theory and theory is regarded as hypothetical, in contrast to an undifferentiated amalgamation of theory and evidence regarded simply as the "way things are" (Kuhn, 1989). This realization is hard won and no doubt needs to be re-accomplished many times in a person's lifetime. It is, however, most likely to emerge in contexts where students learn to expect that problems evoke a variety of models and representational forms, and if they are regularly required to justify their claims against other rival claims.

Therefore, we work with teachers to identify modeling contexts that afford a means of model test. Some kinds of model test are more accessible and immediate than others and we tend to emphasize these with younger students. For example, when students invent models that work like their elbows or when they design jar ecologies, the need for model revision quickly becomes apparent when the elbow model does not move or the jar model can be smelled at a considerable distance. However, many forms of model test are not immediately resolvable and require sustained conceptual effort and logical chains of reasoning. Often, students need to mathematize, structure, and link complex forms of data (which may take time to collect and structure) to an initial question, and typically, the results include margins of uncertainty (which can sometimes be quantified). For example, examining the effects of pH on dissolved oxygen in a system generally entails accounting for patterns of covariance in light of variability introduced by other components of the system, both biological and abiotic. In our view, one of the hallmarks of modeling is that it includes evaluation not only of model fit but also of model misfit, and the appropriate interpretation of data requires ideas about sampling, probability, and uncertainty. As previously discussed, students' mathematical resources are key to their capability to participate in model evaluation. Model test leads to model revision and models build in their power and scope as students seek to retune them to better fit the data or to encompass a wider array of situations.

Pedagogical Norms and Activity Structures That Support Modeling

Orchestrating modeling is more demanding for both teachers and students than using science kits or reading science texts. Modeling approaches to science require careful thought to the kinds of norms and activity structures that make it possible. Initially, students do not even necessarily understand the logical relationship between question posing and data collection; the two activities are easily interpreted as unrelated classroom routines. Without teachers' assistance, students can fail to sustain the extended chains of reasoning that link questions, development of materials and/or observational schedules, data collection schemes and activities, data structure and representations, and conclusions. Unless teachers provide the appropriate press, representations will not necessarily be critiqued, evaluated, and revised. In particular, teachers need to shape environments in which students are accountable to listening closely, questioning, and challenging each other in a respectful way. They need to understand that they are expected to build on the ideas of others in their talk, rather than engaging in the kind of collective monologue (e.g., your turn, my turn, next turn) that is often valued in schools. In addition to these general features of classroom interaction, teachers may need to give explicit thought to disciplinary specific norms.

A classroom activity structure that has proven useful in fostering these norms is the research meeting, originally introduced by Deborah Lucas, a participating teacher, to support the investigations of aquatic systems that her sixth graders were conducting. Ms. Lucas adapted her research meeting structure from the practice originally described by a graduate student in Entomology who was assisting in the classroom as children studied aquatic insects, and who told Ms. Lucas how scientists in her discipline formulate their ideas and investigations by regularly convening to present and discuss them. Ms. Lucas was also influenced by Magnusson and Palinscar's distinction between first- and second-hand investigation (Palinscar & Magnusson, 2001).

Ms. Lucas' research meetings featured reports of ongoing progress by teams of students working together on a particular question or issue. Each week teams were selected by lottery to report. Because students did not know which team would be selected until the meeting began, all were required to come prepared to explain the current state of their research plans and findings. Classmates were expected to offer questions, comments, and help and to provide written feedback. As the research meetings were sustained over several weeks, they were increasingly dominated by student exchanges that challenged the soundness of a team's research design or the assumptions that underlay a planned approach. For example, one team of students worried that their difficulties in creating a sustainable aquatic system were imperiling some of the fish who lived in their one-gallon jar. As a solution, they proposed transporting the fish to a "hospital" aquarium and then returning them to the jar ecosystem once they had recovered. However, a student listener pointed out that this plan, which might perhaps save the fish, would also invalidate the logic of the original design:

Emily: Well, um, if our fish start to have problems, we could just move them back to this tank=

Daniel: =Yeah=

Emily: =and this tank is just like our storage container for the fish=

Daniel: =Yeah=

Emily: =and bubble that.

Daniel: Or else before we put the animals and the substrate in, we could

First bubble it. . .to a pretty high DO [*dissolved oxygen*].

Ilya: But isn't your question how fish and frogs affect the DO? . . .But=

Daniel: =Yeah, but=

Ilya: =just wait. . . .If your fish or frogs start dying in the jar, and you can't take them out and put them in the middle jar, then you can't do your question anymore, because they're not in the jars affecting the DO. They're in some other jar.

Emily: Well, yes.

These discussions relied heavily upon consensus criteria for questions and evidence that had been repeatedly generated and revised by the students over the course of the academic year. As Ms. Lucas regularly solicited students' judgments and justifications about the qualities of "good" research questions, she publicly posted criteria for which there was widespread consensus and these were continually referenced as classroom standards (Lucas et al., 2005). These criteria evolved over the year from an early focus on why a question might be fruitful and how one might go about generating an answer ["Genuine, we don't already know the answer," "Doable"] to growing concern with collective accountability ["People can piggyback on the question, build on previous questions"] and with furthering knowledge within the classroom community ["The answer to the question contributes toward everyone's understanding"].

Students' judgments about qualities of good questions were accompanied by similar criteria for judging the soundness of evidence. These were also summarized in a class rubric that was generated by students and repeatedly referenced during research meetings for evaluating presenters' claims and data. The rubric suggests that students differentiated early on between authority and empirical evidence as sound bases for judgment. As the criteria evolved, they included the embedding of evidence within models, indicating sensitivity to the theory-laden nature of evidence ["I only included evidence that directly related to my question, even if I saw other interesting things"]. Because the class criteria for questions and evidence were repeatedly cited, reinforced, and revised within the research meetings, the meetings encouraged the re-inspection and revision of ideas about questions and the evidence that bears on them. Consequently, students became increasingly aware of, reflective about, and critical of questions and evidence – both their own and those of their classmates.

Conclusion

What, then, is important in determining whether and how young students successfully enter the modeling game? For answers to this question, developmental psychologists might be inclined to look to notions of general developmental readiness. Certainly it may play a role – the emergence of a theory of mind is almost certainly central to children's capability to "bracket" their knowledge and to regard it as hypothetical, that is, as confirmable or disconfirmable in relation to a body of evidence. However, this is assuredly not the whole story. One might also look to the affordances of tasks. As we have explained, we certainly believe that some tasks are more fruitful than others. We favor tasks that emphasize question posing, creating conditions for seeing, and development and evaluation of measurement. In addition, tasks that provoke variability of solutions and representational forms are more likely to support the development of a broad representational repertoire and an understanding of audience and design trade-offs.

However, good tasks do not suffice without good teaching. Modeling is a form of argument that is central to science and that has other instructional advantages as well: it renders student thinking visible to teachers and peers, it fosters representational competence, and it enhances bootstrapping between mathematical and scientific sense-making. However, achieving these advantages depends on students meeting a number of challenges to entering the "modeling game," even at novice level. Teachers must identify and deploy norms, routines, and activity structures that help students construct and then maintain the relationships of all parts of the modeling chain, from questions to conclusions and back again. They must find ways of encouraging students to develop and use thoughtful criteria for evaluating the interest and fruitfulness of scientific questions and for deciding whether evidence is trustworthy and can be accepted as supporting the claims it accompanies. We find it fitting, in a volume that honors Gaea Leinhardt, to close by reminding readers of the interdependencies between explanation (in this case, modeling as a form of explanation) and effective teaching.

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Chapter 3
Learning, Identity, and Instructional Explanations

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According to Leinhardt (1993, 2001), instructional explanations are the contributions to learning provided by teachers and texts. Instructional explanations contribute to learning, first and foremost, by communicating particular aspects of subject matter knowledge, that is, by conveying content in the form of concepts, relationships, procedures, schemas, and other knowledge structures. Instructional explanations can adopt the form of expositions, conversations, demonstrations, and narratives and make use of a variety of representations to capture critical aspects of subject matter knowledge. As communicative devices, the adequacy of instructional explanations depends on how appropriately they sample the domain of interest, that is, on whether they incorporate conceptual referents and relations that are known to be crucial with respect to the topic under consideration. Because instructional explanations aim to communicate aspects of subject matter knowledge, their success lies further on the effectiveness of the communication itself. Whether students understand an explanation or not and whether such understanding translates into actual knowledge in use is, as Leinhardt (2001) has argued, a complex function of when the explanation is given, to whom it is given, and how it is crafted conceptually and representationally.

The point that we want to make, however, is that instructional explanations not only communicate content but also convey a sense of what disciplinary fields are, of how they are organized, and of what it takes to be a legitimate member in disciplinary communities – a point that Leinhardt and Steele (2005) have recently underscored. Instructional explanations are, in addition to communicative devices, social actions, to use Harré's and Van Langenhove's terminology (Harré & Van Langenhove, 1999). As social actions, instructional explanations, often indirectly, but at times quite explicitly, become themselves resources for the students' process of identity formation, in the sense that they portray worlds and forms of agency within those worlds.

In this chapter, we examine the nature of instructional explanations as social, discursive actions. Our goal is to illustrate the role that instructional explanations

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can play in the formation of disciplinary identities, that is, in how one becomes what one is in a disciplinary context. We rely on data drawn from a study that investigated science learning in real-life, authentic scientific contexts. In particular, the study researched what students learned and how they learned during fieldwork in biology, a setting not yet thoroughly explored and of paramount importance for the biological sciences. The study focused on the nature of the interactions between experts and apprentices in the context of joint scientific practices.

One of the analyses that we conducted, and whose results are discussed here, focused on the experts' conversational contributions or instructional explanations within specific scientific practices. We found that instead of lecturing out in the field or acting as museum guides, experts played a much subtler role. They modeled disciplinary practices in a way that defined for students forms of acting in the field, that is, of *being* field biologists. Experts also highlighted legitimate positionings within the discipline and connected what appeared to be simple actions of instruction with debates and tensions within biology as a scientific discipline. Both teaching moves, that is, the *modeling of disciplinary practices* and the *highlighting of disciplinary positionings*, undertaken in the context of an activity aimed to educate young scientists, had, in our view, consequences that exceeded the acquisition of research skills and the learning of disciplinary knowledge. They connected instructional explanations with issues of identity.

This chapter is organized as follows. First, we review literature on the intersection between learning and identity, as both relate to the participation of learners in communities of practice and the positioning of actors in the context of social interactions. Second, we introduce the study about joint practices during biology fieldwork, with an emphasis on the data collection procedures and the instructional context of the field trips under scrutiny. Then, analyses of selected instructional explanations in the field that modeled disciplinary practices and highlighted disciplinary positionings are presented. Final remarks on instructional explanations and identity formation are also offered.

Learning and Identity

Over the past decade, there has been an increasing number of empirical studies and scholarly papers (Boaler & Greeno, 2000; Holland & Lachicotte, 2007; Holland & Lave, 2001; Holland, Lachicotte, Skinner, & Cain, 1998; Packer & Goicoechea, 2000; Penuel &Wertsch, 1995; Roth & Tobin, 2007; Wortham, 2006) that bind learning not only to epistemological ventures but also to ontological processes, that is, using Packer and Goicoechea's words, to the "forging of new identities" (2000, p. 229). Identity is, of course, a concept with its own academic credentials and one that has been a subject of study in many scholarly traditions, from Erickson's psychological theory of identity development to Gergen's sociohistorical treatment of the self and Tajfel and Turner's social identity theory. Broadly conceived, identity refers to the kinds of answers that someone might give to questions such as who am I? How do I fit into the world? And, where am I located within a particular community? The challenge of any theory of identity is to account for the sense of constancy and permanence, on the one hand, and yet of change over time and diversity, on the other, that are simultaneously part of the human experience.

The introduction of the concept of identity into the learning literature can be traced back to the work of Lave and Wenger. If one defines learning, as Lave and Wenger (1991, p. 53) did, as "an evolving form of membership" in a community of practice, it is apparent that learning involves a transformation of how an individual stands and acts within his or her community. Penuel and Wertsch (1995) noted that how an individual acts and where he or she stands is a function of the cultural resources available in the community and the individual choices made in the context of day-by-day, concrete interactions. According to Holland and collaborators (1998), the ever-changing result of the negotiation between individual commitments and cultural resources is precisely a sense of identity. From their perspective, identity formation involves adopting a culturally shared world, establishing a positioning within such a world, and developing a sense of agency, that is, a sense of how one can legitimately act upon and within such a world.

Despite their differences, most modern perspectives on identity in the psychological and educational literature share, in our opinion, three features that are crucial to understanding the contribution of instructional explanations to the emergence of students' disciplinary identity: a focus on concrete activity, an emphasis on the social, and a relational definition of identity. The *emphasis on concrete activity* is better understood if we turn briefly to the work of Nietzsche, an overlooked source for the modern criticism to the radical separation between activity and thought. In *Ecce Homo*, Nietzsche (1968) dealt with the issue of how one becomes what one is and inquired about the distinction between appearance and reality – a distinction that is at the core of reflections about identity. Nehamas (1983) reminds us that Nietzsche criticized two common interpretations of the distinction between appearance and reality (or to put it differently, between what we appear to be and what we supposedly really are). The first interpretation, somewhat Freudian and aligned to depth psychology, is that the core of oneself is always there, waiting to be unveiled. According to this view, manifest actions are, at best, problematic, transient indexes of identity. The second interpretation, somewhat Aristotelian, is that what one is resides in the capacities one has to actualize and for which one is inherently suited. Potentials rather than actions are then the kernel of identity. In either case, there is a profound dissociation between identity and action. Nietzsche went beyond these two interpretations by reducing, in terms of Nehamas, the being and the doer to the deed: "There is no being behind doing, effecting, becoming; the doer is merely a fiction added to the deed" (Nietzsche, 1968, I, p. 12). In other words, Nietzsche suggested that identity is not to be defined in the realm of subjective, metaphysical experiences or entities, but in the realm of what people do, that is, in the activities and practices in which they engage.

A similar move was made by Vygotsky, who, in *The historical meaning of the crisis in psychology: A methodological investigation* (1927/1996), advocated for a study of concrete forms of life, as opposed to just meaning. By privileging the study of concrete forms, life in action, Vygotsky was not referring simply to behavioral repertoires, but to culturally signified and mediated actions, determined by history and circumstance. Identity was, then, to be found in what people do, with attention to what their actions mean in the context of their culture and history.

The second feature shared by modern theories of identity is the *primacy of the social over the individual*. This is a theme frequently found in sociocultural theories of human development (Cole, 1991; Rogoff, 2003; Packer & Goicoechea, 2000) and one that dates back to Vygostky's ideas on the genetic roots of thought and speech (Vygotsky, 1929/1994; Vygotsky, 1927/1996), which in turn are philosophically related to Hegel's notion of recognition (Musaeus, 2006). Vygotsky suggested that what is at stake in development is not a process of socialization, understood as the adoption of cultural forms (e.g., meanings, practices, values) by a fully fleshed individual, but the very constitution of subjectivity or of the individual as a result of sociocultural practice. From this point of view, identity formation is not the process of getting oneself a place in the world but rather of constituting oneself through and in the context of the practices one is already participating in, and whose form and structure are prior to one's agency. In other words, culture provides practices that anticipate one's identity and that constitute resources for forms of individual agency.

Third, and finally, modern theories of identity share a conception of *identity as a relational notion*. As Nietzsche warned, identity is not to be found in the depths of the human experience or in unchangeable subjective essences but in the totality of positions that discourse and social interactions bring about. An influential perspective in this respect has been Harré's theory of positioning (Harré & Van Langenhove, 1992, 1999), which, going beyond the traditional concept of role, assumes identity to be constituted by and in discourse and referred to the set of positionings that someone takes up in the context of conversations and joint practices (the very stuff of social life). "Positioning can be understood as the discursive construction of personal stories that make a person's actions intelligible and relatively determinate as social acts and within which the members of the conversation have specific locations" (Harré & Van Langenhove, 1999, p. 395). According to Harré, one can position others and be positioned by others, as when one presents oneself or is presented by others as independent or dependent, active or patient, hero or villain, happy or sad, advocate or detractor.

Harré and others have underscored different forms of positioning (e.g., social, expressive, personal), but in any case positioning means that one's actions (discursive or otherwise) are hearable or parsed with respect to polarities or, more generally, distinctions within certain dimensions. In this context, identity is not conceived as a fixed matter, but as a stance that cannot be defined except with respect to others. Identity becomes then a topological location. This view of identity as a relational phenomenon is also consistent with a sociocultural perspective, according to which identity is a mediational phenomenon par excellence (Boaler & Greeno, 2000; Holland et al., 1998; Penuel & Wertsch, 1995), whose understanding implies taking into account the ways in which an individual engages in a dialog with traditions, the ways in which an individual organizes his/her own narratives, and the individual's forms of engagement within the context of everyday practices.

Instructional explanations have to do with identity in that they have the potential to change what students do and are, by providing them with new ways of being and acting in the world. Not in any world, though, but in the world of the disciplines and subject matters that the instructional explanations convey. Instructional explanations also map the disciplines and convey their topography by laying out the sides in an argument, the academic traditions in a field or space of inquiry, and the polarities that constitute the major divides of a discipline. In so doing, instructional explanations suggest positionings within disciplinary communities and hint at learning trajectories within them.

Biology Fieldwork as a Scenario of Identity Shift

We have referred to matters of identity because we have been interested over the past few years in how people learn science in real-life, authentic settings and, as a result, often make career-changing decisions. Over the past years, we have focused our efforts in investigating the nature of joint practices during biology fieldwork. Our attempts to understand what goes on during fieldwork have been preceded by a growing interest in the psychological and educational community in investigating scientific reasoning and practices in authentic, real-life scientific contexts. Considerable effort has been devoted to studying distributed reasoning (Dunbar, 1995) and the use of artifacts, representations, and models within lab settings (Nersessian, 2005; Nersessian, Kurz-Milcke, Newstetter, & Davies, 2003; Schunn, Saner, Kirschenbaum, Trafton, & Littleton, 2007). Only recently, however, have studies begun to underscore scientific settings, particularly university labs, as learning environments in which the trajectories of participation of young scientists can be traced (Kurz-Milcke, Nersessian, & Newstetter, 2004).

Our work has been also preceded by efforts to capture the dynamics of field science (Bowen & Roth, 2002; Clancey, 2004, 2006; Goodwin, 1995; Roth & Bowen, 1999, 2001), particularly with respect to issues such as inscription practices, human–computer (or, more generally equipment) interaction, "professional vision," the role of logistics in scientific exploration, and interdisciplinary interaction. In the backdrop of this increasing attention to authentic scientific settings and field science activities there is, of course, the influence of studies in sociology of science (Latour & Woolgar, 1979; Pickering, 1992) and, more recently, in anthropology of science (Vinck, 2007).

Our interest in biology fieldwork stems from several attributes of fieldwork as an activity setting. Fieldwork is a setting that involves valued scientific activities, from observational practices to experimental work. Fieldwork is also a setting in which critical epistemic practices in biology are socialized. Fieldwork is an informal learning environment, usually nested within formal academic programs in the biological sciences. Like many lab settings, fieldwork routinely includes the participation of experts, graduate research assistants, and students in complex patterns of interaction. Although we initially approached fieldwork as a setting for the learning of disciplinary concepts, we soon realized that fieldwork is not simply an arena for intellectual work but also a locus that elicits intense personal feelings (both positive and negative) from professional biologists and an experience that helps define, very early in their academic careers, an appreciation for disciplinary domains (such as organismic biology or field biology) that are associated not only with styles of explanation but also with particular professional and personal trajectories. Fieldwork became for us a context where, to borrow Penuel and Wertsch's expression, identity is "contested or under transforming shifts" (Penuel & Wertsch, 1995, p. 90). Correspondingly, our efforts migrated from an emphasis on learning science to an emphasis on learning to be a scientist, from learning as an intellectual endeavor to learning as a quest for identity.

Research Methods

To approach the nature of learning during fieldwork, we opted for weaving three lines of evidence. First, we reviewed technical literature in the fields of contemporary biology and the history of science about the significance of fieldwork as a disciplinary practice (Futuyma, 1998; Glass, 1966; Whitaker, 1996). We looked for accounts of canonical scientific practices (bound by historical time) and for hints about the heuristic value of fieldwork in terms of its contribution to understanding phenomena under scrutiny.

Second, we conducted a series of in-depth interviews with expert biologists in Colombia. We selected local biologists with accomplished scientific careers, in terms of publications, ongoing research projects, teaching experience, time from graduation from doctoral programs, and fieldwork experience. In all, we interviewed 15 biologists, focusing on their learning trajectories, their current research programs, views of biology as a discipline, conceptions of fieldwork, and actual fieldwork practices.

Finally, we joined two biologists, during field trips conducted in the context of two undergraduate courses in a research university in Colombia. The first field trip consisted of a 2-day visit to Chingaza, a high-altitude ecosystem in the Colombian Andes. This field trip was part of a first-year course in organismic biology. The course covered introduction to evolutionary theory, systematics, bacteria, *Archaea*, *Protista*, seedless plants, fungi, *Ecdysozoa*, *Deuterostomes*, population genetics, biogeography, and conservation. The course included several lab activities and the design and implementation of a term-long research project.

The field trip was tied to an instructional unit on biodiversity and previous units on systematics and botany. The field trip was organized around two major activities: first, observational walks near a high-altitude lake (about 12,300 feet above sea level); and second, inventories of plant species conducted by groups of about five students over an area of 16 m^2 each group. This activity involved students using strings to set up a grid of nested blocks and to identify and count the number of different plant species and the number of organisms for each species found in the blocks. Students worked in small groups, with one student usually in charge of tallying the species and organisms called by the other members. Students used artifacts such as GPS, compasses, magnifiers, and an illustrated guide to the paramo flora.

The second field trip was a 5-day visit to Barú, a tidal coastal ecosystem in the Colombian Caribbean Sea, in the context of an advanced course in marine ecology. Course topics included biological oceanography, marine microbial ecology, marine ecosystems, deep waters, pelagic environments, and anthropogenic impacts. Students conducted research about mangrove roots, marine grasses (*Thalassia*) and calcarean algae, coral fluorescence, and fish populations associated with coral reefs. The students undertook zonation activities (to investigate the distribution of organisms in biogeographic zones), where they differentiated biomes by means of a visual count of organisms around a transect.

Given the serendipity needed to hit data-rich episodes and the impossibility of following everyone around, we decided to obtain information from as many sources as we could. Our data collection procedures included ethnographic field notes, video recording of selected group activities, on-site interviews, audio recording of the faculty members' conversational exchanges with students in the context of joint activities, review of student reports and field logs, and photos of artifacts, inscriptions, and settings.

Research Results

As an illustration of the role that instructional explanations can play in the formation of disciplinary identities, we report here excerpts of the analysis of the experts' instructional explanations in the field. In particular, we focus on two teaching moves that we believe are closely connected with the emergence of disciplinary identities: the *modeling of disciplinary practices* and the *highlighting of disciplinary positionings*, that is, of perspectival views of a discipline, associated with how biologists judge and act in their disciplinary community.

Modeling of Disciplinary Practices

Practices lie at the core of communities, including scientific communities. Scientists are recognized less for what they know than for what they do, that is, for how they engage in practices of measurement, inscription, pattern detection, argumentation, explanation, and so forth. In field biology, some crucial practices are the naming of species, the taxonomic classification of organisms, and the following of observational, sampling, and measurement protocols. Participation in such practices likely transforms how individuals parse the world, how they talk about reality, how they frame questions and craft answers, and how they experience themselves in the field. For example, when we asked the leading biologist at Chingaza about the instructional goals of opportunistic field walkthrough, he argued that one of his major accomplishments was to teach students to see. When we asked further about what he meant, he added (instructional explanations and interview data originally in Spanish; translations have been made as to preserve features of informal speech):

> It means that. . .um, and I don't do this only with students, I do it frequently with friends, and it's that. . .hmm. . .we drive from here to Anapoima or from here to Santa Marta and I always tell my friends, that my trip from here to Santa Marta was different from theirs. They might've seen different things from the ones I saw, and that's obvious, I have different sensibilities and the botanist is very fortunate 'cause he has great sensibilities, because there're plants everywhere, and where they see weed, I see clues, signals, information [. . .] Then first I teach them to see, to see plants, I teach them to recognize things that later become obvious, but that at first are not, and it's that. . .hmm. . .when one is looking down to the ground, looking to the rubble on the ground, fallen flowers, fallen seeds, etc., then one immediately looks back up. . .I teach them that they're not full botanists yet, I tell them that it's good to bring binoculars, not to see birds, which is a little bit arrogant but true, but to see if the leaves are opposite or alternate, if they are whorled or rosulate [. . .] then look to the ground, go with a machete and hit the trunks and smell them.

How do such sensibilities arise? How are young scientists initiated into such practices? The analysis of the experts' instructional explanations showed, much to our surprise, that most of the talk out in the field was not to introduce new content or to engage in disciplinary explanations of environments, species, behaviors, and other biologically interesting phenomena. It was, on the contrary, to model or comment on disciplinary practices such as observation, species naming, taxonomic classification, and data inscription, in such a way as to allow students to capture crucial aspects and meanings. Instances of instructional explanations that supported such practices are presented below.

In several instances, experts supported student learning by modeling and explicating *observational practices*. For example, in the trip to the paramo, during the walks to a eutrified lake, the expert would go first at times, about 15–20 yards ahead of the student group, looking down to the ground, silent, and occasionally kneeling down to observe specimens with his magnifier, a behavior that was imitated on many occasions by enthusiastic students. The biologist explicitly conveyed observational practices as a disposition (Eberbach & Crowley, 2009), advancing a crucial distinction between casual looking and observing, between simply passing by the environment and a careful noticing of features. Such a distinction invited students to new ways of acting in the world. For example, prior to the beginning of one of the walks, the biologist warned the students:

> [Excerpt 1]
> *Expert*: In this place you are going to listen a lot, to listen a lot of things. We are going to walk for a while without talking much, I'm not going to say anything, I want you to walk and observe, getting yourself used to the paramo.

This instruction is particularly interesting because in a way it runs counter to the students' knowledge and experience that the paramo environment is one especially silent and absent of distinguishable fauna. In our view, the request to adopt a silent stance could only mean that students needed to collect their senses to observe. Incidental remarks about observational practices and protocols abounded in this field trip, as when the expert, pointing to a tinny flower on the ground, portrayed observation not as a passive activity but as an intentional action that requires conscious attention and strategy:

[Excerpt 2]
Expert: Here you have some little flowers I love, look at them, you have to get on your knees and look, look and smell, here they are. . .you're stepping down on one of them! They're called *Lysipomia*, this is not the smallest of all, I like'em 'cause of their size, this is not the smallest of all, this is the smallest one, but it's not flowering at this moment. . .

During walkthrough fieldwork and inventories of biodiversity, experts also engaged in frequent naming and taxonomic explication. *Naming* refers to occasions when experts provided the scientific name of a plant or animal species, or the name of traits, structures, or environments, without elaborating on classification criteria or contrastive features. Examples of naming are the following conversational contributions:

[Excerpt 3]
Student: What is it called? This little yellow one. . .

Expert: *Halenia*, yes, Cachos de Venado [deer's horns]

[Excerpt 4]
Expert: How about this little yellow flower? How is it called?

Student A: [Inaudible]

Student B: *Castratella*

Expert: *Castratella*, genus *Castratella*, but what about the species? I'd have to look it up, I'd have to look it up.

Student C: Which one?

Expert: The *Melastomataceae* one. . .um. . .the one from, the one from the family of *Siete Cueros*

Naming was an inconspicuous practice during fieldwork, but one that introduced students to a new language, different from folk denominations, and with far greater demands of precision, as when students were asked to specify, not only the genus but also the species (as it is usually required in binomial nomenclature). There was, in many episodes of species naming (see, for example, excerpt 4), a visible attempt on the expert's part to press the students not to limit themselves to generic terms and take full advantage of the scientific nomenclature.

In contrast, during practices of *taxonomic explication*, experts went beyond mere naming and introduced or made explicit contrastive features. In our data, explication episodes were frequently repair conversational exchanges that occurred after a student had attempted unsuccessfully to name an organism. As can be seen in the following two excerpts, explication episodes served also as prime locations for disciplinary explanations about relevant conceptual issues:

[Excerpt 5]
Expert: How about these?

Student 1: Frailejones [providing the common name]

Student 2: *Espeletia*!

Expert: Right, but *Espeletia* doesn't say much. . .anyone?

> *Expert*:*Espeletia grandiflora,* and why? Because they have the flowers, the inflorescence larger than the leaves, right? And here there is only *Espeletia glandiflora,* if we go to a more humid place, we're going to see *Espeletia killipii* and if we go to a place more forest-like, we're going to see *Espeletia uribei*, then they're separated ecologically not to mix, not to interbreed, and not to compete with one another, right?
>
> [Excerpt 6]
> *Expert*: Here there is a little plant with a flower, a little plant with a flower, this is of the coffee family, the *Rubiaceae*, and if you see the inside of this little flower, uhm, the style and the stigma are down below, right, that little white dot. These plants, as I showed you also in class, are dimorphic as far as the flower is concerned, there're some with long stylus and some with short stylus, this one is one with a short one, look at it carefully…

Together, naming and taxonomic explication introduced students to a new language that complexly mediates their experience and constitutes a departure from everyday speech (e.g., *Frailejón* and *Siete Cueros*, common names, are no longer acceptable). A language, further, that makes visible conceptual systems in the discipline (e.g., distinctions among groups of organisms, hierarchy of taxa, classification of species based on evolutionary ancestry). Specifying the species, together with the genus of a specimen, was not in that sense an empty showing of erudition but a commitment to the logic entailed in biological taxonomy and systematics.

Among the disciplinary practices that we found being supported by experts, either through modeling or through conversational contributions, were also *data inscription practices* (Latour, 1987). By inscription, Latour refers to marks, diagrams, prints, and other signs that re-represent raw data and that constitute objects of knowledge that are mobile, presentable, combinable, and readable. Fieldwork revealed itself to be full of activities aimed to transform, via inscription practices, observations into data.

Students engaged in some activities that required physical layouts (e.g., nested blocks marked with strings on the ground, transects) as a support for data collection. One would think that the use of such instruments would be unproblematic, but it was not and frequently led the students to animated debates. At Barú, for example, students were instructed to lay out a transect (i.e., a straight line, along which ecological measurements are made) to help register gradients of diversity on a terrain near a population of mangroves. Some students rushed to stick the two poles into the ground to set the string without concern for whether the transect itself was located in such a way as to maximize the probabilities of actually recording meaningful variation. A vivid discussion followed about where to locate the transect, the representativeness of the location, and its implications for data analysis and validity. At Chingaza, discussions about the location of the grids to carry out inventories of biodiversity also took place. But once the grids with nested blocks were set, some additional implications of the instrument for data entering became apparent to students. On one occasion, for example, one of the strings that divided the blocks passed through a specimen of *Paepalanthus dendroides*, a grass-like plant with leaves in the form of a rosette, which looks like a collection of individual plants. Students had to solve, assisted by the biologist, what counted as an individual and make a decision as to in what grid block to include the specimen.

The stories of the transect and the *P. dendroides* show that there is nothing self-explanatory about inscription devices and that participating in inscription practices requires a commitment not only to follow procedures but also to construe them as conceptual devices. In both circumstances, the experts made critical remarks about the implications of seemingly trivial issues of measurement and data inscription.

Although this was not a controlled experiment and a number of factors are hopelessly confounded (i.e., different expert biologists, different domains within biology), the data suggest that the conversational contributions supporting the practices of species naming and taxonomic explication were much frequent in the field trip to Chingaza, a trip with less advanced students (who needed to appropriate and learn by heart the initial rudiments of the language of their discipline) and a practice in the domain of botany, where command of scientific nomenclature is particularly taxing. In contrast, at Barú, we observed a greater proportion of instructional explanations aiming at data inscription, perhaps given the fact that students, although already initiated in matters of taxonomy, were still unfamiliar with data collection and data inscription protocols in marine and underwater environments. In all, through their conversational contributions, the experts guided students in new ways of acting in the field. Students learned how to observe, how to name things, how to differentiate species, and how to reduce and transform observations into figures, frequencies, tables, and curves. And they did it not by being told or lectured but in the context of problem solving and activities that they jointly undertook with experts.

Disciplinary Positionings

Instructional explanations not only supported disciplinary practices but also highlighted disciplinary positionings, although this function of instructional explanations was a much subtler one and one that did not lend itself to statistical treatment given the relative rarity (although specialness) of occurrences. As argued earlier, positionings refer to polarities, oppositions, or tensions within a discipline, associated, in our case, with how biologists judge and act in their scientific community. These polarities constitute possible locations either to take up or to assign to others in a dialogical flow. They refer to the topology of discursive perspectives that a speaker creates and to locations within discourse associated with social identities. In the context of fieldwork, we believe some polarities prefigure professional and disciplinary trajectories, that is, disciplinary identities. By disciplinary identity we refer to the positionings someone adopts with respect to a set of disciplinarily relevant dimensions of variation, such as disciplinary goals, foundational disciplinary questions, privileged domains of inquiry, prevailing settings of practice, defining material practices, and canonical discourse practices.

As in many other disciplines, and not surprisingly given their taxonomic proclivities, biologists have always been fond of classifying (or positioning) themselves. For example, Edmund B. Wilson, a pioneering American zoologist, divided biologists into three broad categories: bug hunters (i.e., field naturalists), worm slicers (i.e., morphologists), and egg shakers (i.e., experimentalists) (Nyhart, 1996). In turn, Stephen Jay Gould (1993), in a review of Edward O. Wilson's *Sociobiology* (1975), suggested that biologists could fall in two traditions: Galilean and Franciscan, the former fond of the rationalist, intellectual puzzles of nature, and the latter of its lyrical beauty. Edward O. Wilson himself (1995), in his autobiography, chronicled, under the rubric of *The molecular wars*, the opposition between organismic biologists and molecular biologists. Aspects of this opposition reenact tensions that date back to the origins of scientific biology in the late nineteenth century, when, according to Nyhart (1996), natural historians were thought to uncover the large-scale pattern of living nature, through collecting in the field and classifying in the museum, while the 'modern' biologists in their laboratories sought to penetrate the internal workings of the living organisms to discover their fundamental causes. Yet a more common distinction is drawn between field biologists and lab biologists or, as Latin American biologists say, *biólogos de bota* and *biólogos de bata*, a wordplay that could be roughly translated as boot biologists and white coat biologists. As expected, these dichotomies are epistemologically too simple to be taken seriously. Yet, they populate the imagination of professional biologists and are associated with sensibilities that are not banal (Schmidly, 2005). More importantly, they are connected with ways of practicing biology and acting as a biologist.

An example of how disciplinary polarities are conveyed is Futuyma's criticism of a scientific biology entirely devoted to the pursuit of explanatory models. (Futuyma's remarks were voiced in a presidential address delivered to the American Society of Naturalism at a joint meeting with the Society for the Study of Evolution, the Society of Systematic Biologists, and the Society for Molecular Biology and Evolution in 1994):

> All of us agree that science does and should seek generalizations, formulate and test hypotheses, and develop the simplified conceptualizations that enhance understanding. But possibly we have come to focus too exclusively on the theoretical aspect of our enterprise. For surely the purpose of theories and conceptualizations is not merely to exist in themselves, as monuments to our ingenuity and insight but to organize the myriad details of the natural world as well. Our theories, mutable and usually ephemeral, should be viewed as vessels for the abiding of information on the real properties of real organisms; and our vessels are as meaningless, if they are empty, as a catalog system is for a library that lacks books. (Futuyma, 1998, p. 4)

Notice that Futuyma argues along an axis that opposes, of course not irreconcilably, knowledge of organisms to modeling practices, real properties to theoretical constructs, and simplified conceptualizations to myriads of details. Futuyma's words are actually a call for a particular way of doing biology, one that is concerned not only with the advancement of theories but also with the advancement of our knowledge of real organisms and environments. Futuyma's words are consistent with remarks by our expert biologists in the in-depth interviews, in which they frequently opposed the "excess of life" typical of the tropical forests to the parsimony of theoretical statements. Futuyma's words also go along with a view of biology that praises natural history (often viewed as the opposite of scientific biology) and sees it as a requirement for expertise in biology.

The polarities conveyed by Futuyma point to or suggest possible emphases or foci of professional development or scientific research. They also refer to distinctive points of view that need to be weighed in disciplinary arguments and explanations. In that sense, they call for positioning and perspective taking. The analysis of conversational threads at both Chingaza and Barú suggests that instructional explanations played a role in the establishment of disciplinary polarities of this kind. As an example, let us look at the following instructional explanations from the field:

> [Excerpt 7]
> *Expert:* Now what you're going to do. . .umm. . .what you're going to do. . .instead of calculating mathematical formulas to predict behavior in the context of competence, predation, or optimal foraging, or mate selection, is to leave the models' assumptions away, and look, look at the real stuff [. . .]

> [Excerpt 8]
> *Expert*: An important point is to dimension the complexity of what you study. For a geneticist, complexity is reduced to a mouse or to a fly, which is a lot. . .but to talk, to talk about nature, you got to be out here. There're a lot of simulations, lab sims where you control variables very well [. . .] but what's the significance of an organism in the field, that's a much more complicated problem.

> [Excerpt 9]
> *Expert*: It's a clutter when you're in the forest. We've got to organize it, we have to make people fit the world into a Cartesian plane, which is how we face the world in science. Everything ends in a Cartesian plane, with a curve, and explanation, and a model. What we're doing is sort of natural history, you know, it's like if you had a house with only the plumbing, not bricks, no walls. In human terms it's like Vesalio. Look at the bones, the circulation, but where's the meat? Well, here it is!

These contributions convey semantic oppositions between here and there, field and lab, real organisms and models, complexity and reduction, description and explanation, clutter and control, meat and bones. These oppositions indicate tensions that call for specific actions and stances on a biologist's part. For example, at Barú and Chingaza, parallel to the experts' emphasis on the appreciation of complexity and the insufficiency of models to account for the diversity of life, there was an emphasis on mathematizing reality and squaring it to extant theories and models. Students exposed themselves not only to unanticipated experiences but also to see matters through the lens of questions and theory, to refrain from description for the sake of description, and to reason experimentally.

In our data, fieldwork activities, in addition to instructional explanations, situated students at the crossroads of many of these disciplinary polarities. For example, at Barú, a group of students set up a research project on fish cleaning stations. Cleaning stations are an example of mutualist relationships, where cleaner organisms remove and eat ectoparasites and other material, such as mucus, scales, and skin, from the body surfaces of other apparently cooperating animals, also known as clients. Having read relevant literature, the students set to study surgeonfish (*Acanthuridae*) and gobies (*Gobiidae*). They decided to chase surgeonfish on a shallow coral reef, expecting that the fish would escort them to the cleaning stations. As might be expected, the students faced a number of obstacles in their attempt to run the study. They frequently lost track of the fish and when they did locate the stations, they found not only surgeonfish and gobies but also a plethora of other species. Given that they had limited means to register data (e.g., they were snorkeling, not scuba-diving), the issue was what measures to take so data would be reliable and, most importantly, meaningful to their research question. The students finally decided to go with measuring how long a fish took to clean another one. The students' comments on a group on-site interview revealed their frustration, but most importantly their reaction to situations that seemed to them not to "cooperate" or that were at odds with the procedural simplicity that is customarily reported in most research articles. Fairly or unfairly, the messiness and lack of anticipation of fieldwork were construed as the unruly counterpart of the orderly simplicity and reliability of lab protocols.

Of course, there are documented ways of reconciling these polarities, and the polarities themselves need not be exclusions. The point that we want to make, however, is that instructional explanations not only displayed polarities but in a way also invited students either to reconcile differences or to take sides, or to put it differently, to adopt a position. How should I deal with complexity? What goals should I pursue disciplinarily? What role should I attribute, if any, to natural history? How should I integrate field and lab research? What kind of research is more appealing to me? Should I commit myself to the knowledge of a group of organisms? In our view, answers to these questions are a function of disciplinary positionings that are defined in the context of joint practices and conversations. In that sense, as Davies and Harré (1999, p. 35) claim, who one is, that is, what sort of person one is, or in our case, what sort of biologist one becomes, "is always an open question with a shifting answer depending upon the positions made available within one's and others' discursive practices."

We have referred thus far to how instructional explanations supported and nurtured disciplinary identities via the highlighting of disciplinary positionings and the modeling of disciplinary practices. But how did students' identities actually evolve during fieldwork? We are just beginning to analyze student field logs, on-site interviews, and post-field trip interviews in search of traces of how positionings and practices changed over time. Yet, ethnographic evidence suggests that what goes on during fieldwork indeed touches students' sense of identity. We recorded students doing what otherwise might seem banal imitations of behaviors exhibited by more experienced biologists: students wandering off the trail and reaching inaccessible places only to bring an unexpected specimen to the amusement of their fellow students; students jumping, as the expert biologist had done before, on top of the moss cushions that float on the highly sedimented waters of the eutrified lake; and students warning others to slow down not to get too far from the group and get themselves lost in the mountain midst. These actions resonate in the sense that they reveal students trying out the very practices that they believe hold the key for disciplinary identities: foreground endurance, tolerance to adverse conditions, guts for exploration, solidarity, and sense of caution as ways of being in the world of field biology. These actions remind us of Charles Darwin's excitement for collecting and classifying beetles at Mill's pond in Cambridge, well before he had ever entertained the idea of becoming himself a biologist.

During the field trip to Chingaza, at the end of the day, when the students were about to complete their inventories of biodiversity, the biologist fetched a large pot, water, and a handy gas stove. He sat down on top of a hill overlooking the students and started boiling water to make *aguapanela*, a traditional Colombian sugary drink. The students were concentrated on counting specimens and species, but slowly began to notice what the biologist was doing. Comments and questions grew by the minute, as the students, who had by then finished their activity, approached the biologist. When all the student teams were done, the botanist announced that every field trip in biology ends with a toast, and began serving the drink to the students. Up to that point, the relationships between the students and the professor and the students among themselves had been rather distant, populated by rules, norms, and pressing goals to attain. Then, humor appeared, and students started to tell jokes, but not any kind of jokes, but jokes about biology and biologists.

Of course, the moral of this anecdote is not that a toast makes a biologist. Yet, as Goffman (1959) would say, the performance of a toast, the telling of or the laughing at a joke, the jumping on a treacherous surface, the engagement in naming and explication, and the preparation of specimens and data to take to the lab, do constitute performances that bring about and enact identity. Whatever disciplinary or conceptual learning the students had as a result of their field trip, it is likely that some of them felt that evening, back at their homes, more biologists than ever before. As argued earlier, identity is constituted through and in the context of the practices one is already participating in and by virtue of the sense of agency that such participation brings about.

Concluding Remarks

As Clancey (2004) has argued, an ethnography of field science or field science learning is, in itself, a field science enterprise and a learning experience in the field. It is then subject to the same determinations that act upon what it attempts to study. Despite considerable logistical challenges, we are beginning to understand the instructional dynamics of fieldwork, both as a scientific activity and as a setting for the learning of science. We have found that fieldwork, particularly at the onset of the academic trajectories of young biologists, constitutes a setting where identities, foundational practices, and disciplinary positionings are literally in the making. We have attempted to focus not only on what the students learn but also on what identity resources, in terms of positionings and mediations, fieldwork offers to them.

What the students learn during fieldwork is, at times, fairly procedural: how to set up a tramp, how to use a compass, or how to prepare a witness specimen. But students are also initiated into practices that are distinctive to the discipline. They learn a new language that is far more precise than everyday speech. They learn to discern and look for features that discriminate between species. They also begin, through the expert's instructional explanations, to be exposed to distinctive views of the discipline and possibly to diverging career paths.

Earlier in this chapter it was argued that modern perspectives on identity share three basic features: their focus on concrete activity, their idea of the prevalence of the social, and the relational character of identity. We contend that disciplinary identities do not rest only and primarily on a base of declarative knowledge (i.e., this is what I am) but also, and fundamentally, on a repertoire of enacted, concrete practices. In our case, those practices range from physical endurance and tolerance to adverse conditions to taxonomic explication and the setting of experimental protocols.

We found in fieldwork a setting in which apprentices participated in legitimate practices, even though they were not full participants. Experts anticipated and modeled practices, but also scaffolded situations in a way that made them tractable to students. Experts did not lecture or acted as guides in a tour; on the contrary, they were committed to collaborative activities, where students, regardless of their level of expertise, had a say. Students were thrown in the midst of taxonomic classifications, measurement protocols, and other practices and were made accountable for their decisions. Instructional explanations played a crucial role in all this, in particular because of their conversational flavor, which prevented experts from naming, classifying, and solving issues about data inscription procedures without actively involving their students. Finally, instructional explanations conveyed a world of polarities, sides, and perspectives, that is, a world where disciplinary identity is a function of the changing geography of arguments, views, and debates. In that sense, the students' identities as young biologists are not fixed and independent from what they actually do in the field and from the positions that are advanced in the context of the conversations and joint practices in which they participate.

It is clear that more ethnography needs to be done to consolidate what has been hinted here. Also, studies of fieldwork activities should be done comparing typical practices during pedagogical field trips (like the ones reported here) and those occurring during research field trips. Comparisons need to be done also between different domains of biology (e.g., botany and ecology). Yet, our analyses of the trips to Chingaza and Barú are, in our view, suggestive in showing that instructional explanations do much more than conveying content. Instructional explanations convey a sense of their disciplinary fields and of their fields' argumentative topography and ways of agency. In that sense, instructional explanations constitute resources for the formation of the students' disciplinary identities.

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Chapter 4
Learning Chemistry: What, When, and How?

David Yaron, Michael Karabinos, Karen Evans, Jodi Davenport, Jordi Cuadros, and James Greeno

This chapter is an overview of three projects that address the goals and practices of chemical education. The impetus for this work was the perception that chemical education has an entrenched approach that is out of touch with modern science and modern society. That is, students are not given even a rudimentary sense of what modern chemistry is as a domain of intellectual pursuit and students do not gain information that is of use to understanding chemistry's role in society. The projects summarized here were designed to make traction on a set of questions that can help improve this current situation:

- *What* is chemistry as a domain and what should introductory students learn about chemistry?
- *When* can students begin to engage in authentic chemistry activities?
- *How* can students better learn the more difficult aspects of chemistry?

The target of these questions ranges from the entire domain of chemistry and its interaction with society to individual students struggling with a particularly difficult chemical concept. The methods used to address these questions therefore also span a broad range.

Gaea Leinhardt played a major role in the development of the research methods and especially in helping us maintain balance between the sometimes opposing demands of rigor and authenticity. Rigor demands that the methods be as quantitative as possible with tightly controlled experiments. Authenticity demands that the methods be relevant to real educational issues. To find a balance, it is important to resist the temptation to narrow the research question to a point where it can be rigorously studied, but has lost relevance to chemistry education. The studies below attempted to achieve a balance by posing questions that were both authentic and amenable to rigorous studies.

The tension between rigor and authenticity also arises in the choice of instructional content. In instructional design, the pursuit of rigor can lead to a narrow focus

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on the teaching and learning of specific tasks, especially tasks involving mathematical problem-solving. Such tasks have a number of features that make them alluring from a rigor perspective. Performance on mathematical tasks can often be quantitatively assessed and straightforward instructional interventions, such as problem-solving practice, can lead to measurable improvements on these assessments. Such tasks can also be made sufficiently complex that students must struggle and overcome considerable obstacles to achieve success. To many instructors, the best way to ensure a rigorous course is to create a well-defined set of difficult tasks that can be easily assessed to unambiguously distinguish "A" from "C" students. The danger of this style of instruction is that students may learn the set of tasks without gaining an understanding of how these tasks relate to authentic chemistry. A principal motivator of our work is the perception that introductory chemical education has indeed succumbed to this danger. Chemical education, as a field, needs to better balance the demands of rigor with those of authenticity. One way to do this is by going beyond a list of difficult mathematical tasks and exposing students to what modern chemistry does as an intellectual pursuit and the implications chemistry has for modern society.

The following sections discuss three projects aimed at achieving a balance between rigor and authenticity in chemical education. In each case, the research methodology is also discussed from the perspective of balancing rigor and authenticity. We offer descriptions of these projects as a kind of instructional explanation; that is, we suggest that the projects "demonstrate and justify as well as support problem solving and reasoning in the process of developing understanding" (Leinhardt, 2001, p. 338).

What Is Chemistry?

What is chemistry as a domain and what should introductory students learn about chemistry? This question is clearly at the core of chemical education and all instantiations of chemical instruction must address this question either explicitly or implicitly. The project described below took scientific literacy as the framework in which to explicitly and systematically answer this question. Chemistry is an essential component of scientific literacy since "its methods, concepts, and practitioners are penetrating virtually every nook and cranny of science and technology" (Amato, 1991). In addition to developing a well-trained work force, there is the need for a chemistry curriculum that produces citizens who can read and understand articles about science in the popular press and engage in social conversation about the validity of the conclusions posed by scientific research. The promotion of such scientific literacy is among the strongest arguments one can make in support of the current requirement that high school students must take an introductory chemistry course. In the project described below, we asked: "To what extent does the content of current introductory chemistry courses accurately reflect the domain of chemistry? To what degree is current instruction aligned with literacy goals?"

To answer these questions, two approaches were employed in our first project: an interview with an academic research chemist, and an analysis of news articles about chemistry that appeared in the *New York Times* and *Scientific American* in 2002 and the citations for the Nobel Prize in chemistry awarded from 1952 through 2002. The interview took place between learning scientist (Gaea Leinhardt) and an academic research chemist (David Yaron). The primary question was: "What is chemistry?"

Initial attempts at this interview were unsatisfactory because, as became apparent in retrospect, an experienced instructor tends to use current chemistry courses as a framework from which to construct a response. A breakthrough occurred when the context of the question was changed to "Suppose you are testifying to Congress regarding the chemistry portion of the NSF research budget, and a congressman asks you 'What is chemistry?'" This question prompted a description of the following top-level categories of the activities of chemists: they *explain* phenomena, they *analyze* matter to determine its chemical makeup, and they *synthesize* new substances (Evans, Karabinos, Leinhardt, & Yaron, 2006). The top-level structure of this domain map is shown in Fig. 4.1. An initial draft of a more complete domain map was then developed, which expanded the hierarchy one level below that shown in Fig. 4.1. The map was also expanded to include a *toolbox* of the main notational and quantitative tools used by chemical practitioners.

The next step was to verify and refine the domain map by using the following textual sources that reflect important chemistry activities: the Nobel prizes in chemistry (1952–2002) and all chemistry-related articles (86 total) in the 2002 *New York Times* Science Times and 2002 *Scientific American* News Scan columns. Each article was coded for a main theme (chemistry activity), i.e., what made the reported scientific work new and noteworthy, and for auxiliary chemical themes. For instance, an article about the development of a new computational methodology, which was applied to model a synthetic chemistry reaction, has a main theme of *explain* and an auxiliary theme of *synthesis*. The text analysis supported the top-level activities of the

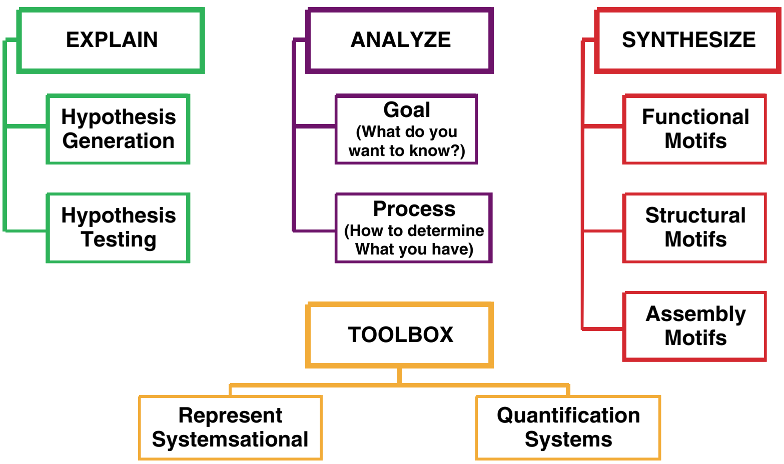

Fig. 4.1 Top levels of the domain map for chemistry

map (*explain*, *analyze*, and *synthesize*), and revealed that the coded chemistry activities were distributed roughly equally across these three categories. The text analysis further revealed a number of chemistry activities that are common but were absent in the lowest level of the draft domain map, and the map evolved accordingly. For example, the initial map did not include formulation, the mixing of chemicals that do not react with one another, as a synthetic approach. Formulation was later added to the map due to its frequent occurrence in news reports.

The resulting domain map enabled a systematic comparison of current instruction with the practices of the field as exemplified by commonly used textbooks in introductory chemistry courses (Smoot, Smith, & Price, 1998; Davis, Metcalfe, Williams, & Castka, 2002; American Chemical Society, 2002). Whereas the Nobel prizes and news articles are fairly evenly distributed among the three main activities of chemists, the textbook objectives focus almost exclusively on the *explain* activity and the *toolbox*. This misalignment is evidence that traditional introductory courses do not meet one of the basic goals of scientific literacy: understanding what chemists do in practice. This misalignment is especially problematic since it essentially hides from students the very things that are most exciting about doing chemistry.

We suggest that the domain map can be used to transform an introductory chemistry course from the current traditional structure to a reformed structure that better promotes scientific literacy. Our approach has been to develop scenarios that embed the problem-solving tasks of a current introductory chemistry course in contexts that show how these tasks are used by practicing chemists. The map guides the choice of scenarios to ensure that the distribution of chemical activities is aligned with those of the domain.

The methodology employed strikes a useful balance between authenticity and rigor that could potentially benefit other efforts aimed at refining instructional goals. A more common approach to setting educational goals, especially for the development of educational standards, is to form a committee of distinguished experts that then come to a group consensus. However, this committee approach places disproportionate weight on expert opinion of what is important to teach. Another danger of this approach is that distinguished experts have likely been teaching for many years, and the answer to the question “What should we teach?” is likely to have considerable overlap with their response to “What have you taught for the past 25 years?” Our experience with the above interview process highlights this tendency as, despite the interviewee’s strong desire to use the process to reform chemical education, major prompting and guiding were required to elicit a response to the question “What is chemistry?” activities that focused on experience with the field instead of instructional experience. The initial draft of the domain map also had strong biases of the interviewee’s research field of computational chemistry. The largest bias was that *synthesis* meant traditional chemical synthesis. This led to the absence, discussed above, of formulation from the original draft. Even for items that were in the initial draft, the statistics from the textual analysis altered the interviewee’s views on the relative importance of various concepts and experimental techniques. For instance, structure–property relationships are the most frequent type of explanation. While this makes sense in hindsight, the interviewee’s experience in computational chemistry had placed thermodynamics and chemical bonding as the most important type of explanations.

We have since adopted a similar textual analysis approach to add rigor to the setting of more fine-grained instructional goals. For instance, many instructional goals of college-level introductory courses are motivated by the need to prepare students for upper-level courses. We have compared the concepts and procedures of traditional instruction in introductory chemistry with the concepts and procedures actually used in follow-on courses. We have found substantial misalignments, especially in the area of acid–base chemistry, and are working to address these.

When Can We Teach the "Real Stuff"?

When can students begin to engage in authentic chemistry activities? Because authentic chemistry situations can be quite complex, there is a tendency to sequence instruction by first laying the groundwork of the formal notations and theoretical frameworks of chemistry. Traditional chemistry instruction takes this to an extreme when an entire introductory course is focused on laying this groundwork. The tasks on which students spend most of their time are designed to make them proficient with the fundamental tools (the *toolbox*) of the field. Although there is an active community of chemical educators working to bring more authentic chemistry activities into the introductory course, the inertia against change is quite strong. One source of inertia is that the tasks of the traditional course are codified in textbooks and standards exams. Another source of inertia is the allure of rigor discussed above, since the complex mathematical and procedural tasks of the traditional course can be readily assessed. A challenge is shifting the course toward authenticity while maintaining a structure that the majority of the community will view as rigorous.

In a second project, we adopted two strategies for maintaining a balance of rigor and authenticity in instructional tasks. The first strategy stays within the *content* list of the traditional course, but changes the *mode* of interaction with this content to make it more authentic. This is accomplished through the use of a virtual laboratory. A virtual laboratory allows students to practice and apply formal knowledge to the design and implementation of chemical experiments (Fig. 4.2). Students are given tasks that require them to design procedures, and collect and analyze data, to *explain* what is happening in a chemical system (e.g., determine what chemical reaction is taking place), *analyze* samples (e.g., determine the amount of arsenic in a sample of drinking water), and *synthesize* solutions with desired properties (e.g., create two solutions that when mixed together will lead to a target increase in temperature).

The affordances of this simulated environment are carefully designed to allow students in an introductory course to engage in this type of authentic activity. Experiments can be done much more quickly than in a physical laboratory, students can immediately see the contents of any solution (chemical species and their amounts), and, in some cases, fictitious chemicals are used to make the simulation easier to understand than an actual chemical system. This has led to many activities

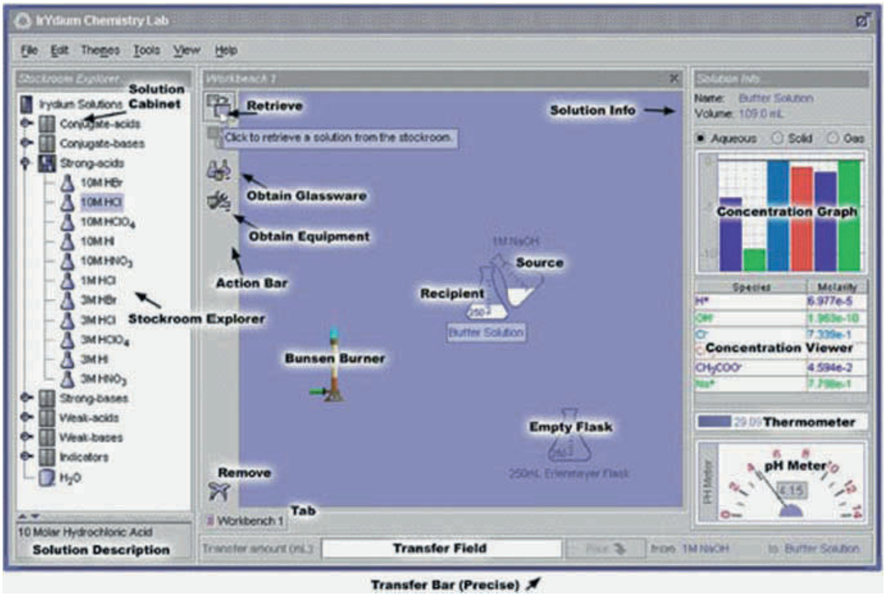

Fig. 4.2 Annotated screen shot of ChemCollective virtual lab (www.chemcollective.org)

that are instructionally useful and authentic in the sense that students are engaged in the primary activities of *explain*, *analyze*, and *synthesize*. However, they are not authentic in the sense of being a replica of the real world.

The second strategy is to embed the content of the traditional course in scenarios that highlight how that content is used in authentic chemistry. The hope is that this strategy provides a smooth pathway between the traditional course and our reformed vision of the course as captured in the domain map.

The research methods used to study the effectiveness of these interventions were highly quantitative, for rigor, but performed in the authentic context of real course instruction occurring over a substantial time period such as a full semester. One such study analyzed all student artifacts collected in a semester-long introductory chemistry course at a large R1 university, to help determine the effects of the use of virtual lab and scenario-based learning activities on students' understanding of basic chemistry concepts. In addition to the typical homework and exams, unannounced pre-tests were given the week before scheduled exams to help measure the learning that took place through the activities prior to studying for the exam. The rigorous quantitative aspects of the study design were successful, as evidenced by a structural equation model that could account for a large proportion (48%) of the variance in students' overall course achievement. The model showed that the virtual lab and scenario activities contributed significantly to overall learning in the course. Furthermore, the influence of the activities is uncorrelated with students' pre-knowledge, suggesting that such activities can help remediate the large disparities in student preparation present in introductory science courses.

The authentic aspects of the study design were useful in revealing some important aspects of the nature of learning in large introductory chemistry courses at the college level. For instance, the results showed quantitatively that a substantial portion of the learning occurs in the few days *before* each of the hour exams. However, this punctuated learning is also strongly influenced by the activities carried out *between* the hour exams. Such aspects of the use of learning materials in real classrooms are overlooked by smaller scale studies. Overall, the results suggest authentic and contextualized homework as *one firm spot* for influencing learning in college classrooms (Cuadros, Leinhardt, & Yaron, 2007).

Another study was conducted in an online course environment. This study used a well-constructed control condition and large collection of quantitative data to allow for a rigorous comparison between online and text-only versions of instructional materials (Evans, Yaron, & Leinhardt, 2008). Students about to enter an R1 university were given the option of completing a requirement of the introductory chemistry course, that of mastering stoichiometry and passing an exam on this material, before arriving on campus. This group was randomly divided into two conditions. One condition used an online course that included explanatory videos, tutors that provided immediate feedback on problem-solving steps, and virtual labs. The online course was also set in the context of arsenic poisoning in Bangladesh, with many of the problem-solving activities being situated in this scenario. Students in the control condition were given a text version of the course that was constructed to parallel all of the problem-solving activities in the online course, but without the scenario contextualization, and without any of the technological affordances. The text version was designed to scaffold student self-explanation. The first worked example of each problem type included both the actions and the explanation for those actions. The second provided only the actions and prompted the students to provide explanations. This was followed by suggested practice problems with only numeric answers provided for students to check their work.

This study was authentic both in the use of a population taking the course for credit and in a head-to-head comparison of what research would suggest is the best possible computer-based and text-based modalities for the course. A small but statistically significant benefit to the computer-based version was found. Furthermore, within the online condition, a large proportion of the variability in performance (39%) could be attributed to the degree of interaction of the participants with the virtual lab problem-solving activities, eclipsing any benefit of prior knowledge.

How Should We Teach Difficult Chemistry Concepts?

Some aspects of chemistry are particularly difficult to teach and learn, and success at these aspects becomes a primary distinguishing feature between high and low performance on classroom and standards exams. As a result, a disproportionate amount of instructional and self-study time becomes dedicated to these topics. For introductory college and Advanced Placement (AP) chemistry, chemical equilibrium (including acid–base chemistry) is arguably the most difficult and time-consuming portion of the course. Improvements in this portion of the course could therefore free up instructional time for other course goals.

Instructionally, chemical equilibrium is very rigorous in the traditional sense of being highly mathematical and complex. However, interviews with students a few months after successfully completing the course revealed that little of this knowledge was retained. A likely cause of this poor retention is that the mathematical procedures were learned simply as procedures, with little connection to the underlying chemical concepts. This led to our goal of creating instruction to connect the mathematics to authentic chemistry concepts, the focus of the third project described below.

The methodology used to create this instruction combined student think-aloud interviews with a detailed analysis of the nature of the knowledge of chemical equilibrium itself. An important part of the analysis was teaching the material to expert learners. By expert learner, we mean a learning scientist who is not familiar with the domain and so can learn the material while simultaneously reflecting on their own learning.

The process of teaching about chemical equilibrium to expert learners revealed a substantial amount of implicit knowledge, that is, essential information that is held so tacitly by domain experts that it remains unverbalized in instruction. The first such piece of implicit knowledge, the "extent of reaction," is relatively simple to teach and learn. This concept derives from a chemical reaction being a rule, $2\ H_2 + O_2 \rightarrow 2\ H_2O$, which operates on a collection of molecules. If we start with a collection of H_2 and O_2 molecules, the reaction converts $H_2$and O_2 molecules into H_2O, and the amounts of reactants that have been converted to products correspond to a single coordinate that measures the extent of reaction. This coordinate is central to many complex problem-solving tasks but is invisible in traditional instruction. A second piece of implicit knowledge, the "majority minority strategy," became apparent only after an extensive analysis of the large set of problem-solving activities posed in this portion of the course. In traditional instruction, students are encouraged to do extensive practice with these problems until they get "it." Our analysis helped reveal what "it" is. This wide set of problems is actually amenable to a single top-level strategy. Use of a single strategy has the advantage of substantially reducing the problem difficulty. In addition, this strategy replaces the highly mathematical approach to solving these problems with a strategy that is intimately connected to qualitative chemical reasoning. This new strategy first examines the chemical situation to identify which chemical species will be present in large amounts, the majority species, and then, once these amounts are known, shifts attention to the minority species. This strategy is much easier to learn than the traditional mathematical approach, as shown by substantial improvements in performance on challenging problems (Davenport, Yaron, Klahr, & Koedinger, 2008). In addition, the time spent on these problem types helps instill qualitative reasoning regarding what chemical species and chemical reactions are most important in any given situation.

Our analysis of subsequent courses such as organic chemistry and biochemistry shows that the qualitative understanding promoted by this new style of instruction is more essential for future learning than the traditional mathematical problem-solving.

This project benefited from a close integration of the learning research and instructional development efforts. The tension between authenticity and rigor in the instructional design was, in this case, resolved not by achieving balance but rather through integration. Instructors consider this portion of the course rigorous primarily because of the complex mathematics involved in its problem-solving. In the new instructional approaches developed here, student performance on these rigorous problems improves and does so by making the problem-solving more connected to the authentic chemical concepts.

Concluding Comments

The projects described above address three key questions facing chemical education: what, when, and how should we teach? Although the methodologies used for each question differed, the approaches were developed with an explicit goal of balancing authenticity with rigor.

In determining *what* to teach, the methodology extended the typical approach of considering only expert opinion to include the use of textual analysis to validate and extend expert input. In determining *when* to teach, the methodology went beyond studying only the extent to which the instructional intervention can instill the target knowledge, and considered also the overall instructional context of large lecture and online course environments. In determining *how* to teach, the methodology not only probed students to determine what is difficult to learn but also reexamined the structure of the knowledge itself to reveal essential components of the knowledge that are left implicit in traditional instruction. This implicit knowledge arises either from the failure of experts to verbalize the knowledge during instruction or from a failure of experts to realize that they are applying an overarching strategy to their problem-solving.

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Chapter 5
Negotiating the Goal of Museum Inquiry: How Families Engineer and Experiment

Kyung Youn Kim and Kevin Crowley

Children have many opportunities to learn about science before they start studying science in school. From an early age, children engage in deep conversation with parents and build their own theories for understanding how the world works (e.g., Callanan & Jipson, 2001; Callanan & Oakes, 1992). As children grow, they frequently have opportunities to visit zoos, botanical gardens, parks, science centers, and museums with their parents. According to Resnick (1987), learning in these informal settings depends on more than the individual cognition, pure thought, and symbol manipulation. Informal settings highlight more socio-cultural processes such as shared cognition, tool manipulation, contextualized reasoning, and situation-specific competencies (Schauble, Beane, Coates, Martin, & Sterling, 1996). Families in informal settings engage continuously in a negotiation about who is directing the activity, what the activity is about, and what content there is to be learned (Falk & Dierking, 2001; Swartz & Crowley, 2004). In this chapter we present a study about the impact that different learning goals have upon the ways families interact and what children may learn from an informal learning environment.

Children have sometimes been described as natural *scientists* in that they construct theories about the world in ways that evoke the history of science (Carey, 1986; Gruber, 1973). However, the ways children construct theories are clearly not the same as scientists (e.g., Kuhn, 1989). In particular, Kuhn has described children as having trouble coordinating theory and evidence (e.g., Kuhn, Amsel, & O'Loughlin, 1988; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995). Children are sometimes described as "data-bounded investigators" who fail to organize evidence into a theory, focusing instead on explaining local patterns of isolated results. They are sometimes described as "theory-bounded investigators" who are likely to adjust evidence to fit their theories and generate positive outcomes rather than seeking negative evidence to disprove a theory (DeLoache, Miller, & Peierroutsakes, 1998). In light of their difficulties in coordinating theory and evidence, how do children come to develop scientific thinking skills? The extant developmental literature does

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a good job providing snapshots of what children can do by themselves, but it has less to say about how they develop and how they actually reason in real-world and social settings.

In this chapter, we explore one setting where children and parents can practice early scientific thinking skills – an interactive science exhibit at a children's museum. Several studies have suggested that enriched informal learning experiences can improve children's inquiry skills (e.g., Gerber, Cavallo, & Marek, 2001; Tamir, 1990). For example, Zuzovsky & Tamir (1989) showed that while knowledge of science facts and concepts was more likely to be predicted by variables such as school environment and teacher interaction, inquiry skills were more likely to be predicted by out-of-school variables such as enriched informal learning experiences, parent's educational level, and availability of books at home. Gerber et al. (2001) also showed that students who had inquiry-based classroom experiences and enriched informal learning experiences were more likely to show higher scientific reasoning abilities. Activity in such informal learning contexts may be a source for children's later motivation and success in formal science education (Crowley & Galco, 2001).

One feature of museum activity is that it is often a social learning context, particularly for young children (Matusov & Rogoff, 1995). Several studies have described how parents shaped and supported children's scientific thinking through talk and joint activity in museums (e.g., Crowley & Callanan, 1998; Crowley et al., 2001; Eberbach & Crowley, 2005). These studies suggested that one role parents often play is to help children generate more informative evidence and to encode evidence in ways that are consistent with the adult interpretation of an exhibit. Gleason and Schauble (2000) showed that greater levels of parent participation during an experimental design task was associated with support for developing better experiments that would then allow children to make more powerful inferences.

This chapter describes an experiment that explored two strategies for supporting parent participation during shared scientific thinking in a museum. We focus on suggesting different goals for the parent–child activity: one goal is for the family to think as scientists and one goal is for the family to think as engineers. This manipulation came out of the scientific reasoning literature, which suggests that children sometimes adopt one goal and sometimes the other (oftentimes vacillating between them in a single task). Prior studies demonstrated that children's choice of goals for a scientific reasoning task not only influences their inquiry process but also affects what they learn (e.g., Schauble, 1990; Schauble, Klopfer, & Raghavan, 1991; Tschirgi, 1980). When children adopt an engineering goal, they seek to produce a desired outcome rather than to test their theories (e.g., Kuhn & Phelps, 1982; Schauble, 1990; Schauble, Glaser, Duschl, Schulze, & John, 1995; Tschirgi, 1980). Children often seek to compare highly contrastive combinations of variables and focus on variables believed to be causal. In contrast, when children adopt scientific goals, they are more likely to explore evidence widely and to make comparisons that support valid inferences that lead to better theory building (Schauble et al., 1991).

In this study we explored the role of science vs. engineering goals in the context of parent–child interactions. Families in the study used a design task that was built around a museum exhibit. One group of families used the exhibit with science goals and a second group used the exhibit with engineering goals. By analyzing videotapes of the parent–child interactions and child performance on a knowledge pretest and posttest, we explore the effects of different reasoning goals on what children learn from the design task, the ways families engage in the task, and the ways parents support children's scientific thinking in real-world settings.

Method

Participants

Participants were 30 families with children between 5 and 8 years old who stopped at the flying machine exhibit while visiting the Children's Museum of Pittsburgh. Families were randomly assigned to either the science condition (seven boys and eight girls) or the engineering condition (eight boys and seven girls).

Materials

The Rotocopter Task

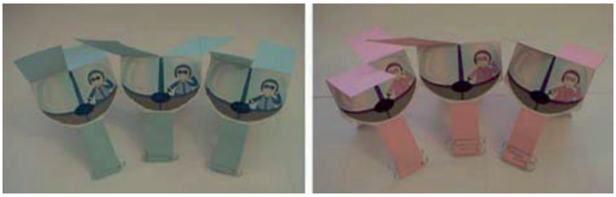
The experimental task we developed involved families dropping rotocopters from a two-story tower inside the Children's Museum of Pittsburgh. Visitors were presented with 12 rotocopters made of paper. Visitors could choose one or more rotocopters, crank them to the top of the tower, and then observe the outcomes as the rotocopters floated down to the floor.

As shown in Fig. 5.1, the 12 rotocopters we designed for this experiment varied by a factorial combination of three variables: wing shape; weight; and color. First, wing shapes differed in length and surface area. Although the rectangle wing had the same wing length as the diamond wing, its surface area was two times larger. The diamond wing had the same surface area as the square wing, but its wing was longer. The second causal variable was weight. Rotocopters with one paper clip were categorized as "light" and those with two paper clips as "heavy." Finally, we included color as a noncausal variable.

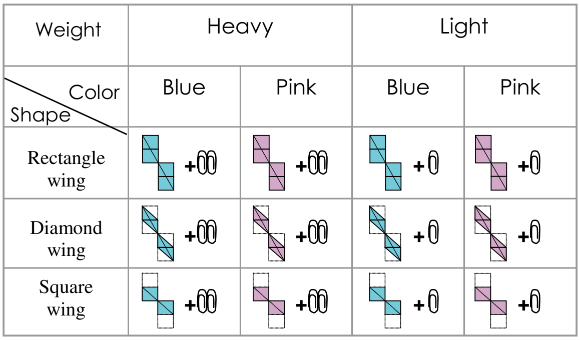
As shown in Fig. 5.1, the rotocopter flight times varied according to wing shape and weight. The rectangle wing flew longest because it had longer wings and the largest surface area. In contrast, the square wing flew shortest because it had shorter wings and the smallest surface area. The light rotocopter with one paper clip flew longer than the heavy one with two paper clips. Therefore, the light paper rotocopter with the rectangle wing showed the longest flying time and the heavy one with a square wing showed the shortest flying time.

In order to manipulate two inquiry goals for this task, we developed two signs for the exhibit that focused either on science or on engineering goals (see Fig. 5.2). Each

a. Rotocopter examples



b. Three variables combined in the rotocopter task



c. Mean (and Standard Deviation) for rotocopter drop times over 10 trials

	Rectangle	Diamond	Square
Light	4.5 (.03)	3.1 (.04)	2.7 (.04)
Heavy	4.1 (.04)	2.9 (.04)	2.5 (.03)

Fig. 5.1 a. Rotocopters provided to the participants. b. Three variables are combined in the rotocopter task: wing shape (rectangle/diamond/square); weight (heavy/light); and color (blue/pink). Wing shape and weight are causally related to flight time. Color is not. Wing shape involves both wing length and the surface area, but the weight of the paper is constant. Without changing the overall weight of each rotocopter, different wing shapes are made by folding the rectangle wings in different ways. Weight is manipulated by attaching one or two paper clips to each rotocopter. c. In order to examine the effect of two causal variables (wing shape and weight) on drop time, we timed 10 drops for the six unique rotocopters (3 wing shape $\times$ 2 weight) from a height of two stories. Step-wise multiple regression suggested that wing shape accounted for 87% of the variance in flying times, $F\ (1, 58) = 408.98$, $p< 0.001$. Weight accounted for an additional 3% of the variance, $F\ (2, 57) = 278.78$, $p< 0.001$, resulting in a final regression equation of flight time = 1.31 + 0.81 (wing shape) + 0.25 (weight)

sign was approximately 3 $\times$ 4 ft and was placed prominently next to the exhibit. The science sign focused families on the idea that their goal was to figure out the effects of different variables while the engineering sign concentrated on the goal of maximizing the effect of the variables.

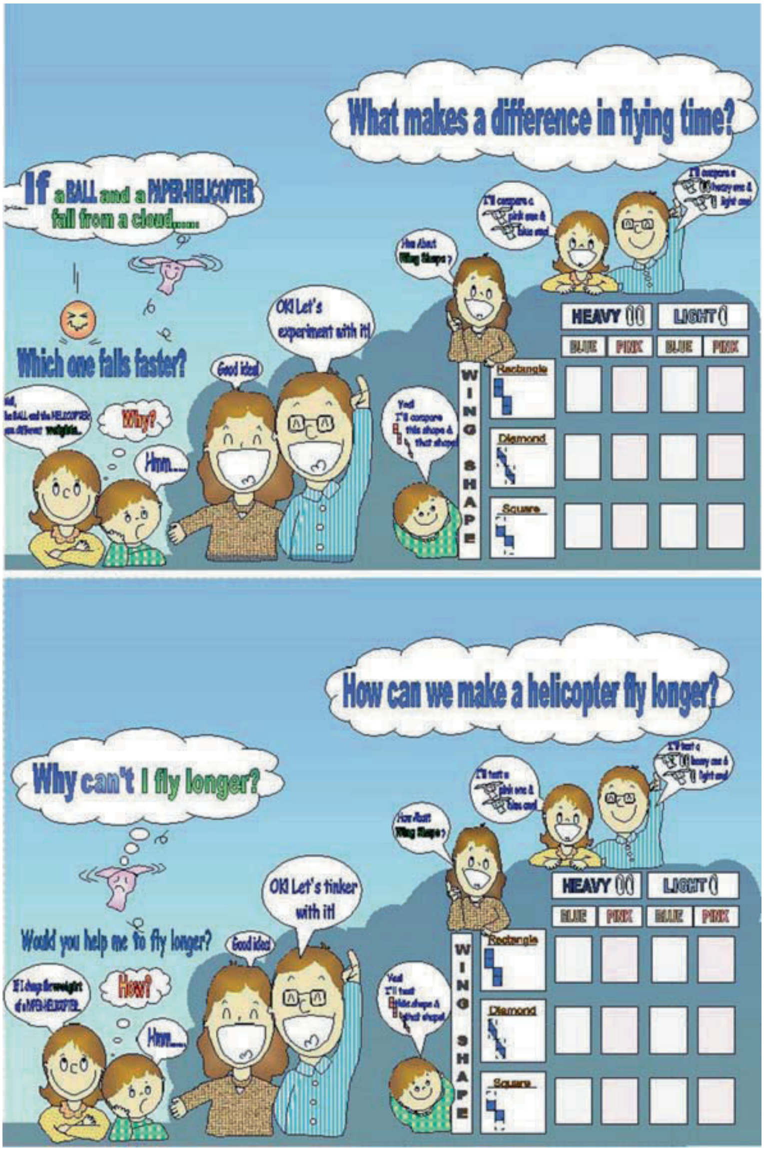


Fig. 5.2 Signs that encouraged families to adopt science or engineering goals. The science sign (top) focused families on exploring the effect of each variable to figure out how the system works. The engineering sign (bottom) encouraged families to approach the task in terms of looking for the rotocopter that could "win" by flying the longest time

Procedure

After setting up video cameras and wireless microphones at a location near the exhibit, a researcher approached families and asked whether they were interested in participating. If families indicated interest, the researcher obtained informed written consent.

First, children were given a pretest designed to assess their understanding of the causal role of wing shape and weight, and the noncausal role of color. Parents sat off to one side as children were shown three sets of rotocopters and asked to order the rotocopters in terms of relative drop speeds. One set of three rotocopters varied by wing shape (rectangle, diamond, square) while holding weight and color constant. One set of two rotocopters varied by weight (heavy, light) while holding wing shape and color constant. One set of two rotocopters varied by color (pink, blue) while holding wing shape and weight constant. Order of presentation was randomized.

After the pretest, families were asked to read the sign together. The intent of the sign was then verbally reinforced by the experimenter who talked families through the information on the sign. Families were then asked to use the exhibit for as long as they wanted and were asked to tell the experimenter when they were done. Family interactions were videotaped.

At the conclusion of the activity, children completed a posttest while their parents sat off again to one side. The posttest differed from the pretest in that, in addition to getting the same judgments as in the pretest, on the posttest we also collected children's justifications for their reasoning at two points. Children were asked first to talk about why the rotocopters have different drop times. Children were then asked, just as in the pretest, to order the rotocopters by drop time. We then asked children to explain the way they ordered the rotocopters.

All videos were transcribed for both action and talk, and coding was conducted with both video and transcripts. We introduce our coding schemes and measurement construction at appropriate times in the results section below. Coding was conducted by single coder. Reliability was assessed by an independent coder who scored 25% of the data. Reliability exceeded 84% for all coding reported in this chapter.

Results

Children in the Science Condition Learned More About the Causal Variables. The primary measure of children's learning was pretest to posttest changes on the three sets of rotocopters that children ordered in terms of flight time. For each set of rotocopters, we assigned scores that ranged from 0 to 2. For the set of three where wing shape varied, children were assigned a 0 if they said that all three would fall at the same time; a 1 if they said that they would fall at different times but did not order correctly within the set; a 1.5 if they ordered two but not three correctly; and a 2 if they ordered all three correctly. For the set of two where weight varied, children were assigned a 0 if they said both would fall at the same time; a 1 if they said they would fall differently but did not order correctly; and a 2 if they indicated the correct order. For the set of two where color varied, children were assigned a 0 if they indicated that the rotocopters would fall at different speeds and a 2 if they indicated that they would fall at the same speed. Adding these scores together, children could have a pretest or posttest score of 0–6. Gain scores were computed by subtracting pretest from posttest scores; thus, gain scores could range from −6 to 6.

Overall, children in the science condition had significantly higher gain scores (M=1.2) than children in the engineering condition (M= −0.5), t (28)= 2.71, $p < 0.05$. When we divided the overall scores into gain scores for each of three variables separately, children in the science condition showed higher gains for shape (Ms=0.3 and −0.1, respectively), weight (Ms=0.5 and −0.5), and color (Ms=0.4 & 0), although only the difference for weight was significant, t (28)= 2.49, $p < 0.05$.

In addition to ordering the rotocopters by drop time, children had also been asked on the posttest to justify their choices. We assigned children a point each time they mentioned relevant variables. That is, children had to mention specific rotocopter features such as wing length or size (e.g., longer vs. shorter or bigger vs. smaller) to get a point for wing shape. For weight, they had to refer to difference in weight (e.g., heavier vs. lighter or more weight vs. less weight) beyond pointing out the number of paper clips. For color, children had to indicate that both rotocopters performed the same regardless of color. Findings were analyzed using one-way ANCOVAs with children's posttest justifications as the dependent measure and their pretest choice score as a covariate.

The justifications provide converging evidence that children in the science condition learned more than children in the engineering condition. In response to the open-ended question that was at the beginning of the posttest, children in the science condition (M=0.9) were more likely to name causal variables than children in the engineering condition (M=0.5), F (1, 27)=5.96, $p< 0.05$. A similar pattern emerged when we examined the justification data for children's wing-shape choices, with children in the science condition (M=0.6) being more likely to be able to offer good explanations for their choices than those in the engineering condition (M=0.2), F (1, 27)=5.42, $p< 0.05$. There were no differences, however, in children's justification for weight (Ms=0.3 and 0.3, respectively) or color (M= 0.8 and 0.5).

Families in the Science Condition Were More Systematic and Engaged. Families in the science condition (M=7 min 38 s) spent significantly more time testing rotocopters than those in the engineering condition (M=4 min 59 s), t (28)= 2.21, $p < 0.05$. Although spending almost 34% more time on task, families in the science condition did not conduct significantly more trials (M=5.9) than those in the engineering condition (M=4.8), suggesting that families in the science condition spent more time conducting each of their trials.

How many of these trials were controlled comparisons that could support valid inferences about the causal status of a variable? Families in the science condition (M=1.9) were more likely to conduct controlled comparisons than those in the engineering condition (M=0.8). The difference was not significant, mostly due to one family in the engineering condition who conducted seven controlled comparisons in their eight trials, which amounted to more than three standard deviations above the mean for the engineering condition. When we excluded this family's data, the mean for the engineering condition dropped to 0.4 and the group difference was significant, t (27)=2.79, $p< 0.05$. Another way to examine these data is to ask how many families used a controlled comparison strategy at least once: more families in the science condition (10) did so than families in the engineering condition (4), χ^2 (1) = 4.82, $p < 0.05$.

Differences in Family Activity Appeared Mostly in the Design and Interpretation of Tests. One of the reasons we chose the flying machines exhibit for this study was that the physical space around the exhibit mapped on to the conceptual space of an inquiry cycle. As shown in Fig. 5.3, families would design tests by going to one place to choose rotocopters, run their test by putting rotocopters on the platform and cranking them over the tower, and interpret their tests by running out in front of the tower to observe the relative drop times. In the final section of the results, we describe how families engaged in each of these three stages.

First, we examined how much parents and children talked to each other while cycling through each of the three inquiry stages. In general, children did not do much talking in any of the spaces. We observed only about one utterance per trial for children irrespective of whether they were working in the design space (M=1.1 and 0.8 for science and engineering conditions, respectively), test space (M=0.9 and 1.3), or interpretation space (M=1.1 and 0.8).

Most of the talk we observed was by parents. And parents in the science condition were often more likely to talk than those in the engineering condition. In the design space, parents in the science condition (M=3.3) spoke significantly more often than those in the engineering condition (M=1.8), t (28)=2.07, $p < 0.05$. The same was true in the interpretation space, where science parents were observed making a mean of 2.7 utterances per trial vs. 1.5 for the engineering parents. In the test space, where most of the parent talk was around encouraging children to keep cranking the handle until the rotocopters launched from the top, science parents also were observed to talk more often than engineering parents (M=3.7 vs. 2.5), but the difference did not prove significant.

Finally, we conducted qualitative coding of the family interaction patterns and talk in each of the design, testing, and interpretation spaces. In coding interactions, we considered two dimensions of parent–child activity: (1) the extent to which parents provided explanatory support and (2) the extent to which parents and children collaborated. We rated each interaction as high or low on the two dimensions, producing four separate categories of inquiry:

1. *Shared and Supported*: Parents were observed to provide talk that directly supported inferencing and were observed to respond to children's comments or choices. Children were observed to actively respond to parent input and to collaborate with parents in using the exhibit. The definition of this category was specific to each of the three spaces. In the design space, parents had to make comparisons of levels of a variable (e.g., "Do you want to see if the different wings make a difference?" "Why don't we try a pink one and blue one, each with two paperclips?" "Do you want to see a diamond make any difference?" or "Look this has square wings! This one has different kinds of wings"). In the test space, parents had to talk about predictions (e.g., "Do you think it makes a difference?" or "Which one do you think will stay up longer?"). In the interpretation

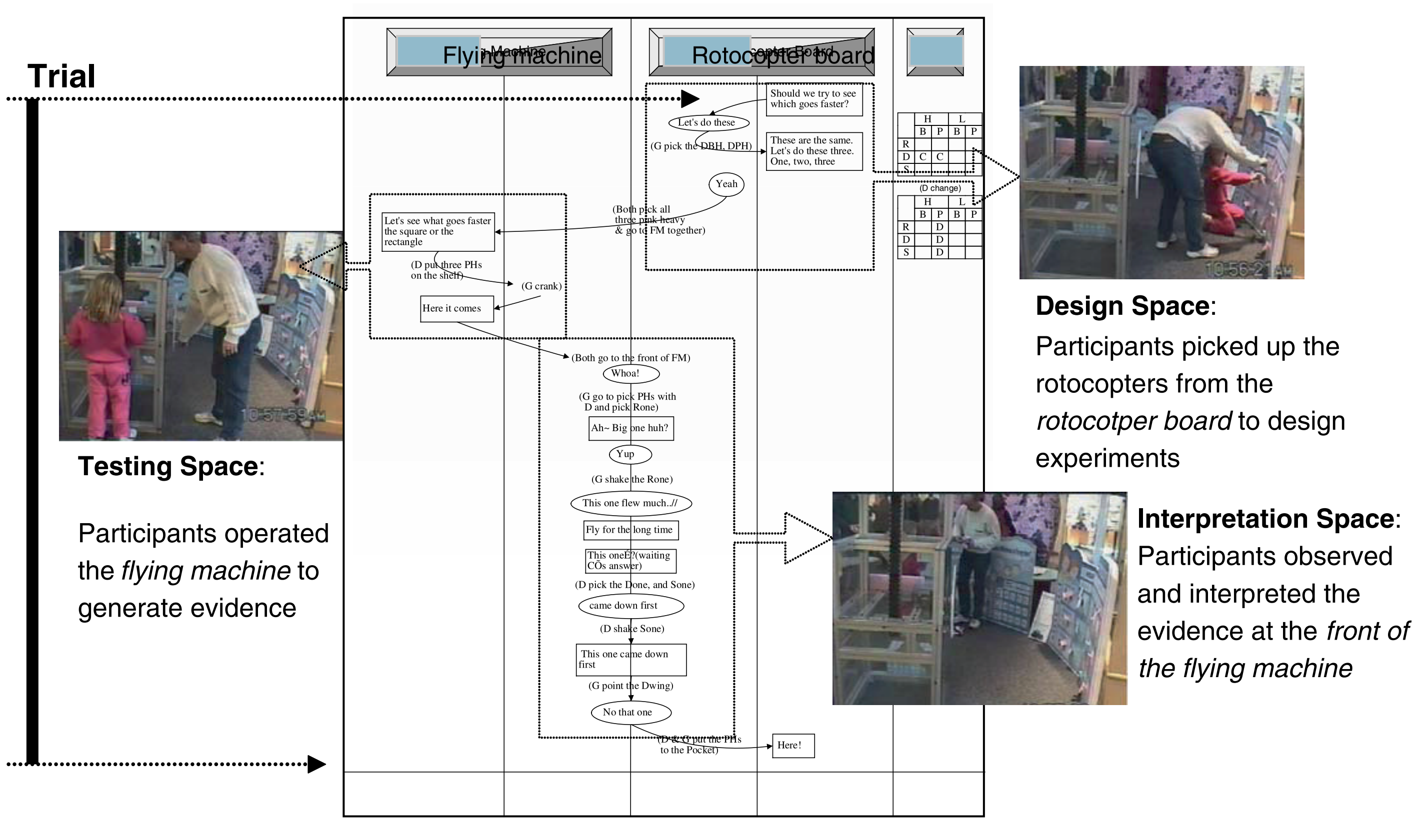


Fig. 5.3 Parent–child talk and action were transcribed with respect to three activity spaces: the design space (where rotocopters were chosen), the test space (where they were cranked up), and the interpretation space (where they landed). On the first column from the right, we recorded which rotocopter(s) was/were chosen at each trial. On the second and third columns from the right, we transcribed parent–child talk and action at the design space. On the first and second columns from the left, parent–child talk and action at the test space were transcribed. On the center line, parent–child talk and action at the interpretation space were recorded. The rectangular boxes represent parent's talk and ellipses represent child's talk

space, parents had to talk about the outcome by comparing different rotocopters (e.g., "This one stayed in the air the longest," "I think that one went even faster," or "This one came down first.")

2. *One-way supported:* This was coded if parents generally engaged in inquiry-specific talk as defined above, but children were not collaboratively engaged. Either the parent was directing the interaction without input from the child or the child was engaged without reference to the parent's talk.
3. *Shared but unsupported inquiry*: Parent and child were observed to be collaborative, but parents were not engaged in providing inquiry-specific support through talk. To be coded in this category, parent support could not go beyond general suggestions (e.g., Why don't you try different one?), verbal directions (e.g., "Pick one out," "Pick a different one," "Put one over here," or "Stand back and watch them"), or simple encouragement (e.g., "You did it," or "Keep going! Keep going!").
4. *Neither shared nor supported inquiry*: Parents were not observed to support children's inquiry directly and parents and children were not engaged collaboratively in the activity. These were the interactions where children worked more or less alone while parents stood back and watched.

The findings, shown separately for each of the three spaces, are in Table 5.1. First consider the findings while families were designing comparisons. In the science condition, 39% of family activity was coded as *shared and supported inquiry*,

Table 5.1 Mean number of trails coded as each kind of engagement broken down by condition

Activity space	Type of parent–child engagement	Science families	Engineering families	t	p
Design	Shared and supported	2.27 (39%)	0.67 (14%)	2.66	<0.05
	One-way and supported	1.40 (24%)	0.87 (18%)	1.00	NS
	Shared and unsupported	0.60 (10%)	0.47 (10%)	0.57	NS
	Neither shared nor supported	1.60 (27%)	2.80 (58%)	−1.57	NS
Test	Shared scientific engagement	1.53 (26%)	0.60 (13%)	1.32	NS
	Scientific engagement directed either by parent or by child	0	0.07 (1%)	−1.00	NS
	Nonscientific but shared engagement	3.40 (58%)	2.60 (54%)	1.17	NS
	Neither scientific nor shared engagement	0.93 (16%)	1.53 (32%)	−1.20	NS
Interpretation	Shared scientific engagement	2.73 (47%)	1.00 (21%)	2.83	<0.01
	Scientific engagement directed either by parent or by child	1.00 (17%)	0.73 (15%)	0.78	NS
	Nonscientific but shared engagement	0.87 (15%)	0.60 (13%)	−1.56	NS
	Neither scientific nor shared engagement	1.27 (22%)	2.47 (51%)	0.93	NS

The percentage the mean represents in the total number of trials in each condition is included in parentheses compared with only 14% in the engineering condition, t (28)= 2.66, $p < 0.05$. In the engineering condition, 58% of parent–child engagement was coded as *neither shared nor supported*. That is, parents in the science condition were more likely to collaborate with children by describing the rotocopters children picked or by suggesting ideas for designing informative experiments. Children in the science condition were also actively engaging in the negotiating process for choosing rotocopters through responding to parent's questions or suggestions. Parents in the engineering condition were less likely to collaborate with children in designing experiments and often left children to pick out rotocopters alone.

In the test space, no difference was found in any of the parent–child engagement codes. Out of the four parent–child engagement patterns, the *shared but unsupported inquiry* was the most frequently coded in both the science condition (58%) and the engineering condition (54%). In both conditions, parents provided similar amount of domain-related support to children in a collaborative way.

In the interpretation space, 47% of parent–children engagement in the science condition was coded as *shared and supported inquiry*, compared with only 21% in the engineering condition, t (28)= 2.83, $p < 0.01$. The most common code in the engineering condition was *neither shared nor supported inquiry*. Parents in the science condition were most likely to collaborate with their child as they evaluated evidence by comparing the flying times of more than two rotocotpers, whereas parents in the engineering condition were more likely to leave children to interpret the outcome by themselves.

Discussion

This study examined how different inquiry goals affected joint exploration, parent participation, and subsequent child learning. At the simplest level, we found that signage and simple instructions were sufficient to change the nature of family inquiry at an interactive science exhibit. When families were encouraged to adopt science goals for inquiry, they talked more to each other, they were more collaborative, and they were more likely to design informative tests. Families who were encouraged to adopt engineering goals were more likely to have parents who pulled back and allowed children to do more of the design and interpretation without adult scaffolding. As one might expect from these differences in family inquiry, we also discovered differences in what children had learned by the end of the session. Children whose families had adopted science goals learned more about the task than children whose families adopted engineering goals.

Our findings suggest that differences in parent talk were most prominent at the design and interpretation phases of inquiry, which are identified as the critical processes for scientific thinking in the scientific reasoning literature (Klahr, 2000; Klahr & Dunbar, 1988). While choosing rotocopters in the design space, parents in the science condition scaffolded children's choice of rotocopters more carefully by describing the specific features of rotocopters, soliciting children's ideas, or suggesting their own ideas about what they wanted to try for figuring out the effects of the embodied variables. In the interpretation space, parents in the science condition were more likely to support children's understanding of the effect of variables by comparing different drop times of different rotocopters, asking children about what they see and what they found out, or discussing which features of the fallen rotocopters were related to their findings.

The following examples illustrate different patterns of family engagement in the science and engineering condition. Our intention in presenting these short examples is to provide the reader with some sense of what the quantitative findings look and sound like when families are engaged in reasoning. We begin with the engineering condition. We often observed children in the engineering condition moving about choosing rotocopters to design a test and then going to pick up the fallen rotocopters while their parents stayed more stationary and provided encouragement but relatively little scaffolding for the experimental activity. Consider the following trial from a family with a 6-year-old girl in the engineering condition:

Design space
Father: Do you want to fly? Go ahead and fly.
[Child goes to the rotocopter board alone and picks up the pink-light-square rotocopter and blue-light-rectangle rotocopter]
Test space
Father: Oh. . .oh..oh. . .you can do one at a time.
[Child puts two rotocotpers one by one on different platforms and goes to the front of the flying machine to watch]
Father: Come here, [name]. Go ahead! Turn!
[Child comes back to the flying machine and cranks]
Get ready!
Interpretation space
Father: All right!
[Father and child watch how pink-light-square rotocopter flies at the flying machine]

In contrast to families in the engineering condition, those in the science condition were more likely to collaboratively explore all the variables, with parents showing more involvement, especially in design and interpretation. The following is a 6-year-old girl with father:

Design space
Father: Which one do you want to start with?
Child: This one [picks up the blue-light-rectangle wing].
Father: All right! Do you want to do a couple different ones?

The square one [picks up the blue-light-square rotocopter], the diamond one [points to the blue-light-diamond and child picks it up], and this one [points the rotocopter that child already has]. We can put them all on there and see which one lands first.

Child: OK

[Both move to FM together]

Test space

Father: Crank this, this way.

[Child starts to crank]

Father: Do you need help?

And watch comes down then.

Child: Keep going! You're almost there! Almost there!

Interpretation space

Father: Oh, Look! Which one was first?

[Both move to the front of the flying machine]

Child: Uhh... this one [picks up the blue-light-square rotocopter].

Father: Well it was close, which one land the last?

Child: This one [picks up the blue-light-rectangle rotocoper and gives it to father].

The contrast between these examples is clear. The first father appeared to have interpreted the engineering goal as a suggestion that he withdraw from the interaction and allow his daughter to find the best combination of variables. In the second example, the father appeared to interpret the science goal as an opportunity to become more involved, and to scaffold design and interpretation. Why did parents make these choices? Our data do not directly address this question but we can make some guesses. It is possible, for example, that parents saw the goal of finding the longest flying rotocopter as a fairly straightforward search problem that would not require their participation. Children, even if they searched blindly, would eventually stumble onto the correct solution. However, in the science condition, parents may have interpreted the science goals as more challenging for their children. Making inferences about the causal roles of variables may be a task that invites talk and collaboration.

Our finding that signage can influence family activity and child learning has implications for the design of museums and other informal learning environments. Others have observed that museum exhibitions and programs often are not well-designed to facilitate family's shared meaning-making and collaborative learning (e.g., Falk & Dierking, 2001; Schauble et al., 2002). Further research has focused on ways that families can mediate their museum experiences through talk (e.g., Borun, Chambers, & Cleghorn, 1996; Borun, Cleghorn, & Garfield, 1995; Leinhardt, Crowley, & Knutson, 2002) and the important role of parents as the family members who often share symbolic information gained from reading labels or from prior experience, while children do most of the touching and manipulating hands-on exhibits (e.g., Crowley et al., 2001; Diamond, 1986; Rahm, 2002). However, it is not always easy for parents to figure out what roles they might adopt in informal learning settings and the impact those roles might have on their children's experience (Gleason & Schauble, 2000; Schauble et al., 2002; Swartz & Crowley, 2004). The present findings suggest that signage is a support that can help parents adopt goals and define roles for themselves in museums. The findings further suggest that signage that supports science goals as opposed to engineering goals may result in greater collaboration and more structured inquiry as families engage in informal science activity in everyday settings such as museums.

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Part II
Instructional Explanations in the Teaching and Learning of Mathematics

Chapter 6
A Framing of Instructional Explanations: Let Us Explain *With* You

Carla van de Sande and James G. Greeno

I don't like it so much when people explain things to me. I like it better when they explain things with me.
— Christiaan, age 6

Our goal in this chapter is to merge our understanding of explanations with perspectival theory. In doing so, we are drawing on Leinhardt's model of an instructional explanation (Leinhardt, 1987, 1989, 1993, 2001, 2005) that has been applied to instruction in several domains (such as history and mathematics) and contexts (classroom, online materials, and textbooks) and has been used to account for differences between expert and novice instructors. In our account (or framing) of an explanation for the solution of a mathematical exercise, we consider the role of perspective, that is the way an individual or group understands the kind of activity they are engaged in, together with the way that information is communicated, interpreted, and organized.

The notion that perspective is bound up in the communication of explanations is captured nicely by the quote at the start of this chapter. Rather than being positioned as a "neutral" recipient of information (having something explained *to* him), Christiaan voices a preference for being positioned as a classroom participant who has a point of view (having something explained *with* him). Our hypothesis is that for an explanation to be communicated successfully, the person giving the explanation and the person receiving it need to have framings that are aligned, at least to the extent that the one who needs to integrate the information in a new understanding has the resources needed to do that. One result of being positioned as a partner in constructing understanding (being explained *with*) is that the recipient of an explanation can provide information that contributes to mutual cognizance of the recipient's framing, allowing the explainer to draw on the recipient's resources and building on them to construct a shared understanding that is coherent and useful in their current activity.

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In order to demonstrate how this merging between perspectival theory and instructional explanations plays out, we have chosen a context in which the explanations are very focused, namely open, online, calculus help forums. These forums are located on public websites and provide a location where students from around the world can post queries arising from their coursework and receive help from volunteers who have the time, experience, and willingness to respond. The exchanges that take place in this context revolve around a well-defined set of mathematical information addressing questions and problems from coursework. Through a perspectival analysis of such an exchange, we provide an account of interaction that demonstrates how an explanation can support the construction of a new resource for framing.

Model of an Instructional Explanation

Although educational approaches and philosophies vary widely, instructional explanations are "a commonplace of teaching" (Leinhardt, 2001). They are found in different learning venues (the classroom, textbooks, and in online instruction), are developed between varied participants (by teachers as well as by students working together), and occur across a wide range of subject domains (from history and politics to mathematics and physics). Crafting a complete and well-formed explanation is a mark of an expert instructor (Leinhardt, 2005) and requires attention to information that will be in use (prerequisite), the demonstration and presentation of the information (co-requisite), and the boundaries of the new knowledge (constraints).

A theoretical model of an explanation can be formalized as a planning net (Leinhardt & Greeno, 1986) that details action schemas, decision points, and goal structures relevant to instruction (Leinhardt, 1987). In the formalism, goals are achieved as a direct and indirect consequence of actions and sub-goals, and an associated grammar designates possible configurations and relationships between elements; for example, higher order goal states may be partially achieved by actions embedded in other goal systems. Figure 6.1 contains a planning net from Leinhardt (1987) with auxiliary illustrations that describe a second-grade classroom explanation for subtraction with regrouping that was conducted over a series of lessons. Goal states are shown in hexagons, supporting actions in rectangles, and decision points in diamonds. The teacher who led this explanation, Ms. Patrick, wanted the students to understand both the procedure (canceling and borrowing) and, to some degree, the mathematical justification behind subtraction with regrouping (preservation of numerical value).

As the series of lessons on regrouping unfolded, a system of actions emerged that supported goals in the service of the explanation. For example, prior to beginning the discussion of subtraction with regrouping, Ms. Patrick sought to ensure that students were familiar with the subskills that would be needed (a goal) and, to achieve

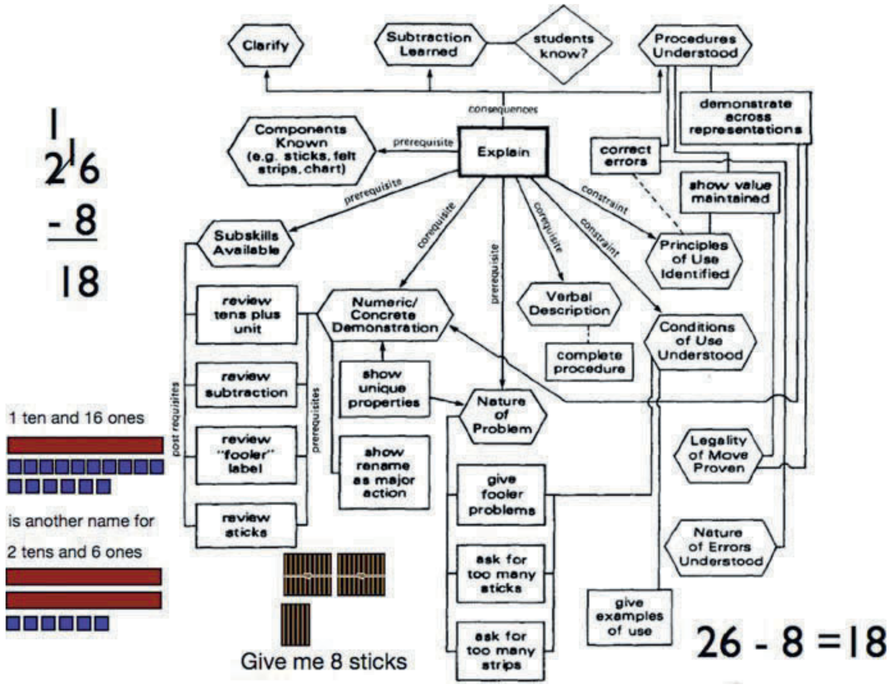

Fig. 6.1 Instructional explanation model for subtraction with regrouping adapted from Leinhardt (1987)

this, she reviewed the tens plus unit, simple subtraction, some informal vocabulary in use, and working with sticks (supporting actions). Ms. Patrick also had as a goal that her students understand the problem that subtraction with regrouping would address (that is, why the normal subtraction procedure would not work), and, to do this, she embedded problems that required regrouping in each of the representations in use. For instance, she requested eight sticks from a student who was given two bundles of sticks and six loose sticks. Other goals of the explanation on subtraction with regrouping included presenting a demonstration, verbally describing the procedure, identifying the conditions in which the procedure can be used, and the mathematical principles that permit its use (here that value is maintained through regrouping).

As the example on subtraction with regrouping illustrates, instructional explanations are intended to communicate a portion of subject matter to participants, that is, to facilitate the understanding of ideas that were not previously accessible to some members of the discussion. Through participation in the explanation, students are "helped to learn, understand, and use information, concepts, and procedures in flexible and creative ways" (Leinhardt, 2001, p. 304). This process of bridging previously inaccessible ideas with a transformative understanding of the information is arguably shaped by participants' points of view.

Perspectival Theory

Perspectival theory is based on the assumption that the point of view or position from which a situation is perceived and conceived is an essential aspect of cognition, and successful communication depends on participants achieving sufficient alignment of their perspectives (Rommetveit, 1974). Theorists have proposed a concept of *framing* that addresses the ways in which activities and situations can be understood differently by different individuals or groups (Bateson, 1972; Goffman, 1986; Hammer, Elby, Scherr, & Redish, 2005; MacLachlan & Reid, 1994; Tannen, 1993). Framing generally pertains to a set of metacommunications that are used to interpret what is happening by invoking certain expectations. These expectations are conveyed in a variety of ways, many of which are subtle and operate at a subconscious level. For example, a physical frame surrounding a canvas sends a metamessage that the observer is to interpret the patterns on the canvas as "art" rather than as "background." In an analogous way, successful communication is dependent on framing so that participants operate using a set of shared expectations, regarding both patterns of interaction and the organization of information. Thus, this broad construct of framing can be understood to operate at multiple levels (Tannen, 1993), and, in particular, can be attributed to aspects of positioning and conceptual organization.

Recently, we have used a notion of framing to account for interactive episodes of problem solving, in which there was an initial lack of alignment in understanding, followed by alignment that was sufficient for the purposes of the participants' activities (Greeno & van de Sande, 2007; van de Sande & Greeno, 2008). In this work, *positional framing* refers to the expectations that members of a group have for the pattern of interaction amongst themselves and the activity with respect to a subject matter or other resources. This includes the establishment of who in the group is entitled, expected, or perhaps obligated, to initiate topics and questions, to question or challenge others' presentations, to indicate that a topic has been resolved, and so on. *Conceptual framing* refers to the selection and organization of information by an individual or group in its understanding of a task or situation. A framing at this level is a cognitive arrangement of entities and some of their properties and relations, organized in relation to each other. Just as perspective operates in the visual organization and interpretation of information, some entities in a conceptual framing are foregrounded over others when they are the subject of more central focus.

Situations in which an explanation is communicated often include a participant who presents the explanation and another participant, or other participants, who receives the explanation, with the goal of strengthening the recipient(s)' understanding.[1] In our view, communicating an explanation successfully requires that

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[1] In many cases, the explainer is positioned in the interaction as the leader of the conversation, but this is not always the case. In one example we have analyzed, a teacher led the conversation but the explanation was provided by a student whose approach to an algebra problem was different from the one the teacher had worked out (Greeno & van de Sande, 2007). In another example, taken from Roschelle (1992), two students jointly constructed an explanation of the behavior of an

the explainer and the recipient have framings that are aligned sufficiently so that the information provided by the explainer can be incorporated meaningfully by the recipient with the recipient(s)' resources.

Perspectival Theory and Resources for Framing in Explanations

According to perspectival theory, participation in an instructional explanation can be understood as an activity in which some participants are constructing a new resource for framing. The teacher who designs and implements the explanation has a conceptual framing that provides coherence to the lesson materials and has the goal of helping students, who do not, achieve alignment through these interactions. To do this, students have to activate components that will make their framing coherent in a way that the teacher's is, and this is achieved through engaging in the supporting actions of the explanation. In this way, an instructional explanation can be viewed as a bridge between previously constructed resources for framing and a novel resource that permits information to be organized in a fruitful and coherent manner.

Our interpretation of Ms. Patrick's explanation includes a specification of the goal of students' understanding subtraction with borrowing. We hypothesize that some students initially frame numerical subtraction as a task of following rules of operating on symbols. Evidence for this includes well-known systematic errors made by some students, such as entering an answer in each column equal to the difference between the larger and smaller number in that column, the "smaller-from-larger bug" (Brown & Burton, 1978). A hypothesis that can explain this pattern is that students learn to frame a multidigit subtraction problem as a sequence of subproblems, finding an answer for each column, starting from the right. This is an appropriate part of the framing they need to learn, which is successful for problems in which every top digit is greater than the bottom digit in its column, which is the case in problems that students are given at the beginning of their instruction in subtraction. When problems that require borrowing are introduced, students are told that when the bottom digit is larger than the top digit, they must borrow. However, if a student does not learn by incorporating that constraint in her or his procedure, encountering a problem such as 26 – 8 produces an impasse, and a student may resolve that impasse by adjusting the procedure to one that produces the smaller-from-larger bug (Brown & VanLehn, 1980; VanLehn, 1990).

A framing that supports correct understanding of subtraction includes conceptualizing each of (a) the several digits in the top number and (b) the digits in the bottom number as representing number, and the problem is to subtract the bottom number from the top number. If a digit in the bottom number is greater than the corresponding digit in the top number, borrowing is required, and borrowing is an

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interactive computer simulation of motion that neither of them had in advance of the interaction (van de Sande & Greeno, 2008).

operation that changes the values of individual digits but keeps the total value of the top number unchanged.[2]

In this hypothesis, resources for framing include a concept of number represented collectively by the digits that are in a row, which allows the information to be organized and related in a specific way. In a productive framing, the minuend can be conceptualized as an alternative configuration of tens and ones that preserves numerical value. At the start, students who have only experienced subtraction that does not require regrouping do not have this resource. We interpret Ms. Patrick's explanation (and other similar explanations often used in teaching subtraction) as an effort to foster students' learning to include this resource for conceptual framing.

Ms. Patrick's explanation (and others that use similar concrete or computer manipulatives), schematized in Fig. 6.2, is an example of what we have called instructional analogies (Greeno & van de Sande, 2007). We have hypothesized that instructional analogies can work by providing a situation that is easily framed by students in a way that can be applied, by analogical mapping, to situations that are the target of instruction. Like other models used for teaching place-value operations, a situation involving bundles of sticks is easily framed (i.e., affords a framing) so that the equivalence between the numerical magnitude of sticks is left unchanged by the operation of unwrapping one of the bundles, producing 10 more individual sticks. That is, using bundles of sticks (or another model such as money) to demonstrate analogous conceptual patterns takes advantage of a resource for framing, namely students' understanding of unbinding/separating sticks (or the denominations of currency). Encouraging vocabulary such as "separate" and "trade" can locate the new notion of "regrouping" as an analogous action that can be carried out on numbers and motivates the notion of "borrowing," including a framing that also includes the

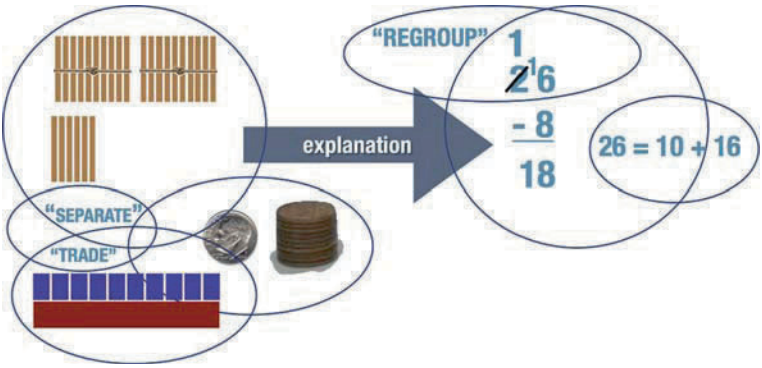

Fig. 6.2 As an instructional explanation unfolds, participants are constructing a new resource for framing

[2]We refer to the minuend and the sutrahend as the "top number" and "bottom number" respectively to match the spirit and vocabulary of a second-grade classroom.

numbers represented by the top and bottom numbers and not changing the magnitude of the top number by the operation of borrowing. Other actions that are detailed in Leinhardt's model of an instructional explanation, such as presenting a wide array of examples and situations when subtraction with regrouping is called for (or not) and showing that value is maintained through this activity, can help students construct a resource for framing subtraction as the difference between numerical values rather than as an operation on pairs of numbers that share place value (which would not work for this set of problems) or as a procedure and set of rules that must be carried out (e.g., if the number below is larger than the one above, borrow *one* from the adjacent column).

With respect to positional framing, the teacher who conducts an instructional explanation may take on the role of leader and explainer in the construction of this new resource, or, alternatively, may position students as co-explainers. In the latter case, the students are accountable for convincing themselves of the coherence of this new perspective and its connection to other, more familiar, situations. We hypothesize that, in a good explanation (i.e., one that meets many of the goals in Leinhardt's model), the teacher is sensitive to the resources for framing that students initially have and uses instructional activities to help build a bridge between alternative framings so that s/he is explaining the new material *with*, rather than *to*, the students. In particular, teaching subtraction with regrouping solely as a procedure that must be carried out in certain situations is inconsistent with making use of resources for framing that students have at their disposal and is not likely to foster generality of learning (Engle, 2006).

As noted earlier, instructional explanations are not restricted to the classroom but occur in a variety of settings. We turn our attention next to open, online help forums, a relatively new learning environment in which students seek explanations for specific questions regarding coursework and receive responses from other forum members who participate in this activity.

Open, Online Help Forums

Open, online help forums are found on websites (*online*) that are accessible to the general public (*open*) and support asynchronous interaction between participants who seek answers and explanations to coursework-related queries and participants who provide assistance (*help*). Many such forums operate free of charge, connecting students and volunteer tutors from around the world.[3] Forums are characterized by the subject areas that are covered, by moderation policies, and by participation structure (that is, who may participate and in what ways). Of particular interest are Spontaneous Online Help (SOH) sites that allow any forum member to respond to a query. Unlike sites that assign incoming queries to select and vetted tutors (Assigned

[3] van de Sande & Leinhardt, (2008) have dubbed these volunteers "Good Samaritans" because they come to the aid of strangers in need and have proposed a variant of the social psychological bystander effect to help account for forum tutor participation patterns.

Online Help), an SOH participation structure permits discussion threads with contributions from multiple members. In some forum communities, an SOH participation structure supports extended conversations that address key mathematical principles in which alternative framings emerge naturally as part of the discussion (van de Sande & Leinhardt, 2007, 2008). In addition, the positional framing in SOH sites differs from our expectations of other learning environments, such as private, one-on-one tutoring sessions. (See Graesser, Person, & Magliano (1995) for a discussion of characteristic tutoring session dialog frames.) Student agency is exhibited in the exchanges as they make assertions and proposals of action, question or challenge others' proposals, and indicate when resolution has been achieved. Volunteers acting as tutors, who generally have more subject matter experience and expertise than students, provide mathematical guidance, and, in exemplary exchanges, draw the student into making a mathematical discovery through the co-construction of an explanation (van de Sande & Leinhardt, 2007; van de Sande, 2008).

The explanations that occur on open, online help forums differ from instructional explanations that are commonly found in classrooms or textbooks. In the latter case, it is generally the teacher or author who sets out to explain some portion of the subject matter to students. In an online forum, it is the student who initiates the exchange, having bumped up against some mathematics that requires explanation, often in the context of solving "routine" exercises from coursework assignments.[4] Students most commonly use the forums to present an exercise in which they have reached an impasse or to request verification for a partial or complete solution that they have achieved. In each of these cases, there is a prompt from the student for a "mini" explanation that addresses the construction of a solution to the problem at hand. In this sense, the explanations that occur in forum interactions are much more focused and bounded than their classroom/textbook counterparts, in addition to providing an opportunity for participants to position themselves differently than in traditional instructional encounters.

An Example

To illustrate a perspectival account of an explanation, we have chosen for analysis a discussion[5] that occurred on FreeMathHelp.com, a popular SOH site that has a subforum for calculus questions. In this exchange, a student was initially unable to make sense of a calculus problem on the concept of limit and came to an understanding of the solution through interaction with a volunteer tutor in the forum. Our

[4]Explanations initiated by student questions can occur in a classroom, of course, if an individual student or a small group asks for help as they work on a problem or requests an explanation during a teacher's presentation of a concept or a method. However, observations of classroom interactions have found that such interactions are relatively rare in typical classroom practice (e.g., Mehan, 1979).

[5]This discussion was presented briefly in van de Sande & Leinhardt (2007) as an exemplary forum exchange of high complexity and quality.

hypothesis is that the student began with an unproductive framing of the problem situation and was able to construct a new resource for framing with the help of the tutor's explanation, analogous to the instructional explanation discussed earlier in which Ms. Patrick facilitated students' construction of a new resource for framing subtraction problems. This episode also illustrates how framings can be nested since the student appealed to a broader framing than applicable during the course of building an understanding for this type of limit problem.

Unproductive framing. The query that the student, *BW52*, posed on the forum involved the limit as t approaches infinity of the composite function $cos(t + 5t^\wedge(- 2))$. In the initial posting (Fig. 6.3), *BW52* revealed how s/he was thinking about the limit: treating infinity as an object (Plugging in infinity gets me to cos(infinity)), recognizing that this is not a fruitful move (which doesn't really help me much), proposing the "squeeze theorem" as an approach (I don't think I can use the squeeze theorem either (but please correct me if I'm wrong)), and finally focusing on algebraically transforming the inner function in order to make sense of the function's behavior (so I've been trying to get the equation to a format that I can use with little success). The accompanying algebraic operations led *BW52* to an acknowledged impasse: " … as if I try to combine the t and $5/(t^2)$ and divide by the greatest power of t in the denominator, it leads me full circle." The focus of this framing, then, is on the inner function of the composition with the goal of massaging it into a certain form,[6] rather than on the concept of limit and description

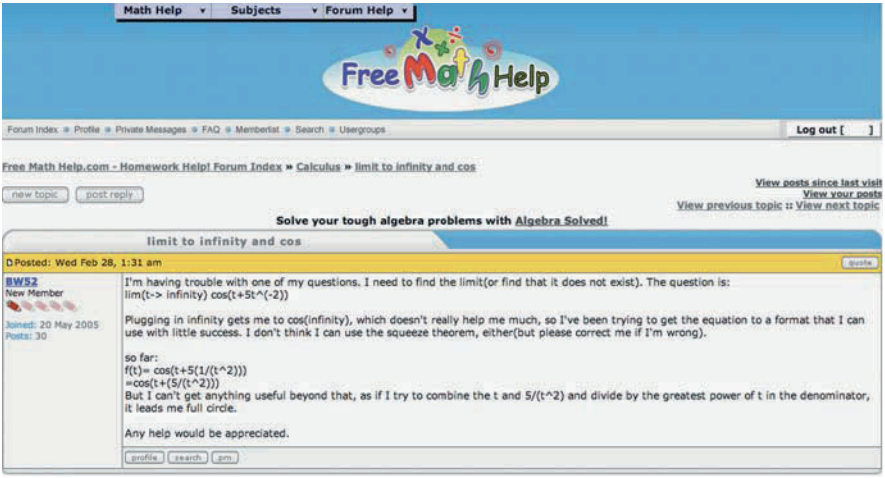

Fig. 6.3 Initial posting with framing focused on inner function

[6] *BW52*'s proposal to "divide by the greatest power of t in the denominator" suggests that s/he is invoking the standard treatment of rational functions in which division of the greatest power of the variable in the denominator is used to interpret the function's behavior.

of the behavior of the given function for large values of x. In particular, the properties of the cosine function and its end behavior are not evident in this conceptual framing of the problem situation. In terms of positional framing, *BW52* has presented him/herself as someone who is requesting assistance but, at the same time, as a participant in a mathematical discussion on the forum who is entitled to make and evaluate proposals for action.

Shift of focus. The forum member who responded to this query, *Skeeter*, led the construction of an explanation (Fig. 6.4) by asking *BW52* to consider the end behavior of "a more simple problem," namely cos(x). Conceptually, the simplification of the problem situation through the substitution of the variable x for the expression $t + 5t^{-2}$ draws attention to the behavior of the cosine family in the treatment of the limit. This move may also have been intended to draw on a resource that *BW52* would presumably have at his/her disposal by invoking the familiar representation of the graph of $y{=}\cos(x)$, together with its salient properties of boundedness and oscillation. Positionally, the response, which begins with a counter-query (o.k. answer a more simple problem . . .) and ends with a request for an analysis of the situation (why or why not?), situates the student, *BW52*, as a co-explainer, that is, as someone who is expected and entitled to explain the mathematics *with* the tutor.

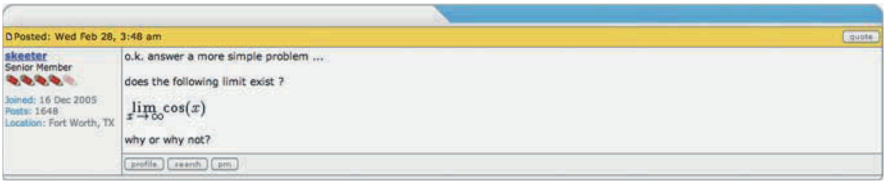

Fig. 6.4 A response which shifts the focus and positions the student as co-explainer

Connecting framings. The next posting in the exchange (Fig. 6.5) shows that *BW52* has taken on the role of co-explainer and is drawing on her/his resources as s/he reasons through the limit behavior of the simpler problem by invoking the representation of the cosine graph: "No, since cos graphs go up and down between –1 and 1 throughout the graph. It won't be closer to either value or to a value in between at infinity." The conclusion of the posting, however, shows that *BW52* still harbors some parenthetical uncertainty regarding the connection between the two expressions and their framings: "And replacing x with $t + 5t^{-2}$ would get us the same answer to the previous question, correct? (although that would do strange things to the $x\rightarrow$ infinity, wouldn't it?)". The mapping between the two framings was not

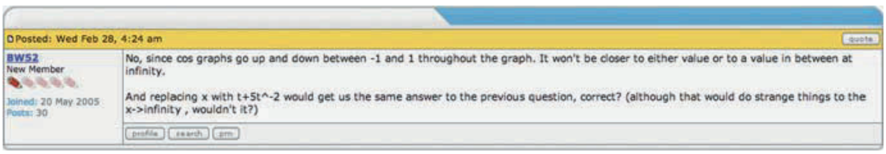

Fig. 6.5 Construction of mapping between two framings

clear to *BW52* so that s/he indicated that the issue had not been resolved to her/his satisfaction and requested further interaction.

Bingo. As the discussion continued (Fig. 6.6), *Skeeter* affirmed *BW52*'s conclusion regarding the limit behavior of the cosine function (bingo) and addressed the concern that the two expressions should be framed differently (however, no strange behavior . . . $\cos(t + 5/t^2)$ would behave pretty much the same as $\cos(x)$ as both x and $t \to$ infinity.). *Skeeter* ended this brief and focused posting by asking *BW52* to supply the reason for this conclusion (why?), a conversational move that invites further engagement and a pedagogical move that supports self-explanation and reinforces the role of *BW52* as a co-explainer.

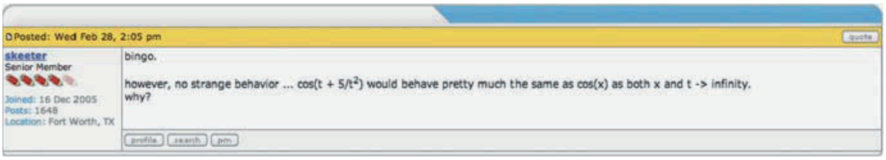

Fig. 6.6 Affirming analysis and establishing mapping between framings

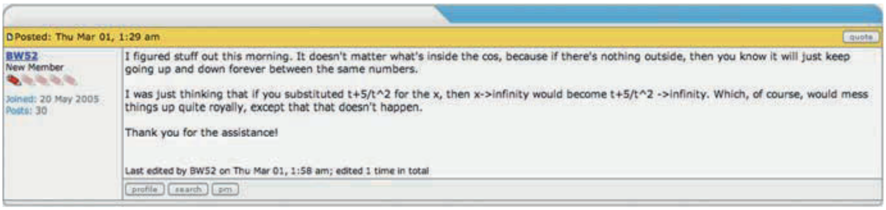

Fig. 6.7 Over-generalization representing nested property of framings

Nested framing. BW52 accepted the invitation to be an explainer (Fig. 6.7) and invoked the boundedness and oscillation of the cosine function: " . . . it will just keep going up and down forever between the same numbers." The focus of this framing is no longer on algebraic manipulations to the inner function but rather on the behavior of the cosine family. However, this explanation also shows that *BW52* has over-generalized the conclusion and adopted a broader framing than is applicable: "It doesn't matter what's inside the cos..." In other words, *BW52* has now adopted a framing in which there is no connection between the limit behavior of the inner and outer functions in the composite expression being analyzed; the limit is solely determined by the behavior of the cosine function. Having voiced this explanation of limit and proposed a mapping between the two problems (I was just thinking that if you substituted $t + 5/t^2$ for the x, then $x\to$ infinity would become $t + 5/t^2 \to$ infinity. Which, of course, would mess things up quite royally, except that that doesn't happen.), *BW52* demonstrated that s/he was convinced that the issue had been resolved and that the discussion could end: "Thank you for the assistance!"

Careful. The way in which forum tutors can be sensitive to others' perspectives is evident in the reply from *Skeeter* (Fig. 6.8), who reopened the exchange with a warning and a counter-example that introduces conditions of (non)use into the

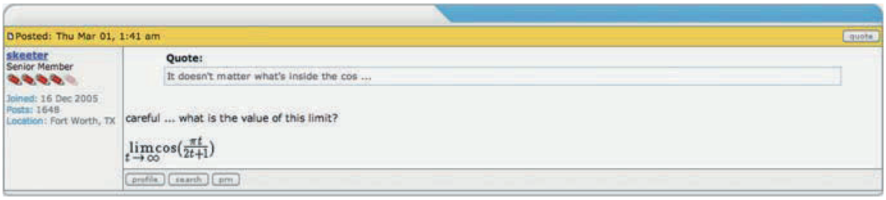

Fig. 6.8 Tutor detects and responds to overly broad framing

explanation of limit that is being co-constructed: "careful ... what is the value of this limit? $\lim_{t \to \infty} \cos\left(\frac{\pi t}{2t+1}\right)$." The limit behavior of this function is different from that of the function that initiated the query and that *BW52* framed incorrectly, although all share a critical feature, namely the cosine as the outer composite function. This move serves pedagogically as part of a Socratic dialogue by presenting the student explainer with a situation in which an argument will be invalid. Positionally, *Skeeter* is inviting *BW52* to engage in mathematical reasoning by working through a counter-example and reflecting on her/his conclusion that "It doesn't matter what's inside the cos ... "

Revised framing. Once again, *BW52* accepted the invitation to contribute to the mathematical explanation (Fig. 6.9) and posted the solution to the counter-example: "Inside the cos can be simplified. It came out as cos pi/(2+(1/t)) Running that by the limit comes out as cos pi/2 = 0." The difference in the limit behavior (the fact that this limit existed and the previous limit did not) was reconciled by *BW52* through an explanation based on the properties of the inner function: "It's because of dividing by the 2t+1, isn't it?" The framing of these limit problems, then, has been revised so that the behavior of both the *inner* and *outer* functions is part of *BW52*'s understanding. *Skeeter* (and other forum members) did not respond to this explanation and the thread ended here, marking implicit acknowledgment that *BW52* had adopted a framing of limit that was productive and could be used for the mathematical analysis of other situations.

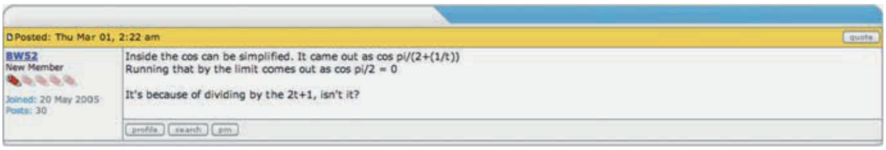

Fig. 6.9 Revised framing following forum interaction

Summary. This tightly knit exchange began with a routine calculus exercise and grew into an explanation *with* a student that touched on key mathematical principles and conditions of use and was marked by sophisticated pedagogical moves.[7] The

[7]The authors thank Gaea Leinhardt for pointing out that forum activity of this nature illustrates how routine tasks of low cognitive complexity can grow in complexity and depth through interaction, just as tasks that are of high cognitive complexity can diminish in complexity through implementation (Stein, Grover, & Henningsen, 1996).

initial, unproductive framing of the problem was addressed through analogy, and the subsequent adoption of an overly broad framing was addressed through counterexample. Throughout the exchange, the participating tutor was sensitive to the way in which the student was framing the situation and tailored her/his explanation accordingly, drawing on resources that the student presumably had available (such as the graph of the cosine function). The result was an improved understanding of the concept of limit in an exchange in which the student was positioned as a co-explainer of the mathematics. Although this exchange involved a single student–tutor pair, we often observe many-to-one exchanges in SOH sites in which multiple tutors respond with (and sometimes discuss) alternative framings of the exercise posted by the student (van de Sande & Leinhardt, 2007, 2008).

Conclusions

We have explored a relationship between Leinhardt's theory of instructional explanations and a theory of perspectives and framings that we have been working to develop. We conclude that the perspectival theory of framing can fit comfortably within Leinhardt's analytic framework. By specifying hypotheses about framings that are constructed in interactions between explainers and recipients, we have arrived at accounts that do not alter the interpretations that result from Leinhardt's planning-net analyses except for providing more explicit and definite hypotheses about the conceptual contents that are constructed and the positional roles of participants in the interactions in which they participate.

We used an episode from an open, online, calculus help forum to show how ideas from perspectival theory can contribute to accounts of explanations in problem-solving activity. In this exchange, the student was initially unable to solve an exercise on limit but emerged with a more coherent understanding of the limit concept. During the discourse, the student adopted an alternative conceptual framing along with a positional framing as a co-explainer of the mathematics. In short, instead of an expert explaining the mathematics *to* the student, both participants framed the activity so that the tutor explained *with* the student. In our account of the interaction, we have taken the opportunity to use Leinhardt's framework for explanations coupled with perspectival theory to explain with you, the reader, problem-solving activity as we are coming to understand it.

Acknowledgment This work was partially supported by a grant from the Spencer Foundation.

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Chapter 7
How and Why Do Teachers Explain Things the Way They Do?

Alan H. Schoenfeld

Introduction

If, as it is said, "one never steps twice into the same river," it is all the more true that one never teaches the same lesson twice. Context, students, and the teacher differ from year to year, day to day, and even minute to minute. Every action is a response to immediate circumstances.

Consider the following musical metaphor. A score, or simply a melody, provides a set of constraints but still leaves much to the discretion of the musician. This is the case with classical music – Jeanne Bamberger points out that the recordings of the Bach unaccompanied cello suites made at different periods in Pablo Casals' career offer very different interpretations of the same score. Perhaps more analogous to the classroom, two different performances by John Coltrane of "my favorite things" (e.g., the rather mellow performance on "The Best of John Coltrane" and the rather "out there" performance on "Live at the Half Note") have core similarities, but also fundamental differences – differences induced by the context, the other players in the combo, and the musician's mood at the moment. Nonetheless, there is a core in every performance. What one hears is recognizably Coltrane, and recognizably his take on "my favorite things." Coltrane might never play the same piece twice, but his playing each time captures what he is trying to do with the music. And, while there is variation, there is also great systematicity.[1]

The same is true of teaching. Specifically, I claim that a teacher's in-the-moment decision-making (which includes instructional explanations) can be explained – indeed, modeled – as a function of the teacher's knowledge, goals, and

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[1]These informal comments point to a fascinating body of literature on individual and group creativity: see, e.g., Berliner, 1994; Klemp et al., in preparation; Sawyer, 2003. My thanks to Jim Greeno for leading me in that direction.

M.K. Stein, L. Kucan (eds.), *Instructional Explanations in the Disciplines*,
DOI 10.1007/978-1-4419-0594-9_7,

orientations.[2] This approach has been explicated in a number of places (Schoenfeld, 1998, 1999, 2000, 2006, 2008; Schoenfeld, Minstrell, & van Zee, 2000). Here I will use one of my own lessons as the object of analysis, partly because I want to expand on the notion of "instructional explanations." The way I would like to frame the discussion of explanations is

> What would the teacher like the class to learn from the discussion of any particular problem, example, or topic? How does the teacher shape instruction toward those goals? How and why does the teacher make instructional choices, on the fly, as a result of classroom contingencies and in the service of those goals?

This framing is deliberately expansive. I wish to include a broad range of instructional and personal goals as desired outcomes for instruction, and a comparably broad set of classroom practices orchestrated by the teacher as contributing to their development. This kind of framing is entirely consistent with the approach taken by Leinhardt in her seminal (1993) paper "on teaching," which uses the idea of *agendas* in a way consistent with the musical metaphor explored here, and her more encyclopedic (2001) handbook chapter, although the framing proposed here is somewhat more expansive in character. In this view, instructional goals and planning – and their realization through instructional explanations – include the creation of classroom norms and culture through discourse around explanations of content.

I have chosen to examine by way of explication a subset of the first week of my problem-solving course(s). The first week is important because it establishes the ambience for the course – which is non-standard, with regard to both goals and classroom practices. Here I describe my goals for the beginning of the course, the tasks I have chosen as the means to attain those goals, and my intentions for the discussions of those tasks. To return to the musical analogy, this is the melody – my "favorite things," planned for the first week.

I say "the" first week although I have taught a version of the course in either the mathematics department or school of education roughly every other year since the mid-1970s. There have been many first weeks. They have varied, depending on the students, my mood, and myriad other factors. How things actually play out is, as always, a function of context. But, despite contextual differences, those first weeks have also played out in regular ways. I argue that there is an underlying systematicity to that regularity, just as there is in jazz improvisation.

After laying out my goals and intentions for the first week, I discuss in some detail part of the transcript of the second day of the course, using the transcript to show how my decision-making during that problem discussion can be described in terms of my knowledge, goals, and orientations.[3] The lesson discussed here has been

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[2]Here I use "orientations" as an inclusive term to encompass what have been referred to variously in the literature as beliefs, dispositions, values, tastes, and preferences – see Schoenfeld, in preparation.

[3]Using myself as a subject in this case may seem all too self-referential, and that readers may question the generality of what I say on the basis of this case. There is extensive evidence that the in-the-moment decision-making characterized here applies to in-the-moment decision-making

the subject of a detailed analysis by Arcavi, Kessel, Meira, and Smith (1998).[4] Their paper can be seen as establishing a firm foundation for the comments made here.

Goals for the Course (and the First Few Problems)

The overarching goal of my problem-solving course is to provide my students with an authentic mathematical experience – to have them learn to engage in and with mathematics in the ways that mathematicians do. Thus, my students and I spend the vast majority of classroom time doing mathematics and reflecting on what we have done. In a chapter contextualizing the course and my intentions, I wrote:

> Elsewhere (see, e.g., Schoenfeld, 1985) I have characterized the mathematical content of my problem solving courses. Here, in an extension of the themes explored in a number of recent (and one not-so-recent) papers (Balacheff, 1987; Collins, Brown, & Newman, 1989; Fawcett, 1938; Lampert, 1990; Lave & Wenger, 1989; Lave, Smith, & Butler, 1988; Schoenfeld, 1987, 1989, 1992) I focus on the epistemological and social content and means. The content of my problem solving courses is *epistemological* in that the courses reflect my epistemological goals: that, by virtue of participation in them, my students will develop a particular sense of the mathematical enterprise. The means are *social,* for the approach is grounded in the assumption that people develop their values and beliefs largely as a result of social interactions. I work to make my problem solving courses serve as *microcosms of selected aspects of mathematical practice and culture* – so that by participating in that culture, students may come to understand the mathematical enterprise in a particular way. (Schoenfeld, 1994, p. 61)

My goals, then, include the mathematical, epistemological, and social. The vehicles toward those ends are the problems we discuss in class. The problems are chosen with an eye toward both content and process. On the content side, I want the students to be engaged in interesting and important mathematics. On the process side, discussions of the problems provide opportunities for me to demonstrate problem-solving strategies and to engage the students in discussions that help the students to understand and internalize productive mathematical habits of mind.[5] These include seeing the world from a mathematical point of view (having the predilection to view situations through a mathematical lens; to symbolize, model, and abstract; and to apply mathematical ideas to a wide range of situations) and having the knowledge and problem-solving wherewithal to do so successfully.

Characteristics of such problems – what I have called my "problem aesthetic" (Schoenfeld, 1991) – are as follows:

A. I prefer problems that are relatively accessible, so students can sink their teeth into them without having to learn a great deal of vocabulary or "machinery" beforehand.

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during most activities with which one has extensive experience (see, e.g., Schoenfeld, 1998, 2002, 2008, in progress).

[4] Thanks to Cathy Kessel for providing the transcript of the problem discussed extensively below.

[5] See, e.g., Cuoco, 1998.

B. I prefer problems that can be approached and solved in a number of ways. It is good for students to see multiple solutions – they tend to think that there is only one way to solve any given problem (usually the method the teacher has just demonstrated in class). They need to learn that the “bottom line” is not just getting an answer, but seeing connections, exploring extensions, etc. Also, the possibility of multiple approaches lays open issues of “executive” decisions: what directions or approaches should we pursue when solving problems, and why?
C. The problems and their solutions should serve as introductions to important mathematical content, processes (learning problem-solving strategies), and habits of mind.
D. The problems should, if possible, serve as invitations to mathematical explorations. As discussed below, solving a problem is not merely an endpoint; the mathematician always asks “what can I do next?” Problems that can be generalized or extended provide the opportunities for students to *do* mathematics.

I have many other “local” goals for my classes, especially the first week of class. I need to let the students know that this is a very different kind of course than they are used to; that they will have to work hard, but that there are intrinsic rewards for doing so; that the norms of the class will be very different from what they are accustomed to, e.g., that we will do a lot of problem-solving together in class, and that I will expect them to be major contributors to the mathematics we develop during the course, and arbiters of its correctness. (That is, I tone down my role as certifier and judge. Over the course of the semester I want the students to come to believe that they can both generate mathematics and be certain of its correctness, rather than turning to me as judge.) These are powerful long-term goals, and it will take time to achieve them. My students enter the course with more or less standard expectations for the classroom didactical contract and for my behavior as a professor. Thus at the beginning of the course I need to establish myself both as someone who merits their trust in “standard mathematics instructor” terms and who will, with that trust established, lead them into new territory.

The class meets for two hour-and-a-half sessions per week. I begin the course with a lecture, explaining my intentions and some history – e.g., that there is ample testimonial (and evidence) that my students are much better problem solvers after the class than before and that the hard work they put in during the semester will pay off. I explain how we are going to do things, saying that I will not lecture again during the semester. I then hand out the first problem set and tell them to get into groups of three or four and get to work. I tell them I am about to leave the room; my experience is that students feel more comfortable at the beginning if I am not there and they can get to work by themselves. I then “disappear” for 10 min. When I return I roam around the room, listening to conversations and taking stock of student progress on the problems. Then I call the class to order and begin to discuss the problems.

The problems I hand out the first day of the course are given in Appendix. Readers might want to play with the problems before proceeding through the narrative. It typically takes us a week or more to work through them.

The main focus of this chapter will be on the way the discussion of problem 3 plays out, as a function of my knowledge, orientations, and goals. To set the stage, I briefly describe my goals for problems 1, 2, and 3.

Problem 1. A main goal of the first day is to show the students I have something to teach them. The two tasks in problem 1 can appear mysterious to students, but they yield rather quickly to the heuristic strategy "If you don't know what to do and the problem has an integer parameter n in it, try test values of $n = 1, 2, 3, 4, \ldots$ and look for a pattern." Discussing this strategy has a powerful effect – the students are introduced to a useful strategy and learn that such strategies help them solve problems that they were unable to solve on their own. (My classroom discussion of these tasks also includes a satirical replay of how they were most likely shown the solution to the first problem, known as the "telescoping series," in a second semester calculus class. This establishes my mathematical/pedagogical *bona fides*, showing that I know the traditional college curriculum and can lecture like a typical mathematician if I choose to.)

Problem 2. This rather difficult problem introduces the heuristic strategy "if you can't solve the given problem, try to solve an easier related problem and then try to exploit either the method or the result." Issues of working forward, working backward, and establishing subgoals will arise and be discussed. With this problem I begin introducing some major themes of the course. For example, I tell a student who comes to the board to present a problem solution and who looks directly at me while presenting it that in this course we will use a non-standard norm for presenting and certifying results: the class, relying on its mathematical knowledge, must be able to judge the correctness of his presentation. I then ask the class if they accept his argument. Also, I ask "are we done" more than once, at points where we have reached a solution. Each time the class says yes, and each time I say no – because there might be other ways of solving the problem, which might help us to gain new insights, or because it might be possible to extend or generalize the solution to the problem that we have solved. All told, we spend more than an hour on the problem over the course of 2 days.

Problem 3. This problem, discussed extensively below, continues the introduction to the mathematical ethos I want to develop in the course. The problem as stated is trivial: most students will find a solution via trial and error within a few minutes. And, most will leave it there – the problem is done, what's our next task? One point, as mentioned above, is that finding a solution does not mean that our work with the problem is done. There are various ways to think about the problem as posed, and many more ways to think about extensions and generalizations. Making connections, extending, and generalizing are a major part of what mathematicians do, and I use this problem to focus on those themes. But, there is much more. Precisely because the arithmetic involved in the problem is trivial, I can focus on a range of heuristic and strategic issues. The problem serves as a mechanism for introducing notions such as exploiting symmetry, establishing subgoals, working forward, working backward, and considering extreme cases. I enter the discussion with a strong set of expectations, of course; but, what I do must be modified in the moment because of the things the students say and do.

From Goals to (Inter) Action

Up to this point I have described my goals – in terms of my musical analogy, I have provided the score. Now the question is, how do things play out live, in the classroom?

My theoretical argument is that what a teacher does, in the moment, is a complex but analyzable function of that teacher's knowledge, goals, and orientations – that the teacher's decision-making can be understood as the selection among salient alternatives at the time, and that what is salient is shaped by what the teacher values, perceives, and knows (see Fig. 7.1).

The balance of this paper is devoted to a discussion of problem 3 in Appendix, known as the magic square problem. The full discussion of the problem, which the students had solved on their own in about 5 min, took 40 min of class time. In what follows, I present the full transcript of the discussion using the following format:

Classroom dialog, with turns numbered in bold, is printed flush to the left margin. Figures are interspersed with the dialog. *Classroom actions are described in italics*, and *comments related to the decision-making mechanism are indented and printed in italics.*

Discussion of the magic square problem (problem 3, introduced above).

I wanted this problem to introduce the students to a number of important problem-solving strategies. I chose the magic square problem because the mathematics in the problem is trivial; thus the students could focus on the thinking process without too much "cognitive load" devoted to the problem itself. Having taught this problem many times before, I had well-founded expectations for what the students were likely to say, and well-developed routines for dealing with what they were likely to produce.

1. AHS: OK. The next one was the magic square. Can you fill in the numbers from 1 to 9 so that the sum of each row, column, and diagonal is the same? *As I speak, I draw a blank three-by-three box.* I presume the answer is yes. Someone got a solution?

This (standard) move initiates discussion and sets the stage for what is to come. I expect a volunteer to present a solution and say something about his/her thinking, but I do not have high hopes for the exposition – the idea is more to get a conversation going.

Jeff [6] *raises his hand and says yes.*

2. Jeff: . . . [inaudible]. . . 5 in the middle? Want me to. . . ?

3. AHS: I respond by saying "go ahead" and toss him a piece of chalk.

[6] All students are referred to by the pseudonyms used in Arcavi, Kessel, Meira, & Smith (1998).

- An individual enters into a particular context with a specific body of knowledge, goals, and orientations (beliefs, dispositions, values, preferences, etc.).
- The individual orients to the situation. Certain pieces of information and knowledge become salient and are activated.
- Goals are established (or reinforced if they pre-existed).
- Decisions are made, consciously or unconsciously, in pursuit of the high-order goals.
  - If the situation is familiar, then the process may be relatively automatic, where the action(s) taken are in essence the access and implementation of scripts, frames, routines, or schemata.
  - If the situation is not familiar or there is something non-routine about it, then decision-making is made via an internal calculus that can be modeled by (i.e., is consistent with the results of) the subjective expected values of available options, given the orientations of the individual.
- Implementation begins.
- Monitoring (whether effective or not) takes place on an ongoing basis.
- This process is iterative, down to the level of individual utterances or actions:
  - Routines aimed at particular goals have sub-routines, which have their own subgoals;
  - If a subgoal is satisfied, the individual proceeds to another goal or subgoal;
  - If a goal is achieved, new goals kick in via decision-making;
  - If the process is interrupted or things don't seem to be going well, decision-making kicks into action once again. This may or may not result in a change of goals and/or the pathways used to try to achieve them.

Fig. 7.1 How things work, in outline

By now, Jeff knows that I expect student presentations at the board. From this point on the norm will be for students to present their work, with discussions orchestrated by me. The chalk-tossing, as well as the informal language, are intended to indicate that there is a relaxed, casual atmosphere for talking about mathematics. These too are standard moves.

What's your name?
4. Jeff.
5. AHS: Jeff. Go ahead.

6. Jeff: (*Filling in the square as he talks:*) The sums will be 15 in all directions. Want me to explain why I came up with 15?

6	7	2
1	5	9
8	3	4

7. AHS: Yeah.
8: Jeff: The way we looked at it was, having an odd number led to a nice center number of 5, it's the middle number of our set, so we took that and realized that you can have three parts . . . each row, column, or diagonal . . . and if your average number in each row, column, or diagonal would come to five, from our superset, and if you multiply by 3 you get the 15, because each row has to add up to 15, which Devon actually figured directly.

Jeff has faced the class during his explanation, which is good – a step toward the class discussing things themselves. As it happens, his explanation leaves much to be desired. For example, he alludes to the sum of each row, column, and diagonal being 15, without a careful explanation of why it must be; he appeals to symmetry tacitly (the middle number is in the middle square) without saying much about it. But, this is an early attempt at explanation, and the answer is clearly correct.

I decide to let the answer stand on its own and to move the discussion forward along the dimensions I had expected to cover; I can further explicate some of the things Jeff said later in our conversation. I move into a "set piece," where I start by showing that it would be hard to solve this problem by pure trial and error – that in fact, all the students used some sort of strategies, which I will now make explicit.

9. AHS: OK, Well, the answer speaks for itself; we can do the addition. What I want to do is play with this a little bit. First of all it's not a problem you want to do by pure trial and error. There are 9 ways that you can stick a number in this square [*pointing to upper left hand corner of the 3-by-3 magic square*], 8 in that one [*pointing to the square to its right*], 7 in the next one . . . *After pointing to each box I write the corresponding number on the board, writing*

$$9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1$$

So it turns out that there are that many different ways you might put in the numbers in randomly. Now, a number of them are equivalent by symmetry. For example, if you had this solution [*bracketing Jeff's solution with my arms*] you could turn it 90 degrees [*gesturing as though rotating Jeff's solution 90 degrees clockwise*] you get a different set of numbers but it's essentially equivalent to this solution. Same for 180; if you had this you could turn it over that way [*gesturing as though flipping the solution through its vertical axis of symmetry*]. It turns out that any position has eight equivalent positions, so that you only need to check [*I write an 8 under the sum on the board*]

$$\frac{9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1}{8}$$

before you're likely to get one. However, if you do that randomly, that's, what? *I cancel the 8's and then multiply out loud:* Two, six, twenty-four, one twenty, seven twenty, five thousand forty, forty-five thousand things to check, that might take a while if you used brute force.

This monologue is intended to do a number of things. In establishing that there are more than 45,000 non-equivalent ways to fill in the 3 × 3 magic square I set the stage for our later conversation, when we determine a solution without trial and error. I quickly mention symmetry, which will return later as an important component of our solution. I display standard lecturing competency, which is important at this point in the course – if the students think my approach is too weird, they will leave the course.

10. Devon: Other than symmetry is there [more than one solution]?

This is an excellent mathematical question, but one that I do not want to discuss now, because it is premature to take it up. The answer, that the solution is unique, will emerge naturally from the discussions that I have planned. To honor the suggestion (and thus the notion that good mathematical questions should be taken seriously) I write it on the side board and promise it will be taken up later. [Note: This is an example of emergent decision-making, entirely consistent with my overarching goals and made possible by my knowledge of the mathematics to come.]

11. AHS: That's a good question [*I write it prominently on a side board, where it remains visible through the class discussion*], let's leave it as something to look at.

Having put Devon's suggestion temporarily on hold, I return to the previous discussion. My goal is first to unpack Jeff's presentation, elaborating on the tacit strategy that resulted in the choice of 5 for the center square and 15 for the sum. I want to honor the intuitions and use of symmetry that led to Jeff's group's solution. Then I want to pursue the planned discussion of heuristics (establishing subgoals, working backward, working forward, exploiting extreme cases) that will ultimately show that that one need not guess at all. I have well-developed routines for achieving all of these goals, and I implement them as needed.

12. AHS: So if you don't want to do it by trial and error, then what you really want to do is look for ways that you can reduce the number of cases that you have to consider. I think that what happened in Jeff's group was a strong appeal to symmetry, the notion that we're dealing with the numbers from 1 to 9 [*writing 1, 2, 3, 4, 5, 6, 7, 8, 9 on the board*], 5 sort of plays a central role [*underlining the 5 in the middle of the numbers*], it's right in the middle, so for whatever reason, things seem to revolve around 5 [*pointing to the 5 in the middle of the list, and then in the middle of Jeff's magic square*]. Wouldn't it be nice if it turned out that five is in the center? Five is the average of all those numbers [*pointing to 1–9*] and things should sort of average out. In some sense the average of all these things is 5 [*pointing to the cells in the first row, then the second, then the third*] so maybe 15 is the sum across three of them. So, if you make those two guesses – five is in the center and 15 is the sum [*writing "5 in center, 15 is the sum" on the board*] then you don't have too much trial and error to do before you guess it. That's a good sane way to go about solving the problem.

Having met the dual goals of crediting Jeff's group for their answer and unpacking some of the processes involved in their solution, I start the transition to the set piece on subgoals and related heuristics.

13. AHS: What I want to do is ask a couple of questions that illustrate some of Pólya's strategies and use the answers to make progress on this problem. So we're going to revisit the problem a little bit. My first questions are going to seem rather simple but I want to indicate how some very obvious looking questions can help you make progress on things like this.

We're back to the beginning – we want to place the digits from 1 to 9 into this so that the sum of each row, column, and diagonal is the same. [*I re-draw the blank 3 × 3 box on the board, and the statement "the sum of each row, column, and diagonal is the same."*]

The first question is generic: What piece of information would make the problem easier to solve? [*I write "What piece of information would make the problem easier to solve?" on the board.*] That's a really broad generic question. But you're facing a problem, it's posed in a particular way. Now you can ask yourself is there some piece of information, some bit of knowledge, so if you just had that, would make this problem easier to solve?

Turning to a student: You're nodding your head yes, what would it be?

14. Student: What is the sum?

15. AHS: OK. So a key piece of information is... this says that the sum of each row, column, and diagonal should be the same. It would be awfully nice to know what that number is, so... what is the sum? [*I write "what is the sum?" on the board.*]

And we had a suggestion about how to think about that, that I'll mention in a second. Let me throw some more jargon at you. This is called – simple as it seems, in other contexts it's a little bit more complicated and worth having a name – establishing subgoals. [*I write "Establishing subgoals" on the board.*] You've got a problem, you want to solve the whole problem, you ask yourself is there something that would get me halfway there. So I want to put the numbers in so that the sum of each row, column and diagonal is the *same*. If I knew what that number was that wouldn't be a solution to the problem, but it could be a stepping stone toward a solution. If I set myself the goal of finding out what is that number, that's establishing a subgoal.

And one suggestion for seeing what the range might be, now before we had a suggestion based on intuition and symmetry, that it would be 15, one way to start from ground zero is to say... look, we're sticking in the numbers from 1 to 9. The smallest numbers we can stick in are 1, 2, and 3, which says that the sum is going to be at least 6, the largest are 7, 8, and 9, so whatever it is the sum is between 6 and 24. Is there anything else I can say about that sum?

The mathematics in my example is trivial; it's a gambit to get them involved. The goal here is to engage the students and to see where their suggestions may lead.

16. Greg: You can narrow it even closer because if you used 1, 2, 3 in a single row, column, or diagonal then you know that you're going to be building something even larger, 2 and 3 for instance are already gone so you have to use 4, 5, and 6.

Greg's reasonIng is flawed – in a magic square 1, 2, and 3 cannot be in the same row, column, or diagonal (other sums would be larger), so whatever conclusions one can draw from this point onward only apply to the case where they are. I could point this out, but I am wary of being too directive at this point: if the students get the feeling that I am leading them by the nose to what I want them to produce, this will shut them down. So, I decide to pursue this line of thought, figuring it won't take long. It's good for the class to see that, as a collective, we will sometimes make errors and/or run into dead ends. I work through the example with my standard poker face, which I'd explained the first day: sometimes what we do is right and sometimes not, and I do my best not to signal which is which.

17. AHS: OK, so in some sense the very least I can get for a sum if somewhere I've used 1, 2, and 3 in a row, the 3's going to be involved in another sum, and that's going to use at least 4 and 5. If that uses 4 and 5 . . . [*I am filling in the blank magic square as we talk:*]

1		
2		
3	4	5

What else can I say?
18. Greg: This says that there's going to be one sum that's at least 12.
19. AHS: Can you say anything else?
20. Greg: If you actually wanted to build it this way you'd go up on the right with 6, and 7 next.

1		7
2	6	
3	4	5

21. AHS: Can you say anything else? Well, that's good, you go 3, 6, and 7. Is the argument now that every sum has to be at least 16? That's what it looks like we just proved. No matter what magic square you draw, you're going to get one sum that's going to add up to 16.

We've now run into a problem, which I point out. We sort it out in the next two exchanges.

So the claim is, well I could put the 6 and 7 after the 1, that gives me a 14, but then I've got to use an 8 and that says now I've got a proof that I get at least a 17.

What's happening here? We already saw that there's a magic square with a 15, but it looks like we just proved that you've got to get an 18. What's happening?
22. Greg: Well, we know that we can't have 1, 2, 3 in the same line anyway because we can't construct a magic square from it.

Greg's statement dismisses the magic square on the board, but doesn't address the general argument. I plan to tidy up a bit and move on.

23. AHS: What we just showed is if you start with a 1, 2, and 3 in a row then you get some fairly large sums, that doesn't mean that every sum has to be that way. [I erase the square we have been working with.] So the sums are going to be larger than 6.

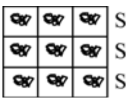
The exchange in turns 16 through 23 was, perhaps, an unnecessary detour – but it didn't cost too much time and the discussion has shown that it's fine to make mistakes, there are no penalties. So, I make the transition to the conversation that results in the determination of the "magic number" (the sum of each row, column, and diagonal).

Is there any other way to get a handle on this besides good guessing? And I don't at all, want to put good guessing down, a symmetry guess is an excellent way to go. Is there any other way we might get a handle on what this might be?
24. Devon: Just forget about the columns and diagonals, since each row has the same sum add all 3 rows and that's the sum of all the numbers from 1 to 9, that gives you 3 times the sum.

There goes another set piece down the drain! I had planned to conduct a leisurely interactive discussion of how one might work backward to find the sum. Devon summarized the result of the entire planned discussion in a sentence. Thus my plan has to change, while the goal remains the same: rather than conduct the conversation and have the process emerge from it, I have to recap and unpack what Devon has said. I opt for a mini-lecture instead of the planned discussion.

25. AHS: [*drawing an empty magic square*:] Let me once again backtrack a little bit and show you where one might come up with that, that's a nice observation. There's a very useful strategy that it turns out you can use quite often, it's called working backwards. And it goes like this: It often helps to assume that you actually have a solution to the problem and then under that assumption find out what properties that solution has to have. [*I write on the board: "Working backwards. It often helps to assume that you have a solution to the problem, and determine the properties it must have*."]

So in this case, suppose we have a solution, I can't quite read it, because it's a little bit messy. [*I draw a smudge in each of the boxes inside the magic square.*] But I've managed to stick the digits from 1 to 9 into that square so that the sum of each row, column, and diagonal is the same. The observation Devon just made was: that means that the sum of this row, call it S for sum, is the same as the sum of that row, is the same as the sum of that row. [*I trace across the three rows, marking each sum with an S.*]



So what's the sum of all the numbers in the square? On the one hand if I add up this row and that row and that row, I've got 3S. On the other hand this is the sum of a solution to the magic square which uses each of the digits from 1 to 9. So if I add up all the digits in the magic square, 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9, I get 45. So 3S is 45. So there's an actual proof that the magic number is 15.

I now move into the next set piece, the next application of the strategy "establishing subgoals." [Note that this transition, like many of the others, follows the architecture of the model described in Fig. 7.2. A major goal has been satisfied, so I move on to the next goal in the stack.]

26. AHS: Since I have this statement, establishing subgoals, in a box on the board, why don't I take advantage of it again. We now know that the sum of each row, column, and diagonal ought to be 15. What's the next major piece of information I need in order to make significant progress on this problem?

There is a long pause with no response. Needing student participation, I repeat:

We've just gotten to the point where we know that the sum of each row, column, and diagonal ought to be 15. If I said what's the next thing you want to know, what would it be?
27. [Unidentified student, possibly Austin:] What goes in the center.
28. AHS: Yeah. What goes in the center. Again, 5 is a good bet, but there's another technique that's actually quite nice that helps us do that. You'll notice what I'm doing is out of this one problem, identifying a wide variety of techniques that are not only valuable for this one but across the board in a whole lot of mathematics.

I now move into another set piece, part of my overall plan.

The next strategy is called "consider extreme cases." [*I write "Consider Extreme Cases" on the board.*] And that is. . . Often if you're trying to make sense of something, it helps to determine the range of possibilities, to look at some really far-out possibilities. And if you get a sense of what allows them to work or keeps them from working, that may give you a handle on what's going to be useful for you to do.
29. AHS: Can 9 go in the center of the square? [*I write 9 in the center of the square.*]
30. [student] No.
31. AHS: Why not?
32. [student] You run out of numbers that you can add pairs of to 9.
33. AHS: If the magic number is 15, that raises a serious problem: where's 8 going to go? If I put an 8 there [*I write 8 in the upper left corner*], I need a minus 2 over there [*pointing to the corner opposite the 8*] and I ain't got none. If I put an 8 there [*pointing to a side slot*], I need a minus 2 over here [*the opposite side slot*] and so on. So 9 can't go in the center. [*I erase the 9 from the center square.*]

How about an 8? [Students indicate it doesn't work.] Same problem, where's 9 go?

How about 7? 6? 5? . . . Maybe.

How about the other extreme? [I write 1 in the center square]
34. [Student] Same problem basically.
35. AHS: Yeah. If I put a 2 here [*writing a 2 in the left-hand side slot*] then I need a 12 here.

2	1	12

So 1 doesn't work; 2 doesn't work; 3 doesn't work; 4 doesn't work, because I can put a 1 somewhere and opposite that I need a number larger than 9. [*I clear the square.*]

So *if* there's a solution then 5 has to go in the center. [*I place 5 in center*.]

36. AHS: Having gotten that far we could consider some trial and error. But we ought to at least take advantage of symmetry to see how much trial and error we really have to do.

So let me ask the question, how many different places are there where we might stick a 1?

There are really only two different places. If I had a solution with a 1 over here [*writing a 1 in the upper left-hand corner*], and all the rest of these were filled in, then I could take that solution, take the board, rotate it 90 degrees [*gesturing as though rotating the magic square 90 degrees clockwise*] that gives me a solution with 1 in the corner over here. Or equivalently, a solution with 1 in the corner over here, rotating it that way gives me a solution with 1 here. So, a solution with 1 in this corner is equivalent to, or generates a solution with a 1 in any of the other corners. Similarly if I have a solution with 1 in a side pocket, that generates any of these [*pointing to the other middle outside side slots*]. So there are really only two places that I might place a 1. [*I write "Exploit Symmetry" on the board, directly underneath "Consider Extreme Cases."*]

That's another strategy that comes in handy.

37. AHS: OK. Suppose we've got a 1 up there [*upper left-hand corner*]. Where can we place a 2? The 1 forces a 9, how many places are there we might place a 2?

1		
	5	
		9

38. AHS: [*I go on to show that a 2 can't be placed in the first row or column, because one would need a 12 to complete that sum. Placing a 2 in one of the remaining side slots would require an 8 adjacent to the 1, and a 6 in the corner; but then 6 and 9 would be in the same row or column, which is impossible.*]

That means that there is a 1 on the side,

	1	
	5	
	9	

And let's see, I can't put a two there [*I point to the upper left corner*] or there [*I point to the upper right corner*], but I can put it here [*I point to the center left side*]. If I do, the 2 forces an 8.

	1	
2	5	8
	9	

Now I can ask, where does the 3 go? It can't go there [*upper left*] or there [*upper right*], and if I put it here [*lower left*] or here [*lower right*], 3 and 9 make 12 and we can't use another 3 and I can't do that. So 2 can't go in the side, and the only place left for it is down here.

	1	
	5	
2	9	

[*From there the rest of the solution is forced. I fill the square in, starting with 8]:* 8, 6, 4, 3, 7,

6	1	8
7	5	3
2	9	4

is essentially the solution that Jeff showed us. What we learned along the way is that a 1 has to go in a side pocket, a 2 has to go into one of the two bottom positions opposite it, and the rest is forced. So [*pointing to Devon's question on the side board, "Other than symmetry is there more than one solution to the 3 × 3?"*] the answer is that *that* [*pointing to the solution on the board*] is the only solution modulo symmetry, which answers Devon's question.

39. AHS: [*After a five second pause to let the solution sink in*] Are we done?

This too is a set piece. A leitmotif of our discussions is that our job involves more than simply solving the problems we have been given. The first day of the class, the question in turn 39 ("Are we done?") had consistently been answered "Yes;" and I had consistently said, "No, we're not." That message had clearly begun to get through, as evidenced by the response:

40. [Student] We're never done.

41. AHS. You're learning!

At this point my goal is to lead the class into a discussion of solving the problem by working forward. Doing so involves another set piece. I will ask the students to generate triples that add up to 15, and I am confident that I know what will happen when they do so. Things do play out as expected, as seen in turns 42 through 61.

42. AHS: What I want to do is to go back to this problem in an entirely different way. What we did to solve the problem *this way* was to work backwards and say, "Suppose we had a solution, what properties does it have?"

What I'd like to do is also approach the problem the other way by saying, "Hey look, we know some of the properties it ought to have, can we lay out the tools we have at our disposal and out of that see what properties the final solution ought to have"?

So let's go back about half-way, when we knew that the magic number is 15.

That's enough to enable us to make some fairly straightforward progress on the problem. What the problem calls for is a whole bunch of sums – rows, columns, diagonals [*gesturing at the board as I mention them*], triples of numbers that add up to 15. It's a perfectly reasonable thing to say "Why don't I list all of those so that I know what I have at my disposal?" Having found all triples it'll be easy to stuff them in the magic square.

Also, if we didn't know there was a solution that would also provide a possible way of showing that the problem is impossible. Suppose there was no solution – although we know there is. Suppose you found all the triples that added up to 15 and there were only six triples that added up to 15. The magic square has [*gesturing across the square as I count*] 1, 2, 3, 4, 5, 6, 7, 8 triples that add up to 15. If there were only 6, there could be no solution since the magic square would demand 8. OK?

So let's just be crass empiricists. Who can give me a triple that adds up to 15?

43. Student: 1, 5, 9
44. AHS: Anyone got another one?
45. Student: 2, 9, 4.
46. AHS: Another one?
47. Student: 2, 5, 8.
48. AHS: Another?
49. Student: 3, 5, 7.
50. AHS: Another?
51. Student: 4, 5, 6.
52. AHS: Another?
53. Student: 2, 9, 4.
54. AHS: Another?
55. Student: 1, 6, 8.
56. AHS: Another one?
57. Student: 1, 9, 5.
58. AHS: Oops, we got that already. [*I put a large X through it.*] Another?
59. Student: 7, 6, 2.
60. AHS: Another one? [*After a 5 second pause...*] Are we done, is that all of them? [*A tensecond pause...*]
61. Student: 8, 3, 4
62: AHS: 8, 3, 4. Another one? Are there any more?

As expected, the students have generated the triples randomly, providing me with the (expected) opportunity to discuss the need to be systematic. (Had they approached the generation of the triples systematically, I would have praised them and recapitulated the strategy.)

This is now something like the 142nd time I've used this particular problem and I get to ask the same next question for the 142nd time: How the hell would you know? You sort of generated them [*pointing to the triples on the board*] randomly, so you got a whole bunch of them – but you might've caught them all and you might not.

There's another important strategy:

[*I write on the side board: "IT HELPS TO BE SYSTEMATIC!"*]

It often helps if you go about being really systematic in generating the things you need.

A couple of things happened here. One of them was, we got this far [*I point to the 1, 9, 5 triple*] and you'll notice that someone generated a triple that we generated before.

One way to avoid that is to adopt the simple convention which says, I'll only list my triples in increasing order. That way I won't get into problems listing something like this. [*I point to the crossed-out 1, 9, 5*].

Second, why not find a really systematic way of generating them so that when I'm done, I know I'm done?

Starting with 1 5 9 is a fairly good way to start. Why not exhaust all the triples that use 1 as the first number?

What's next? [*I list the triples in increasing order as the class generates them, resulting in the following list*:]

1 5 9
1 6 8
2 4 9
2 5 8
2 6 7
3 4 8
3 5 7
4 5 6

63. AHS: So we've got a total of 8 triples, ... , that's nice, because there are 8 rows, columns and diagonals. Now what was the most important square in the magic square? The middle. How many sums was that square involved in?

64. Student: Four.

65. AHS: How many digits appear 4 times?

66. Student: The 5.

67. AHS: Only the 5, that's the only digit that appears four times. So guess what, we just found a second, completely independent proof that 5 has to go in the center square.

Now let's take a look at this one. [*Pointing to the upper left hand corner.*] How many sums does the upper left corner involve?

68. Student: Two.

69. AHS: Three: [*Tracing the paths with my fingers*]: one column, one row, and one diagonal.

Can 1 go in the upper left hand corner? No, it only appears in two of our sums.

How about 3? Same problem. It turns out that [*pointing to the numbers that appear in the list of triples*] 1, 3, 7, and 9 each appear only twice, which means they can only appear in places that have two sums, namely side pockets. The even digits 2, 4, 6, and 8 each appear three times, which means that they can fit into places that have three sums.

That does it. There's actually no trial and error.

[*I then complete the argument, showing that if one sticks an even number in any of the corners, the rest is forced. If, for example, a 2 goes in the upper left, the 8 must be diagonally opposite. The 6 and 4 must take the other corners. (Which goes where is irrelevant, because of symmetry.)*

2		4
	5	
6		8

Once the even numbers are in place, the odd numbers are forced, producing this solution:]

2	9	4
7	5	3
6	1	8

So that argument says there's only one solution again.

70. AHS: Now we've beat it to death. Are we done? [*10 second wait.*] Of course not, because so far we've only solved the problem I gave you. If that's how mathematics progressed, mathematics wouldn't progress. Solving known problems is not what mathematicians get paid for nor is it anything they have any fun doing.

> *This, set piece, as planned (with the elaborations below), brings me to the conclusion of the discussion.*

So the question is, now that we know that this guy [*pointing to the 3 by 3*] can be solved, what are the things you can do to play with it? So, let me seed the discussion with a couple of suggestions and then leave things for you to think about. We'll get back to this next week...

What we found was a magic square using the digits 1 through 9. [*Writing on the board simultaneously:*]

How about a magic square with the numbers 24, 25, 26, . . . , 32?

How about . . . 12, 24, 36, . . . , 108?

How about . . . 12, 17, 22, . . . , 52?

I'll give you one that's a little more interesting. That is, we found out that the "magic number" of this [the original] square was 15. So if you use the digits 1–9 the magic number is 15. Can you find a magic square where the magic number is, say, 87?

71: Student: What kind of number can we use in the magic square if we want to make the magic number 87?

72: AHS: We can decide ourselves... What are the constraints? We get to decide the rules of the game, we get to decide ask the questions. So, we can ask, "Can you find a magic square using consecutive integers the sum being 87? Can we find one using an arithmetic sequence? If the answer to those turn out to be no, then can we find one using any integers at all that have the magic number 87?" [*We continue discussing possible extensions for another five minutes or so. In response to a question I tell the students that some classes in the past have explored magic squares at great length, while others have gotten bored with them; what we do will depend on what they find interesting.*]

Discussion

I want to emphasize two main points. The first is that classroom teaching, like jazz, is both planned and improvisational – and that it is deeply principled, in that teachers' decision-making can be seen as following in a very natural way from their knowledge, goals, and orientations. The second is that there is a lot more to "explanation" than content-related explanation. The substance that I am elaborating in this opening week of the problem-solving course includes (a) an introduction to productive mathematical habits of mind and (b) the first steps toward the creation of a mathematical community that will evolve throughout the semester and have very different norms and interactive patterns by the time the semester is over.

Can This Discussion Be Modeled, with the Teacher's Decision-Making Seen as a Function of Goals, Orientation, and Knowledge?

In order to keep the narrative straightforward and this paper down to manageable size, I have not provided a detailed model of my decision-making during the discussion of the magic square problem. In other, more detailed analytic papers (see, e.g., Schoenfeld, 1998, 1999, 2008) I have analyzed every decision made by the teacher, in the light of the teacher's in-the-moment goals, orientations, and available knowledge. The carefully documented argument in those papers is that each teacher's decision-making was consistent, on a turn-by-turn basis, with the goal-oriented decision-making procedure characterized in Fig. 7.1. In the italicized comments above I have tried to suggest that the same could be done here. It is a straightforward exercise to show that each of the pedagogical decisions made in the magic square discussion is consistent with my entering agenda and with the constraints and affordances resulting from the student comments.

I believe that the musical metaphor that opened this paper holds up well. In Leinhardt's (1993) terms, I had an agenda that guided my actions; in these metaphorical terms, I had a score that structured my activities but within which I could act flexibly in terms of responding opportunistically to circumstances. New circumstances were interpreted in the light of my beliefs and orientations; new goals emerged; and I reached into my pedagogical tool kit to address those new goals.

Everything I said and did during the discussion of the magic squares problem can be modeled, in fine-grained detail, using the approach outlined in Fig. 7.1.

On Explanations

The classic model of instructional explanation is given by Leinhardt (2001). Typically, one thinks of explanations as being *content-related*: for example, a teacher explains the origins of the quadratic formula and how to use it, or the historical and triggering conditions that led to World War I. In discussing her model, Leinhardt "considers a variety of elements that are common to explanations: a sense of query; the use and generation of examples; the role of intermediate explanations such as analogies and models; and the system of devices that limits or bounds explanations (identification of errors, principles, and conditions of use)" (p. 344).

In concluding I would like to plead the case that Leinhardt's frame can actually play a much broader, process-oriented role. During the first week of my course in general and in the magic square discussion, I was doing a fair amount of *culture-shaping* and *norm-building*; I was working on building *habits of mind* as well as helping to build conceptual understanding. Consider, for example, the question of mathematical disposition: A problem is not a task to be done (and considered completed when one has a solution) but a site for mathematical exploration. My ritual question "are we done?" has begun to have an effect, as evidenced in Turn 40; it will continue to shape the culture until it is no longer necessary. Later in the semester, the students will propose problem modifications, abstractions, and generalizations without my prodding them. Similarly, Jeff's question in Turn 7, "Want me to explain why I came up with 15?", reflects an early understanding that explanations as well as results are the coin of the realm in this course; this will become increasingly natural as the course goes on.

At a different level, much of the "content" of the course is *process*. The process-related lessons to be learned from the magic square problem have to do with establishing subgoals, exploiting symmetry, considering extreme cases, being systematic, and more. For each of these process-related goals I have a repertoire of examples and classroom routines that introduces the relevant issue, problematizes it, illustrates, elaborates and refines it, and explicates bounds, limits, and conditions of use. This is evident in the ways the discussions take place the first week. For example, the strategies of working forward and working backward are introduced in the discussion of problem 2 and revisited in the discussion of problem 3; the heuristic strategy "when there is an explicit integer parameter *n,* try values of $n =$ 1,2,3,4 and look for a pattern" used to solve problem 1 is explicitly extended in the discussion of problem 5 to cases where the integer parameter is given implicitly rather than implicitly. In short, it seems to me that Leinhardt's (1993, 2001) model of instructional explanation can be expanded to encompass a broad range of process goals including the establishment of classroom norms and attempts to foster the development of productive habits of mind.

Appendix: The First Day's Problem-Solving Handout

Some Problems for Fun (Believe It or Not)

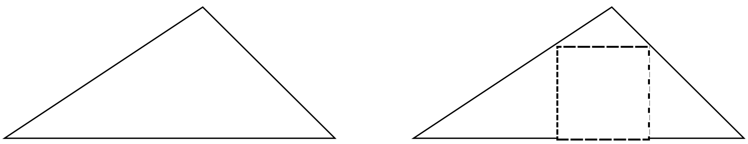
1. What is the sum of the numbers

$$\frac{1}{1 \times 2} + \frac{1}{2 \times 3} + \frac{1}{3 \times 4} + \frac{1}{4 \times 5} + \cdots + \frac{1}{(n) \times (n+1)}?$$

   For those of you who've seen this series, how about

$$\frac{1}{1!} + \frac{2}{3!} + \frac{3}{4!} + \frac{4}{5!} + \cdots + \frac{1}{(n+1)!}?$$

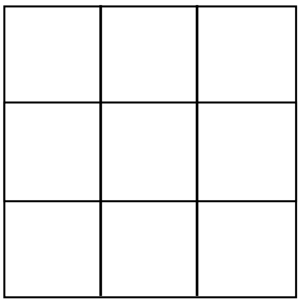
2. You are given the triangle on the left in the figure below. A friend of mine claims that she can inscribe a square in the triangle – that is, that she can find a construction, using straightedge and compass, that results in a square, all four of whose corners lie on the sides of the triangle. Is there such a construction – or might it be impossible? Do you know for certain there's an inscribed square? Do you know for certain there's a construction that will produce it?



The given triangle What you'd like to get

   Is there anything special about the triangle you were given? That is, suppose you did find a construction. Will it work for all triangles, or only some?

3. Can you place the numbers 1, 2, 3, 4, 5, 6, 7, 8, and 9 in the box below, so that when you are all done, the sum of each row, each column, and each diagonal is the same? This is called a magic square.



   If you think that the 3×3 magic square is too easy, here are two alternatives.

(1) Do the "4×4" instead of the "3×3".

(2) Try to find something interesting to ask about the 3×3.

(This alternative is better. There are lots of things you can ask.)

4. Take any three-digit number and write it down twice, to make a six-digit number. (For example, the three-digit number 789 gives us the six-digit number 789,789.) I'll bet you $1.00 that the six-digit number you've just written down can be divided by 7, without leaving a remainder.
   OK, so I was lucky. Here's a chance to make your money back, and then some. Take the quotient that resulted from the division you just performed. I'll bet you $5.00 that quotient can be divided by 11, without leaving a remainder.
   OK, OK, so I was very lucky. Now you can clean up. I'll bet you $25.00 that the quotient of the division by 11 can be divided by 13, without leaving a remainder? Well, you can't win 'em all. But, you don't have to pay me if you can explain why this works.
5. What is the sum of the first 137 odd numbers?
6. For what values of "a" does the pair of equations

$$\begin{bmatrix} x^2 - y^2 = 0 \\ (x-a)^2 + y^2 = 1 \end{bmatrix}$$

   have either 0,1,2,3,4,5,6,7, or 8 solutions?
7. Here's a magic trick. Take any odd number, square it, and subtract 1. Take a few others and do the same thing. Notice anything? Does it always happen? Must it? Can you say why?
8. Since $3^2 + 4^2 = 5^2$, we know that there are three consecutive positive whole numbers with the property that the sum of the squares of the first two equals the square of the third. Can you find three consecutive positive whole numbers with the property that the sum of the *cubes* of the first two equals the *cube* of the third?
9. The figure below was found in an old cemetery in the Midwest. Can you decipher the message?

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Chapter 8
The Explanatory Power of Examples in Mathematics: Challenges for Teaching

Orit Zaslavsky

> *The generation or selection of* examples *is a fundamental part of constructing a good explanation... For learning to occur, several examples are needed, not just one; the examples need to encapsulate a range of critical features; and examples need to be unpacked, with the features that make them an example clearly identified.*
>
> *(Leinhardt, 2001, p. 347)*

Instructional Examples in Mathematics Learning and Teaching

Instructional examples are fundamental elements of an explanation, as described by Leinhardt, Zaslavsky, and Stein (1990):

> Explanations consist of the orchestrations of demonstrations, analogical representations, and examples. [...]. A primary feature of explanations is the use of well-constructed examples, examples that make the point but limit the generalization, examples that are balanced by non- or counter-cases (ibid., p. 6).

I use the term "instructional example," to refer to an example offered by a teacher within the context of learning a particular topic. The important role of instructional examples in learning mathematics stems firstly from the central role that examples play in mathematics and mathematical thinking. Examples are an integral part of mathematics and a significant element of expert knowledge (Rissland, 1978). In particular, examples are essential for generalization, abstraction, and analogical reasoning. Furthermore, from a teaching perspective, there are several pedagogical aspects of the use of instructional examples that highlight the significance and convey the complexity of this central element of teaching.

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According to Watson and Mason (2002) an example is any particular case of a larger class (idea, concept, technique, etc.), from which students can reason and generalize. By and large, an example must be examined in context. Any example carries some critical attributes that are intended to be exemplified and others that are irrelevant. The irrelevant features are what Skemp (1971) considers the *noise* of an example. A teacher must be aware that students may not see through an example what it stands for, or what general case it represents, and may be attracted to its "noise." As Rissland (1991) maintains "one can view an example as a set of facts or features viewed through a certain lens (ibid, p. 190)."

Bills, Dreyfus, Mason, Tsamir, Watson and Zaslavsky (2006) suggests two main attributes to make an example pedagogically useful. Accordingly, an example should be "transparent" to the learner, that is, make it relatively easy to direct the attention of the target audience to the features that make it exemplary. This notion of transparency is consistent with Mason & Pimm's (1984) notion of generic examples that are transparent to the general case, allowing one to see the general through the particular, and with Peled and Zaslavsky (1997) who discuss the explanatory nature of examples.

A "good" instructional example should also foster generalization, that is, it should highlight the necessary features of an example of the illustrated case and at the same time point to the arbitrary and changeable features. Examples with some or all of these qualities have the potential to serve as a reference or model example (Rissland, 1978), with which one can reason in other related situations, and can be helpful in clarifying and resolving mathematical subtleties.

Clearly, the extent to which an example is transparent or useful, the way it is interpreted, and the features that one notices are subjective and context related. For instance, in order to exemplify "a function that has a value of -2 when $x=3$" one can bring a trivial example such as $f(x)=-2$ (Hazzan & Zazkis, 1999). Although this example satisfies the required condition, it may be regarded too simple or too narrow, in the sense that it does not convey the wide range of examples of such a function, including its mathematical complexity. Thus, while many objects may be used as an example, it is clear that from a pedagogical perspective some have more explanatory power than others (Peled & Zaslavsky, 1997), either because they highlight the special characteristic of the object or because they show how to build many other examples of the focal idea, concept, principle, or procedure.

Peled and Zaslavsky (1997) differentiate three types of examples used by mathematics teachers, according to their explanatory power: *specific*, *semi-general*, and *general* examples. They maintain that general examples offer explanation and provide insight about a certain phenomenon as well as ideas about how to generate more examples of this phenomenon. For example, a general example of a pair of distinct rectangles with the same diagonal could be the one shown in Fig. 8.1, while in contrast, Fig. 8.2 provides a sketch of a specific example.

One can easily notice the difference between these two types, in terms of their generality and explanatory power. The first has a stronger explanatory power. As

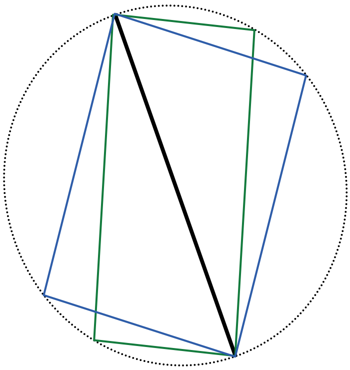
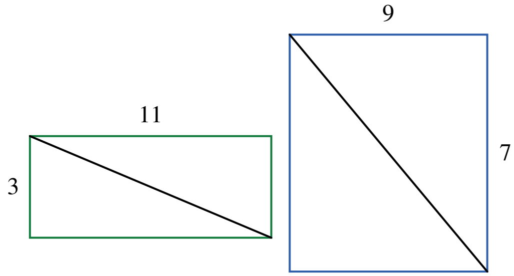


Fig. 8.1 A “general” example of a pair of distinct rectangles with the same diagonal

Fig. 8.2 A “specific” example of a pair of distinct rectangles with the same diagonal



shown later, there are instructional situations in which a specific example is more appropriate than a general one. Interestingly, constructing a specific instructional example may be more complicated and demanding than constructing a more general example (see Case 5 below).

Another important aspect of the use of examples is the representation of the example. To illustrate this issue, consider the following examples of a *quadratic function*:

$$\text{(i)}\, y = (x + 1)\,(x - 3)\,;\text{(ii)}\, y = (x - 1)^2 - 4;\text{(iii)}\, y = x^2 - 2x - 3.$$

These are three different representations of the same function. Each example is transparent to some features of the function and opaque with respect to others. For example, the first example conveys the roots of the function (-1 and 3); the second communicates straightforwardly the vertex of the parabola (1, -4); and the third example transmits the y-intercept (0, -3). However, these links are not likely to be obvious to the student without some guidance of the teacher. Moreover, it is not clear that students will consider all three examples as examples of a quadratic function; for instance, in example (i) it is less obvious that there is an exponent of a power of two; thus, it may not be seen as a quadratic function. A teacher may choose to deal with only one of the above representations or s/he may use the three different representations in order to exemplify how algebraic manipulations lead from one to another, or in order to deal with the notion of equivalent expressions. What a student will see in each example separately and in the three as a whole depends on the context and classroom activities surrounding these examples. A student who appreciates the special information entailed in each representation may use these examples as reference examples in similar situations, e.g., for investigating other quadratic functions.

In terms of irrelevant features, although commonly used, in the above examples of quadratic functions, it is irrelevant what symbols we use, i.e., we could change x to t and y to $f(t)$. Yet, a student may regard x and y as mandatory symbols for representing a quadratic function. Another irrelevant feature is the fact that in all three representations all the numbers are integers. A student may consider this a relevant feature, unless s/he is exposed to a richer "example space" (Zaslavsky & Peled, 1996; Watson & Mason, 2002). Mason and Pimm (1984) warn about a mismatch that often occurs between the teacher's intention and students' interpretations. Thus, an example that is meant to demonstrate a general case or principle may be perceived by the learners as a specific instance, ignoring its generality.

In addition, one may generalize and think that for any quadratic function all three representations exist, while the first one depends on whether the specific quadratic function has real roots. Hence, the specific elements and representation of an example or set of examples, and the respective focus of attention facilitated by the teacher, have bearing on what students notice, and consequently, on their mathematical understanding. Thus, the role of the teacher is to offer learning opportunities that involve a large enough variety of "useful examples" to address the diverse needs and characteristics of the learners.

It follows that the use of examples is a significant and complex terrain. Apparently, teachers are not used to articulate their considerations, not to mention sharing and debating surrounding the issue of exemplification.

In spite of the critical roles examples play in learning and teaching mathematics, there is only a small number of studies focusing on teachers' choice and treatment of examples. Rowland, Thwaites, and Huckstep (2003) identify three types of elementary teachers' poor choice of examples: choices of instances that obscure the role of variables, choices of numbers that are used to illustrate a certain arithmetic procedure when another procedure would be more sensible to perform for the selected numbers, and randomly generated examples when careful choices should be made.

Rowland et al.'s (2003) findings concur with the concerns raised by Ball, Bass, Sleep, and Thames (2005) regarding the knowledge base teachers need in order to carefully select appropriate examples that are useful for highlighting salient mathematical issues. Not surprisingly, the choice of examples in secondary mathematics is far more complex and involves a wider range of considerations (Zaslavsky and Lavie, 2005; Zodik and Zaslavsky, 2007, 2008).

In this chapter, I offer ways of examining instructional examples in mathematics from two perspectives: (1) their explanatory power and (2) the demands they present on teachers. I am aware that the explanatory power of an example is "in the eyes of the beholder," and as discussed above, one cannot automatically assume that the teacher's intention in offering a particular example will be perceived as expected. This applies for any example. However, I maintain that there is great value in analyzing examples in terms of their *potential* explanatory power.

As to the demand on teachers, as illustrated below, generating an appropriate example for a given purpose is often an art, or a problem-solving process. I use a number of cases to unpack and highlight these two aspects of instructional examples in mathematics, namely, their explanatory power and the challenge of coming up with appropriate ones. The cases I discuss address main themes in teaching mathematics, all related to explanations: (1) conveying generality and invariance; (2) explaining and justifying notations and conventions; (3) resolving uncertainty (or establishing the status of (pupils') conjectures or assertions); and (4) connecting mathematical concepts to real-life experiences. In addition, I examine the challenges of example generation, with a focus on unexpected difficulties in generating an instructional example with certain constraints. The issue of the "correctness" of an example is also discussed.

All the cases presented in this chapter evolved from actual observations of classroom situations or carefully designed workshops with experienced and highly reputable secondary mathematics teachers or with prominent mathematics educators (i.e., researchers in mathematics education who teach in teacher education programs). The workshops drew on real classroom events (some described in the literature and some from my own work on examples, as well as the work of Zodik and Zaslavsky, 2008). The work with teachers involved ongoing reflective accounts that often included an iterative process of designing – analyzing – re-designing experiences that engaged participants in dealing with instructional examples in mathematics and probing for their thinking and guiding principles (similar to the processes described in Zaslavsky, 2008). My overarching claim is that there is much more to examples than meets the eye. It is a complex and fascinating domain to explore. I see a great challenge providing teachers with experiences that prepare them for such demands.

As mentioned above, the chapter is organized around illustrative cases that to some extent share the features of the cases in Stein, Smith, Henningsen, and Silver (2000). These cases serve as "meta-examples"; they may not all be *generic* meta-examples, but they are at least *existential* examples. They reflect genuine practice, thinking, and concerns surrounding instructional examples. My intention is that the reader will be able to see through and beyond them to more general issues, ignoring the "noise" attached to them. To assist in capturing the issues these cases are meant to convey, I offer my own lens by addressing, for each case, the question: "what is this case an example of?".

Cases Illustrating the Challenges Entailed in Teacher's Choice and Use of Instructional Examples in Mathematics

Conveying Generality and Invariance with Examples (Case 1)

Zaslavsky, Harel, & Manaster (2006) describe an eighth-grade teacher, who chose a set of examples that build on students' knowledge of how to calculate the area of a rectangle and lead them to a way of calculating the area of a triangle.

According to their report (ibid), the teacher began the lesson by putting on the board three examples (Fig. 8.3), in order to move from a rectangle and its area calculation – already familiar to her students – to a right-angled triangle that is clearly half of the rectangle, to a seemingly more general triangle. She chose to keep the given measurements constant. This allowed a better focus on the varying elements, e.g., the type of figure, the connection between a side and its corresponding height.

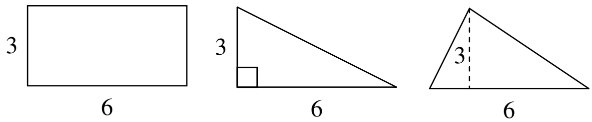


Fig. 8.3 A teacher's initial set of examples

Then, with the "help" of some students who she invited to the board, she moved from one case to the next, adding auxiliary segments (the dashed segments in Fig. 8.4) and building on the previous one.

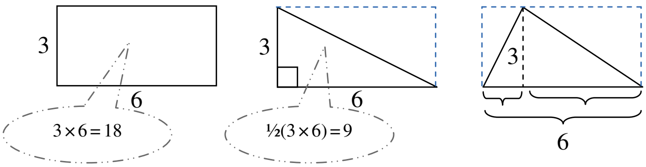


Fig. 8.4 Building gradually from one example to its subsequent

In the third case – the more general triangle – it is not obvious how to calculate its area and how to build on the previous example. The teacher pointed to the two right-angled triangles into which the height divides the triangle, and helped the students notice that embedded in the drawing are two cases that are just like the previous case. She repeated the method of "completing" a right-angled triangle up to a rectangle that is twice the area of the triangle. In order to continue in this direction and calculate the area of each sub-rectangle, as done in the middle example, it is necessary to know the lengths of the sides of each one. Thus, it appears that in the third example (see Fig. 8.4) the lengths of the sides of each sub-rectangle are missing.

The teacher turned to the students and asked them for suggestions how to “split the 6 up”. They were expected to choose two measurements that added up to 6 in order to fill what seemed missing in the example. They chose to “split” it into “2 and 4”, and once these measurements were determined, the calculation became straightforward.

Figure 8.5 depicts the stages the class went through to calculate the area of the triangle. It clearly depended on the choice of 2 and 4.

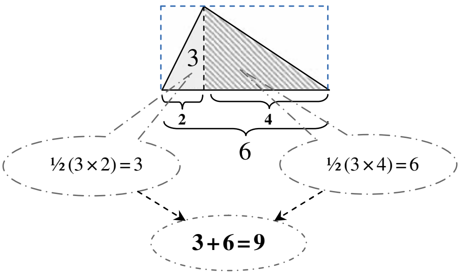


Fig. 8.5 Deciding at random how to “split” the side of length 6

What Is Case 1 an Example of?

Case 1 is an example of a sequence of examples for which one provides an explanatory basis for the next. It leads from a specific case of a right-angled triangle to a more general case of a triangle that is not necessarily a right-angled triangle.

It is also an example of an attempt to convey generality by a random choice of the specifics of an example. The choice of 2 and 4 as the measurements of the two parts of the side of the triangle was actually arbitrary. The students obviously relied on the drawing and estimated that the left part is shorter than half the side of length 6 and the right part is longer than its half. Tending toward whole numbers, they naturally picked 2 and 4. Therefore, in this sense, the choice was not done totally at random. However, this approach could have been reinforced to reach a more sound generalization and a better sense of one of the “big ideas” in mathematics – invariance.

Constructing a set of examples by controlling variation and keeping a core of elements constant may be helpful in moving from one case to another and allowing focus on those that change. Along this line, a more powerful set of examples would be one that better deals with the general case of a triangle (even if still restricted to acute-angled triangles, it could set the grounds for dealing in a similar way with a set of obtuse-angled triangles, where instead of adding two area measurement you need to subtract one from the other).

This would be equivalent to asking the students to suggest alternative ways to split the (6-unit length) side of the triangle. By actually repeating the same reasoning and calculation procedure as in Fig. 8.5 for each case in Fig. 8.6 (as suggested by Harel, 2008) the generality would probably be made more *transparent*, and the sense that the area of the triangle is invariant under change of location of its vertex along a

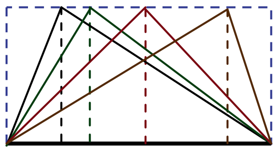


Fig. 8.6 A range of instances that captures the invariance of area of a triangle

line parallel to its side could be developed. It would also allow connection between the distributive law and this invariance.

To convey more of the complex web of considerations that a teacher needs to make in choosing or generating explanatory instructional examples, note that although a random choice of specifics of an example could be powerful in many cases, randomness has its limitations. In Case 1, the choice of lengths of 3 and 6 is not as "generic" as, for instance, 8 and 5. In the procedure that is illustrated in Fig. 8.5, a student is more likely to attend to irrelevant features of the specifics (as in Mason and Pimm, 1984); this case may lead some students to over-generalize the mere coincidence that the area of one triangle is 3 as is the length of the height, and the area of the second triangle if 6 as is the length of the side. When a large variety of such examples are encountered, this kind of over-generalization is less likely to occur.

This case can be regarded to a certain extent as a worked example, which Leinhardt (2001) considers key features in virtually any instructional explanation.

Another word of caution with respect to random choice of instructional examples stems from the studies of Zodik and Zaslavsky (2007) and Rowland et al. (2003). In their work, they identify several cases where a random choice impedes the purpose of the example and limits its explanatory power. There are many cases in which a careful choice of examples is needed. Case 2 that follows indicates how subtle the choice may become.

Explaining and Justifying Notations and Conventions (Case 2)

In school mathematics, we introduce students to several mathematical conventions and notations. Many seem quite arbitrary and convey a rigid conception of the discipline of mathematics. In many cases, there is a reason for such conventions that is not always obvious to the students. The "big idea" of an agreed upon notation is a communicative one: we want to avoid ambiguity and make sure that when using a certain notation it is well defined and it clearly indicates to what it refers. Thus, it is important to find examples for which this really matters.

For example, the common notation of a polygon requires listing its vertexes consistently either clockwise or counterclockwise. This requirement offers a degree of freedom, yet has its restrictions. Why do we insist on this? Why not name it by listing its vertexes in any order that suits us? A group of mathematics educators examined this question for quadrangles. Very soon they realized that a random

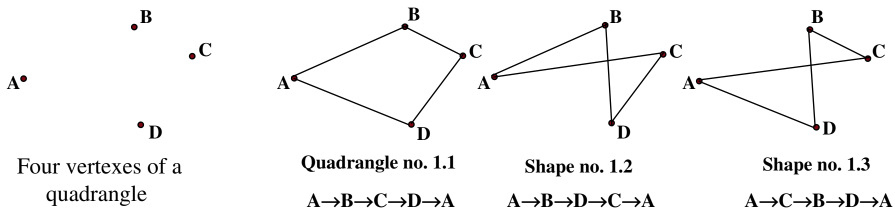


Fig. 8.7 A specific choice of 4 points that determine a unique quadrangle

choice of four vertexes will not be equally helpful in explaining this convention. They wanted to find an example for which unless we follow this convention it will not be clear to which quadrangle we refer.

Figure 8.7 is an example of a set of four specific points, **A**, **B**, **C**, and **D**, that determine one and only one quadrangle with these vertexes (Quadrangle 1.1). Note that the order in which the vertexes are listed determines how they are connected.

In this case it really does not matter how we "name" it. There are eight acceptable ways to name a quadrangle with these vertexes: clockwise – ABCD, BCDA, CDAB, and DABC; or counterclockwise – ADCB, DCBA, CBAD, and BADC; however, for this particular example, violating the clockwise–counterclockwise convention does not create ambiguity regarding the designated quadrangle. For instance, ABDC violates the convention but its corresponding shape (no. 1.2 in Figure 8.7) violates the definition of a quadrangle. Thus, ABDC does not designate a quadrangle, so no ambiguity is caused.

ABDC corresponds to Shape 1.2, while ACBD corresponds to Shape 1.3. Both do not satisfy the definition of a quadrangle, thus raising the question: so why fuss? If we restrict ourselves to notations of quadrangles, non-quadrangles do not count, and so Quadrangle 1.1 could be denoted by its four vertexes regardless of the order in which they are listed.

After much contemplation the group came up with another set of four points as in Fig. 8.8, which determines three different quadrangles; thus, they considered it a rather good explanatory example, since here the "name" must uniquely correspond

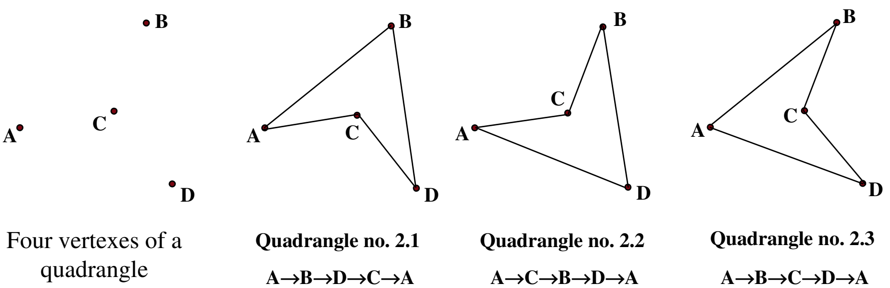


Fig. 8.8 A specific choice of 4 points that determine three different quadrangles that seem congruent

to one of the three quadrangles. Thus, thanks to the agreed-upon convention, ABCD refers only to Quadrangle no. 2.3, ABDC refers to Quadrangle 2.1 and ACBD to Quadrangle 2.2.

When presenting this example at an in-service workshop with secondary mathematics teachers, most of the teachers were overwhelmed – they had never managed to convince their students of the necessity of this convention – and instantly felt they now had a tool with which to explain and convince (themselves as well as their students). However, one teacher claimed that this was not a convincing example. She argued that this particular choice of points is symmetrical; therefore, all three quadrangles are congruent, so in a sense there is just one quadrangle. Thus, for her the example in Fig. 8.8 was not the most effective in convincing why the convention is necessary.

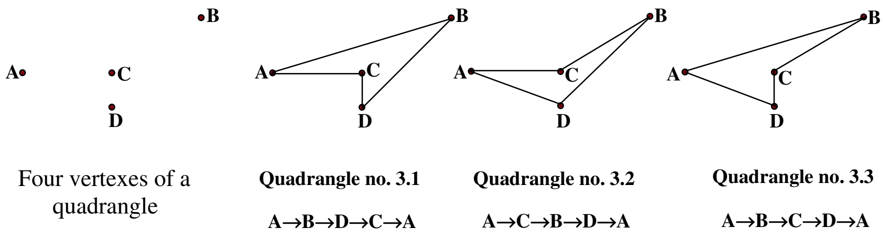


Fig. 8.9 A specific choice of 4 points that determine three distinct quadrangles

This argument led to a generation of an example that was agreed to be of a stronger explanatory power (Fig. 8.9): it is a case of four points that determine three different non-congruent quadrangles. Thus, unless we strictly follow the convention, it will not be possible to avoid ambiguity with respect to the specific quadrangle in question. For instance, without the convention, how would we know which Quadrangle we mean by ABCD?

Thanks to the well-defined convention, Quadrangle 3.1 is ABDC, Quadrangle 3.2 is ACBD, and Quadrangle 3.3 is ABCD. There is still a degree of freedom for each notation, and an alternative notation can be used provided the order is maintained (e.g., Quadrangle 3.1 may also be denoted as BCDA or CDBA, but not as ADCB).

What Is Case 2 an Example of?

Case 2 is an example of the potential power of examples to justify mathematical conventions. Its explanatory power rests on its potential in convincing that without the convention ambiguity may arise and impede (mathematical) communication.

It also illustrates the subtleties and iterative nature of a judicious choice of an instructional example that is neither commonly found in textbooks nor addressed in teacher education settings. This process involves problematizing the situation, setting an explicit goal that addresses this problem, and checking each example in light of this goal. The goal reflects a sound understanding of big ideas in mathematics. Achieving it involves thinking "out of the box" – in this case, moving from rather common convex quadrangles to concave.

Case 2 is also a manifestation of a necessity-based approach to learning mathematics (Harel, 2008). Even if this particular convention is not a central one (compared, for instance, to the order of executing arithmetic operations), it conveys a desired "explanation-based" mindset that drives a teacher to constantly deal with the natural question of "why?". As reflected in Case 2, such explanations often rely on convincing examples.

Establishing the Status of Pupils' Conjectures and Assertions (Case 3)

Bishop (1976) begins his paper with a classroom event, which he experienced as a teacher and invites the reader to think of how s/he would deal with it. It goes as follows:

Teacher:	Give me a fraction which lies between $\frac{1}{2}$ and $\frac{3}{4}$
Pupil;	$\frac{2}{3}$
Teacher:	How do you know that $\frac{2}{3}$ lies between $\frac{1}{2}$ and $\frac{3}{4}$?
Pupil:	Because the 2 is between the 1 and the 3, and the 3 is between the 2 and the 4

How would you deal with that response?

Bishop, 1976, p. 41

A group of secondary experienced and highly reputable mathematics teachers discussed this case. None of them had the prior knowledge regarding the validity of the pupil's claim, although their initial gut feeling was that it could not be true for all cases; thus it is not a valid argument.

They began by examining several examples. Note that generating an example in this context requires a choice of a pair of fractions, and a choice of another fraction for which two properties are checked: Does it lie between the two fractions? Is its nominator between the nominators of the two fractions? Is its denominator between the denominators of the two fractions?

All in all, the teachers examined 12 examples until they reached a warranted consensus:

(1) 3/4 as a fraction that lies between 2/3 and 4/5, and indeed the 3 is between the 2 and the 4, and the 4 is between the 3 and the 5; thus this is a *supporting* example (i.e., an example that satisfies the pupil's claim).
(2) 2/3 as a fraction that lies between 1/2 and 4/5, and indeed the 2 is between the 1 and the 4, and the 3 is between the 2 and the 5; thus, this is another supporting example.
(3) 3/4 as a fraction that lies between 1/2 and 4/5, and indeed the 3 is between the 1 and the 4, and the 4 is between the 2 and the 5; strangely – another supporting example.

These examples reinforced a sense that the pupil may be right. One of the teachers expressed this feeling in the following words: "If you can't find a counter-example easily the claim is probably right." However, they continued checking and looking for additional supporting or refuting examples. The next three were as follows:

(4) 2/4 is a fraction that does not lie between 1/2 and 4/5, although the 2 is between the 1 and the 4 and the 4 is between the 2 and the 5. This example seemed to contradict the pupil's claim; however, it was treated as a (degenerate) special case; since 2/4 = 1/2, it did not seem to violate the general assertion.
(5) 3/3 is a fraction that does not lie between1/2 and 4/5, although the 3 is between the 1 and the 4, and the 3 is between the 2 and the 5. However, for similar reasons this was treated as another special case; since 3/3 = 1, it did not seem to violate the general assertion.
(6) 3/4 is a fraction that does not lie between 1/3 and 5/10, although the 3 is between the 1 and the 5, and the 4 is between the 3 and the 10. However, this again appeared as a special case; since 5/10 = 1/2, it did not seem to violate the general assertion.

They now decided to approach the problem more systematically. They articulated the implied pupil's claim to say: "Given two fractions, a/b and c/d, the fraction k/n lies between them if the k is between the a and the c, and the n is between the b and the d." Thus, the teachers chose two fractions – one for a/b and the other for c/d, kept them fixed, and began checking and listing some examples of fractions that work and some that do not, as in Fig. 8.10.

At this point, the entire group was convinced that the pupil's assertion did not hold for all fractions. They were so preoccupied with figuring out for themselves the status of this assertion that they did not attend to the original question that was posed to them, namely, "How would you deal with that response?" Bishop (1976) describes his way of dealing with this response as "buying time," until he managed to think on his feet and come up with a counter-example.

What Is Case 3 an Example of?

Case 3 is an example of a classroom situation that calls for in-the-moment decision. It is a case where the teacher is uncertain regarding the validity of a student's

The fixed fractions were chosen: $\frac{1}{2}$ and $\frac{5}{7}$	
Examples that support the pupil's claim	Examples that violate the pupil's claim
$\boxed{\frac{2}{3}}$, because $\frac{1}{2}<\frac{2}{3}<\frac{5}{7}$	$\boxed{\frac{2}{5}}$, because it does not lie between $\frac{1}{2}$ and $\frac{5}{7}$
$\boxed{\frac{3}{5}}$, because $\frac{1}{2}<\frac{3}{5}<\frac{5}{7}$	$\boxed{\frac{3}{4}}$, because it does not lie between $\frac{1}{2}$ and $\frac{5}{7}$
$\boxed{\frac{4}{6}}$, because $\frac{1}{2}<\frac{4}{6}<\frac{5}{7}$	$\boxed{\frac{4}{5}}$, because it does not lie between $\frac{1}{2}$ and $\frac{5}{7}$

Fig. 8.10 A systematic sequence of examples for a fixed pair of fractions

assertion, thus raising a genuine need to generate various examples in search for evidence and conviction. It shows how the process of moving from a sense that the conjecture is true to a conviction that it is false depends on the specific examples under investigation. This case is also a not so common case – for which there are many supporting examples as well as many counter-examples. In a way, this case reflects a typical intellectual need for example-based reasoning (Rissland, 1991). It is also an example of a sort of Lakatos (1976) style dialog involving “monster barring”; some of the examples that violated the pupil’s assertion were treated as extreme or special cases that do not count. It follows that Case 3 is also an example of how the process of example generation may serve to resolve teachers’ uncertainty with respect to whether a conjecture is true or not. A similar situation could be rather easily orchestrated in a real classroom.

Case 3 highlights the challenge and demands that teachers face with respect to choice of and inference from examples as well as the significance of teachers’ subject matter knowledge in being able to act in the moment and come up with appropriate examples (Mason & Spence, 1999). Actually, as explained below, the pupil’s assertion would be valid if he meant the nominator lies *exactly in the middle* between the two nominators, and the denominator lies *exactly in the middle* between the two denominators. This knowledge and understanding on the part of the teacher would change dramatically his or her ability to choose appropriate examples. Moreover, as illustrated below, the analysis of case 3 suggests a significant interplay between examples and (visual) representations, and the explanatory power of a visual representation of a particular example.

Bishop’s pupil’s assertion relates to the mediant property of fractions: The mediant of two fractions a/b and c/d (for which a, b, c, d are positive integers) is $(a+c)/(b+d)$. That is to say, the numerator and denominator of the mediant are

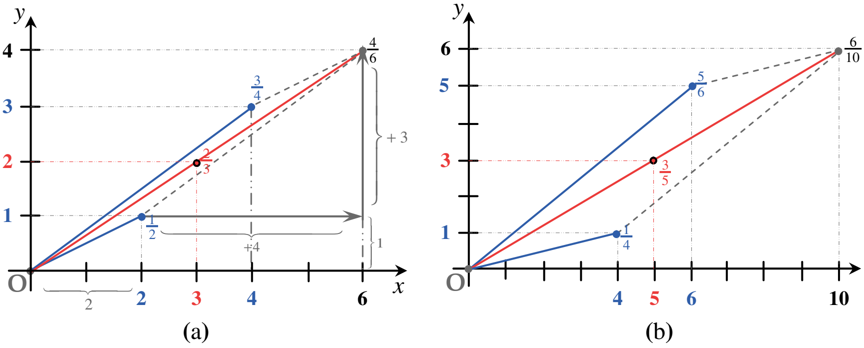


Fig. 8.11 Visual representations of the pupil's response that convey an explanatory feature to the generalizable elements of his method

the sums of the numerators and denominators of the given fractions, respectively. Interestingly, as illustrated in Fig. 8.11, if $a/b<c/d$ then $a/b<(a+c)/(\mathrm{b}+d)<c/d$. This is a valid way to construct a fraction that lies between two given fractions – a task that the teacher posed to the pupils without realizing this connection. In fact, the pupil's assertion is valid if you restrict it to the (arithmetic) mean, and can be formulated as follows: if $a/b<c/d$ then $\frac{a}{b} < \frac{\frac{a+c}{2}}{\frac{b+d}{2}} < \frac{c}{d}$. Knowledge of this property of fractions would help dealing with the classroom event and coming up with examples that shed light on the affordances and limitations of the pupil's generalization.

One of the main properties of a mean (of any kind) is that it is an intermediate value. So this provides an explanation why the pupil's strategy worked. He took a special intermediate value: the (arithmetic) mean.

As Arcavi (2003) suggests, we can represent the fraction 1/2 by the point (2,1) in a Cartesian coordinate system. Thus, the fraction 1/2 is the slope of the line that connects the origin O with the point (2,1). Similarly, the fraction 3/4 is the slope of the line that connects the origin O with the point (4,3). Actually, in this representation all equivalent fractions lie on the same line and correspond to the same slope. For example, 1/2 and 2/4 are on the same line. If you continue the line with slope 1/2 you will see that it passes through the point (4,2). The slope corresponds to the angle between the line and the x-axis; the larger the fraction, the larger the angle and the line's slope.

This representation has an explanatory power for why the pupil's suggestion works if you construct a new fraction from the two given ones by taking the means of the nominators and denominators, respectively; indeed, $\frac{2}{3} = \frac{\frac{1+3}{2}}{\frac{2+4}{2}}$ lies between 1/2 and 3/4. This method will always work. The line of slope 2/3 is the diagonal of the parallelogram, the vertexes of which are the origin O, (2,1), (4,3), (6,4). (Note that (6,4) is (2+4,1+3); this relationship guarantees that it is the 4th vertex of the parallelogram determined by the origin and the two given fractions).

Connecting Mathematical Concepts to Real-Life Experiences (Case 4)

This case is a fair description of an actual classroom event that was a trigger for a workshop with a group of prominent secondary mathematics teachers. It is based on the work of Zaslavsky and Lavie (2005).

An eighth-grade teacher whom we observed in a lesson that aimed at introducing the notion of the *slope* of a (linear) function in its qualitative sense rather than as a specific measure decided to draw on students' real-world experiences. For this, she chose the mountain metaphor, and sketched the following example of two mountains M_1 and M_2 (Fig. 8.12):

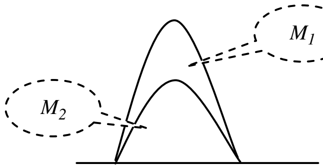
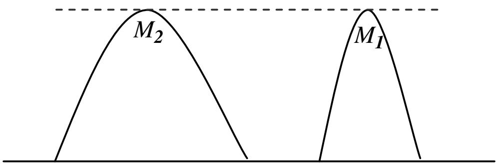


Fig. 8.12 The initial example for introducing the notion of slop – two mountains with different heights

Her intention was to draw students' attention to the differences between the two mountains, by focusing on their relative difference in terms of their "steepness." In fact, all the students agreed that mountain M_1 was "steeper" than M_2. However, one of them gave his reason for this assertion, by explaining that M_1 is *higher* than M_2 (this was a manifestation of a well-known (mis)-conception of students, confusing height for slope (Leinhardt et al., 1990), of which apparently the teacher was not aware. However, as a response to the student's claim, she immediately "corrected" the example and drew a different one (Fig. 8.13), highlighting that they now have the same height, yet M_1 is steeper than M_2.

Fig. 8.13 A modified example for introducing the notion of slop – two mountains with the same heights



She went further and drew two "steps", for which the horizontal sides were equal in length, in order to give the students a measurable way to look at and compare the relative degrees of "steepness," as illustrated in Fig. 8.14.

She then went back to deal with linear functions and their graphical representations and used a similar drawing to highlight the visual aspects of slope (Fig. 8.15), that is, the ratio between the "rise" and the "run." Without defining slope, they were able to discuss the relative "steepness" of the two graphs, by comparing the "rise" for a fixed "run."

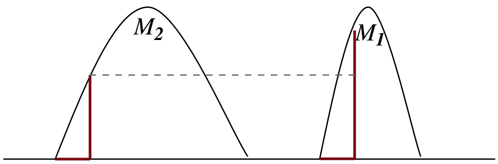


Fig. 8.14 Adding "steps" for comparing the relative steepness of the two mountains

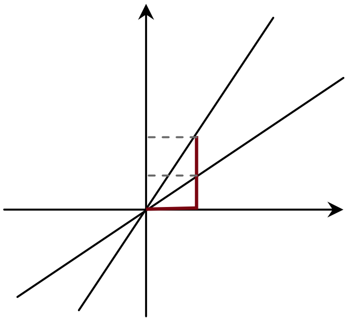


Fig. 8.15 Connecting the measure of relative steepness of the mountains to linear functions – keeping the "run" fixed and examining the "rise"

What Is Case 4 an Example of?

This case illustrates that "exampleness" is in the eyes of the beholder. It begins with a manifestation of the gap that may occur between a teacher's intentions and what students actually notice. Teachers are not always aware of such discrepancies, mainly because the focal location of attention is not always explicitly expressed. In this case, the student's explanation revealed what he was attending to and the interpretation he attributed to it.

Case 4 also demonstrates a learning opportunity for the teacher. The student's reaction drew her attention to the limitation of her original example (Fig. 8.10) and led her to improve it (Fig. 8.13). Moreover, the state of awareness led the teacher to further considerations that are reflected in the additional visual aid that she added (Fig. 8.14), in anticipation that this would help her students focus on the relevant features of the example, which reflect the main idea that she was trying to highlight through it. In an interview that followed, it appeared that this classroom event would affect the teacher's future choice of examples. Thus, this episode can also be seen as a glimpse into the way knowledge of and about instructional examples in mathematics is crafted in the course of teacher practice (Leinhardt, 1990; Kennedy, 2002).

This classroom event is also an example of a case that elicited a rich discussion among teachers who considered the merits and limitations of such "real life" example for their own classrooms. The discussion focused on the idea of using mountains as examples to set the grounds for learning about the slope of a linear function.

Although there was a consensus, that learning mathematics should relate to students' informal knowledge and out-of-school experiences, some teachers objected to the use of mountains in this context. They argued that the graph representing the mountain (which resembles a parabola) does not have a constant slope, so comparing the degree of steepness of the two mountains is not straightforward. These teachers felt it would be misleading to connect the notion of slope of a linear function that is constant for any point on its graph to the steepness of a mountain. They suggested replacing the metaphor of mountains by cable cars or pyramids. In short, constructing instructional examples that connect to familiar context and map well to the mathematical concepts they are supposed to illustrate relies on a web of complex and often competing considerations.

The Challenge of Constructing Examples with Given Constraints (Case 5)

In their study on counter-examples, Peled and Zaslavsky (1997) analyzed examples that mathematics teachers gave of two non-congruent rectangles that have diagonals of equal length. Looking back at the data from that study, it is striking that the specific examples that were proposed were not the kind one would expect as an example of a rectangle. While it is likely that a specific example of a rectangle would have its two sides' measurements, e.g., in Fig. 8.16, what teachers proposed were examples of pairs of rectangles with measurements of one side and a diagonal, as in Fig. 8.17.

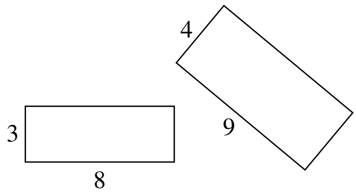


Fig. 8.16 Typical specific examples of rectangles

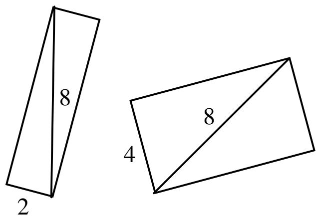


Fig. 8.17 An example of two non-congruent rectangles with diagonals of equal length

This can partially be attributed to the request to focus on the equal-length diagonals. However, there is more to it. In order to better understand this phenomenon, the following task was given to a group of highly prominent mathematics educators:

Suppose you wanted to design a hands-on activity for your students, to help them realize that two non-congruent rectangles could have equal-length diagonals, by constructing two different rectangles, on a grid paper (15×20), and measuring or comparing their diagonals.

What example would you use for this purpose?

Note: To accurately construct a rectangle on such a grid paper, it would be helpful to offer the students the measures of the "length" and "width" in integers, between 1 and 15 or 20.

This task proved rather demanding. Aparently, finding two specific rectangles with integer measurement and equal-length diagonals is a non-trivial task even for expert mathematics educators, and perhaps more so for mathematics teachers. It is based on the Pythagoras theorem: The relation between the lengths of the sides of a rectangle – a and b, and its diagonal – c, satisfies the following equality: $a^2+b^2=c^2$. In other words, the solution to the task is four integers, a, b, m, n, between 1 and 20, that satisfy the following equality: $a^2+b^2 = m^2+n^2$. Here are a few of the responses we received:

One approach was by systematic trial and error: "If we determine one rectangle, for example, with sides of lengths 1 and 8, thus the diagonal is the square root of the sum 1^2+8^2 which equals 65; now we need to find another pair of integers for which the sum of their squares also equals 65. We begin by subtracting integer squares from 65: 65–4, 65–9, 65–16, and so on, until we reach a integer square. This occurs at 65–16=49, so since 49 is an integer square, a second rectangle can be obtained, of lengths 4 and 7. Indeed, $\sqrt{1^2+8^2} = \sqrt{4^2+7^2}$, so the students could be asked to construct, on their grid paper, two distinct rectangles, one of measures 1×8 and the other of measures 4×7. By comparing the lengths of their diagonals, they can see that they are of equal length."

Another systematic search for such pairs of integers was suggested, as illustrated in Table 8.1.

This method provides several specific examples of pairs of rectangles. The following pairs of rectangles have the same diagonal, and can be accurately sketched on a 15×20 grid paper: They are given by their side lengths: (1,7) and (5,5); (1,8) and (4,7); (2,9) and (6,7); (7,9) and (3,11); (2,11) and (5,10); or (1,12) and (8,9).

Another response to this example-generation problem was as follows: "I recalled that a prime number is the sum of two squares if and only if its remainder in the division by 4 is 1. Then I recalled that it is possible to have two representations, for example for numbers that are a product of two primes whose remainder in the division by 4 is 1. The smallest are 5 and 13. Their product is 65. Then I had to find the integers a, b, m, n. I noticed that 65=64+1 and that $64=8^2$, so 8 and 1 are two of these numbers. I had to find the others. At this point I tried and I found that 49+16=65, and that the other numbers are 7 and 4."

Table 8.1 A systematic search for examples of two pairs of integers for which the sums of their squares are equal

+	1^2	2^2	3^2	4^2	5^2	6^2	7^2	8^2	9^2	10^2	11^2	12^2
1^2	2	5	10	17	26	37	50	65	82	101	122	145
2^2		8	13	20	29	40	53	68	85	104	125	148
3^2			18	25	34	45	58	73	90	109	130	153
4^2				32	41	52	65	80	97	116	137	160
5^2					50	61	74	89	106	125	146	169
6^2						72	85	100	117	136	157	180
7^2							98	113	130	149	170	193
8^2								128	145	164	185	208
9^2									162	181	202	225

To give the reader a sense of how far this task went, here is another solution that was sent to me: "I asked a number theorist about this. He said that there are many examples and that there is a theory which gives, in a number of cases, the number of solutions in the integers of pairs, (a,b) with $a^2+b^2=N$, for the same integer N. Here's a specific solution: Pick any four distinct positive integers a, b, c, d. Then: $(ac-bd)^2+(ad+bc)^2$ and $(ac+bd)^2+(ad-bc)^2$ are both sums of squares and are both equal to the same integer $N=(a^2+b^2)(c^2+d^2)$. If you choose $a=1$, $b=2$, $c=3$, $d=4$, then you get the two pairs of lengths of the sides of the rectangle, (5,10) and (2,11). For both the diagonal length is $\sqrt{125}\ \left(\sqrt{5^2+10^2}=\sqrt{2^2+11^2}\right)$. So an example for the students could be to draw on a grid paper two rectangles: one with sides 5 and 10, and the other with sides 2 and 11."

What Is Case 5 an Example of?

Case 5 is an example of the mathematical challenge of generating instructional examples, even for elementary pupils. The intended task for the pupils is a simple and straightforward one, but finding specific measurements that allow pupils to explore such relationships without tedious calculations is extremely demanding on behalf of the teacher.

This clearly was a genuine problem-solving situation for the mathematics educators. As demonstrated above, it was rich in the possible approaches to the problem – some relied on sophisticated number theory and others mainly on the knowledge of the Pythagorean relationship. This experience was helpful in conveying that generating (instructional) examples in mathematics is an art.

Concluding Remarks

As demonstrated throughout this chapter, the task of choosing an example to illustrate a mathematical idea is a non-trivial one. The choice of an example for teaching is often a trade-off between one limitation and another. Choosing instructional examples entails many complex and even competing considerations, some of which can be made in advance, and others that only come up during the actual teaching. Many considerations require sound curricular and mathematical knowledge.

Zodik and Zaslavsky (2008) add another dimension to this complexity by raising the issue of correctness of an example. In their study, they identified three types of "incorrectnesss" with respect to teachers' treatment of mathematical examples: The first has to do with whether the case that is treated as an example of a more general class in fact satisfies the necessary conditions to qualify as such example, e.g., treating $0.33\dot{3}$ as an example of an irrational number. The second type has to do with counter-examples. Treating an example as a counter-example for a particular claim or conjecture when it does not logically contradict the claim is mathematically incorrect, e.g., bringing the example of the following binary operation $a * b = a^b$ as a counter-example to the false claim that any commutative operation is also associative. A third type of mathematical incorrectness is manifested in treating a non-existing case as if it were a possible example, e.g., bringing the supposed triangle in Fig. 8.18 as an example of an isosceles triangle illustrates the third type of incorrectness, since, contrary to this "example," the sum of the lengths of any two sides of a triangle is always larger than the length of the third side.

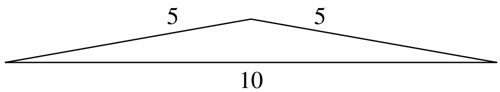


Fig. 8.18 An "example" of a non-existing isosceles triangle

The choice of examples presents the teacher with a challenging responsibility, especially since the specific choice of and treatment of examples may facilitate or impede learning (Zaslavsky & Zodik, 2007). The knowledge teachers need for judicious construction and choice of mathematical examples is a special kind of knowledge that can be seen both as core knowledge needed for teaching and as a driving force for enhancing teachers' knowledge (Zodik and Zaslavsky, 2009). It builds on and enhances teachers' knowledge of pedagogy, mathematics, and student epistemology. In Ball, Thames, & Phelps' (2008) terms, it encompasses knowledge of content and students and knowledge of content and teaching, as well as "pure" content knowledge unique to the work of teaching.

In this chapter I tried to unpack and capture some of the ingredients of mathematics teacher thinking, knowledge, and practice surrounding the art of crafting instructional examples of explanatory power. The cases I presented and analyzed may be considered meta-examples – some specific and some more general – of what Leinhardt (2001) refers to in the following passage:

In developing or selecting an example, teachers are faced with difficult tasks. They must understand the critical features that they need to explicate. These features may be critical because they are important within the subject matter domain or because they are key to the students' understandings. The teacher needs to be aware of the purposes that the example may help to serve: Can the example exemplify the way a principle is to be applied, the way new ideas connect to the older ones, or the ways in which the question can be problematized? Finally, the teacher needs to have the skills to refine and extend examples posed by the students themselves. Examples can fail because they are irrelevant, because they are confusing, or because they themselves are so complex that untangling them leads the instructional explanation astray and the point is lost. (ibid., p. 348).

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Chapter 9
Using Designed Instructional Activities to Enable Novices to Manage Ambitious Mathematics Teaching

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It has become commonplace among educational reformers to assert that all students should learn and that learning should involve complex ideas and performances. In mathematics, the universal goal of education has been characterized as "mathematical proficiency" in which conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition are intertwined in mathematical practice and learning at every grade level for every student (Kilpatrick, Swafford, & Findell, 2001; Rand Mathematics Study Panel, 2003; US Department of Education, 2008). This intellectually and socially ambitious goal leads to new definitions of teachers' work. We define this kind of work – aimed at ambitious learning goals – to be "ambitious teaching." Our vision of ambitious mathematics teaching is informed by a growing body of research built over the last three decades to understand what teachers need to do to accomplish ambitious mathematical goals (Franke, Kazemi, & Battey, 2007). Our concern is with making this kind of teaching more common and, in particular, with designing a specific form of what Leinhardt (2001) refers to as "instructional explanation" and teaching it to novices using what we call Pedagogies of Practice.

Challenges of Ambitious Teaching

Developing students "strategic competency" means the teacher needs to get them to be willing to reason and make decisions about what procedures to use while solving problems, and this requires a kind of social management that is not necessary when students are simply expected to follow directions (Chapin, O'Connor & Anderson, 2003; O'Connor & Michaels, 1993; Forman, Larreamendy-Joerns, Stein, & Brown, 1998; Cobb & McClain, 2002). "Intertwining procedures with concepts" means not teaching lessons on small discrete topics, but working from different angles on big ideas like place value and ratio and expecting students to explain why procedures make sense (Henningsen & Stein, 1997; Hiebert et al., 1997). Because students need

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to interact to refine their understanding, teachers need to structure those interactions to focus on mathematical goals while managing different levels of competence and interest, while also attending to all students maintaining a productive disposition toward the subject (Ball & Wilson, 1996; Lampert & Cobb, 2003; Greeno, 2007).

As students perform authentic problem-solving tasks, teachers need to observe and listen and adjust both content and methods to what they observe in those performances to enable diverse learners to succeed in doing high-quality academic work (Smith, Lee, & Newmann, 2001; Wood, Scott Nelson, & Warfield, 2001; Ball, Hill, & Bass, 2005; Hill et al., 2008). Stein, Engle, Smith, and Hughes (2008) review several studies of expert mathematics teachers who "make rapid online diagnoses of students' understandings, compare them with disciplinary understandings, and then fashion a response" (p. 302). They highlight the challenges of this kind of teaching and question whether it is reasonable to expect novices to do such sophisticated improvisation. But other mathematics education research has established that teachers who can adjust both content and methods to what they observe in student performance are more likely to enable all kinds of learners to succeed at high-quality academic work (Fennema, Franke, Carpenter, & Carey, 1993; Hill, Rowan, & Ball, 2005; Smith, Lee, & Newmann, 2001; Knapp, Shields & Turnbull, 1992). Such deliberately responsive and discipline-connected instruction greatly complicates the intellectual and social load of the interactions in which teachers need to engage, making ambitious teaching particularly challenging – but fundamentally important – for novices to learn.

Routines as a Tool for Managing These Challenges

In 1986, Gaea Leinhardt was going against the grain when she asserted, on the one hand, that teaching should be characterized as a "complex cognitive skill" requiring the making of rapid online decisions and, on the other hand, that skilled teachers have a large repertoire of activities they perform fluently, which she referred to as "routines". Leinhardt and Greeno (1986) observed that "routines play an important role in skilled performances because they allow relatively low-level activities to be carried out efficiently without diverting significant mental resources from the more general and substantive activities and goals of teaching" (p. 76). Over more than a decade, Leinhardt conducted several studies of elementary mathematics teachers, explicating the nature of teaching routines in elementary mathematics, refining our understanding of and ability to articulate the work of teaching, and enabling us to identify what to teach novices.

Research in other fields suggests that all kinds of professionals working in complex relational domains rely on routines to manage complexity of key elements of this kind of practice (e.g., Axelrod & Cohen, 1999). These routines are not "standard operating procedures" that provide mechanical solutions to the problems of practice (Feldman & Pentland, 2003). Rather they are well-designed procedures that have been proven in practice, that take account of the complexity of the goals that need to be accomplished, and that allow the practitioner temporarily to hold some things constant while working on others. The use of such routine procedures involves not only acquiring the capacity to do the steps in the routine in an actual working environment but also the learning professional norms or "principles" that would enable the practitioner to make appropriate judgments about when and where it is appropriate to use the routines (Weick & McDaniel, 1989). Feldman and Pentland (2003) term these judgments the "performative" aspects of using routines. The performative aspects of ambitious teaching routines would occur as teachers use them in response to elicitations and interpretations of student skill and understanding.

A Focus on Instructional Dialogue

A relatively recent focus of Leinhardt's work on teaching routines has been how they are used in "instructional dialogue" (Leinhardt & Steele, 2005), a practice we would consider to be the centerpiece of ambitious mathematics teaching. In this kind of teaching, an explanation is co-constructed by the teacher and students in the class during an instructional conversation. Maintaining a coherent mathematical learning agenda while encouraging student talk about mathematics is perhaps the most challenging aspect of ambitious teaching. In their study of teaching through instructional dialogues, Leinhardt and Steele (2005) demonstrated the use of eight kinds of "exchange" routines in this kind of teaching to accomplish explanatory work, including maintaining mathematical clarity in the face of student inarticulateness, fixing the agenda of the class on a single student's idea, making it safe for students to revise incorrect contributions, and honing students' contributions toward mathematical accuracy and precision. The exchange routines that Leinhardt and Steele (pp. 143–144) identified include the following:

- The *call-on* routine, which is initiated by a rather open invitation to discussion and has two separate components: the initial identification of a problem and the speaker who responds, followed by a second part in which the class is prompted to analyze, justify, or critique the statement given by the first speaker or another speaker in the discussion.
- The related *revise* routine in which students were asked to rethink their assertions and publicly explain a new way of thinking about their solutions.
- The *clarification* routine "which was invoked when a confusion arose regarding an idea or conjecture volunteered into the public space, which in turn involved understanding the source of confusion."

In the back-and-forth dialogue among students and teacher that occurs in these routine kinds of interaction, the work of the teacher is to deliberately maintain focus and coherence as key mathematical concepts get "explained" in a way that is co-constructed rather than produced by the teacher alone.

In exchange routines, the seeming contradiction between responsive complexity and interactive routines is at the heart of the work. Leinhardt and Steele (2005) directly state that this interactive work requires the teacher to invent the dialog in response to student contributions: "The orchestration and creation of an instructional dialogue that serves to provide a mathematical explanation is not routine. It is a unique pattern of actions and responses that serve overarching sets of valued goals" (p. 142). But they go on to note that the instructional dialogues they analyzed fundamentally "rest on some shared routinized behavior." Constructing an instructional dialogue is an intellectual and social challenge that needs to be met in the immediacy of the moment, in response to particular students and particular mathematics. Leinhardt and Steele (2005) see the identification of routines as a step in the direction of making this kind of work teachable to novices: "By untangling some of these complex elements, perhaps we can begin to free new teachers from the linear, often overly procedural presentation that textbooks afford. By making aspects of explanations explicit, we may provide tools for teachers' self-analysis of lessons. By understanding the routines that facilitate different types of teaching, we may also clarify some of the complexities of the tasks" (p. 142).

It is here that our work and Leinhardt's converge. It is not insignificant that the teaching in which Leinhardt and Steele identified and examined the use of exchange routines was done by Lampert. Over the course of more than 20 years, Lampert (e.g., 2001, 1992a, 1992b, 1989, 1986), Franke (e.g., Franke & Kazemi, 2001; Carpenter, Fennema, Franke, Levi, & Empson, 1999; Fennema et al., 1993), and Kazemi (e.g., Kazemi & Stipek, 2001; Kazemi, 1998) and several others[1] have investigated what ambitious and authentic learning goals imply for the work of teaching in classrooms. Leinhardt's work on routines has contributed substantially to enabling us to take the next step, which is to teach this kind of teaching to novices.

Instructional Activities Using Routines as Tools for Teacher Education

If teacher education is to prepare novices to engage successfully in the complex work of ambitious instruction, it must somehow prepare them to teach within the continuity of the challenging moment-by-moment interactions with students and content over time. With Leinhardt, we would argue that teaching novices to do routines that structure teacher–student–content relationships over time in order to accomplish ambitious goals could both maintain and reduce the complexity of what they need to learn to do in order to carry out this work successfully. These routines would embody the regular "participation structures" that specify what teachers and students do with one another and with the mathematical content (Ghousseini, 2008; Stein et al., 2008; Erickson & Schultz, 1981). But teaching routines are not practiced by ambitious teachers in a vacuum and they cannot be learned by novices in a vacuum. In Lampert's classroom, the use of exchange routines occurred inside of *instructional activities* with particular mathematical learning goals like successive approximation of the quotient in a long division problem (Lampert, 1992b),

[1] See for example, Chazan (2000), Herbst (2003), Cobb & McClain (2002), Ball (1993), Heaton (2000), and Schoenfeld (2008).

charting and graphing functions (Lampert, 1992a), and drawing arrays to represent multi-digit multiplications (Lampert, 1989).

How Instructional Activities Using Routines Might Work in Teacher Education

To imagine how instructional activities using exchange routines could be designed as tools for mathematics teacher education, we have drawn on two models from outside of mathematics education. One is a teacher education program for language teachers in Rome and the other is a program that prepares elementary school teachers at the University of Chicago. Both programs use instructional activities built around routines as the focus of a practice-oriented approach to teacher preparation. They both teach content and methods to novices through the use of these activities in a cycle of demonstration, planning, rehearsal with feedback, teaching actual lessons, and debriefing those lessons using video records and other evidence of student learning. In the past, teacher educators sought to prepare beginning teachers to use instructional routines and specified skills (Kennedy, 1987). However, these efforts typically neglected considerations of how to prepare beginners to make judgments about when to use and how to adapt routines, or the role of subject matter knowledge in making these judgments effectively (Grossman & McDonald, 2008).

Lampert, together with her Italian colleague, Filippo Graziani, studied the structure of a program in Rome (called “Dilit”),[2] which prepares novices to teach Italian using the “communicative method,” an approach to language teaching that presents many of the same challenges as ambitious mathematics teaching. (See Lampert & Graziani, 2009 for a complete description of this program.) We were attracted to study this program because we found that it was able to successfully prepare teachers from a wide range of backgrounds to teach the Italian language to foreigners in ambitious ways (Lampert, Boerst, & Graziani, in press). In this program, we saw teacher educators structuring their work around a small, carefully chosen set of “instructional activities” that novices were taught to use. The routine components of these activities served as a stable and rehearsable backdrop for the dynamic work of responding to student thinking. In terms of social dynamics, they enabled both new teachers and their students to take the kinds of risks associated with working on authentic problems of communication (reading, writing, speaking, listening) because they carefully specified the kinds of student performances that students would be expected to produce. They also helped to manage the intellectual dynamics as they constrained the range of content that would need to be engaged to extend student performance toward ambitious learning goals. Novice teachers could thus get started with doing and learning from ambitious teaching on somewhat safer and more manageable ground.

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[2]Dilit is an acronym for ***Di**vulgazione **L**ingua **It**aliana*, which translates as “making the Italian language accessible.”

We simultaneously found an example of the use of ambitious instructional activities in the Urban Teacher Education Program (UTEP) at the University of Chicago. Teacher educators in this program specify early literacy activities like Guided Reading (Fountas & Pinnell, 2006) in terms of action protocols that can be taught to novices. Guided reading is a series of structured interactive routines for tapping students' prior knowledge about the subject of a text, introducing the book to be read, having students "whisper-read" the book independently, and so on. In doing Guided Reading, the same protocol for relating teacher, students, and content can be used no matter what the book or reading level of the students. The routine parts of a Guided Reading Lesson can be practiced and mastered; they do not require tailoring to be enacted responsibly (Bryk et al., under review).

Like the activities taught to novices in the Dilit program in Rome, the routine parts of Guided Reading and other "balanced literacy" activities are an important backdrop for the part of the activity that, in contrast, requires a great deal of teacher observation and judgment: namely, choosing a "teaching point" and giving a mini-lesson on this point to the group of students who needs it (Glazer, 2005). The guidelines for the activity as it is used in the UTEP program direct novice teachers *to decide* what to teach: "If you notice a new reading behavior or a pattern of difficulty experienced by the group, teach a strategy lesson on that topic. For example, some children may remark that the words *cat*, *sat*, and *mat* rhyme. This provides an opportunity to focus on word families" (Urban Teacher Education Program, 2004, p. 1). By holding some aspects of teacher–student–content interaction constant, while leaving others to the teachers' professional judgment, instructional activities like Guided Reading give novices some control over practice while at the same time enabling them to learn to use their knowledge to make well-informed, responsible, on-the-fly judgments about what students need to learn. The guided rehearsal and debriefing of instructional activities like Guided Reading can scaffold the novice's entry into complex interactions with students, giving them particular instances of teaching to practice, enact, and analyze with input from a teacher educator (Scott, 2008).

In talk about teaching, using the term "instructional activities" as we use it here – to encompass routine structures that are regular features of social and intellectual interaction and materials use – is a bit unusual. Pointing out the difference between how we use the term and how it is commonly used will further help to explain why we argue that instructional activities can play a central role in knowledge building for teacher education. Ordinarily, the term "instructional activities" would be used to refer to a collection of different things that teachers and students can do together to get at some content. Typing "instructional activities" into a search engine together with a topic like "Shakespeare" or "electricity" or "fractions" generates long lists of different materials, different things to do, and instructions for how to do them. Although such lists of miscellaneous activities may have a use, collections of idiosyncratically configured ways of relating teacher, students, and content do not serve very well for either teacher learning or teacher educator learning because each has a unique participation structure and each requires a unique set of material and intellectual resources. The kinds of activities we are interested in, by comparison, have a regular structure for interaction among teacher, students, and materials.

Regularizing a spare set of interactive structures reduces the cognitive and social load of ambitious instruction on teachers and students since the kinds of social and intellectual skills that are required to carry them out are repeated, and therefore practiced. As they make ambitious teaching more doable by novices, they also make it more teachable by teacher educators (Lampert & Graziani, 2009). Deliberate practicing builds skills and knowledge about how to teach as the same interactive structure would be used over and over again in different circumstances (Ericsson, Krampe, & Tesch-Romer, 1993; Ericsson, 2002). Learning common activity structures in teacher education settings means that all of the novices in a class can produce lessons with similar characteristics when they try out what they are learning in classrooms, generating similar problems of practice to work on with teacher educators (Kazemi, Lampert & Ghousseini, 2007; Franke & Chan, 2008). Similar to what occurs in medical "rounds" and other kinds of professional work on problems of practice, novices can acquire professional judgment by being guided by more knowledgeable others in the collaborative evaluation and revision of the forms of their interactions with students (Patel, Kaufman, & Magder,1996; Weick & McDaniel, 1989).

This conception of instructional activities suggests that preparing novices for ambitious mathematics teaching would mean finding structured ways to enable them to get deep enough into authentic interactions with specific learners to practice inventing educative responses while not being overwhelmed with the unpredictability and complexity of creating improvised interaction (Ball & Cohen, 1999; Grossman & Mc Donald, 2008; Ghousseini, 2008). It would mean establishing the groundwork for maintaining the mathematical complexity of activities like discussing multiple solutions to a problem by structuring the components of interaction between teachers and students around content in ways that are regular over time (Silver, Ghousseini, Gosen, Charalambous, & Strawhun, 2005).

Moving to the Preparation of Ambitious Mathematics Teachers

A Work in Progress

In teaching novices at the University of Michigan, the University of Washington, and UCLA, we are currently employing several key instructional tools and methods intended to reduce some of the inherent risk and complexity of ambitious mathematics teaching. First, we are developing a set of key instructional activities that collectively embody the core practices and professional principles that we believe are central to the work of teaching. Individually, these instructional activities are "chunks" of teaching that maintain the complexities of practice while simultaneously providing manageable, structured routines that constrain instructional choice. They are intended to maintain complexity in that their structure encompasses an instructional sequence that enables a teacher to address a particular instructional purpose (albeit at a range of different levels) in principled, ambitious ways. The predetermined, stable structures of the instructional activities we are using constrain the set of decisions a beginning teacher (or experienced teacher, for that matter) must make during their enactment.

Drawing on recent research that relates computational fluency with conceptual understanding, we have identified four instructional activities to teach to novices. They all target teaching and learning in the domain of number and operations at the heart of elementary mathematics and can be used to accomplish multiple learning goals in lessons across the elementary spectrum. Our hypothesis is that this set of activities will serve as a productive starting place for novice teachers, enabling them to develop broadly applicable skills and knowledge. We plan to adapt these and add others through a design research process. If this work proves to be successful, we expect the field to take on other activities and other domains as we work toward building a theoretically and empirically grounded instructional system for elementary mathematics (Cohen, Raudenbush, & Ball, 2003; Raudenbush, 2008). The four activities we will begin with are described below:

- *Choral counting*: The teacher leads the class in a count, teaching different concepts and skills by deciding what number to start with, what to count by (e.g., by 10s, by 19s, by $\frac{3}{4}$s), whether to count forward or backward, and when to stop. The teacher publicly records the count on the board, stopping to elicit children's ideas for figuring out the next number, and to co-construct an explanation of the mathematics that arises in patterns.
- *Strategy sharing*: The teacher poses a computational problem and elicits multiple ways of solving the problem. Careful use of representations and targeted questioning of students are designed to help the class learn the general logic underlying the strategies, identify mathematical connections, and evaluate strategies in terms of efficiency and generalizability.
- *Strings:* The teacher poses several related computational problems, one at a time, in order to scaffold students' ability to make connections across problems and use what they know to solve a more difficult computational problem. This activity is used to target a particular strategy (as compared to eliciting a range of strategies). For example, posing 4×4, then 4×40, and then 4×39 is designed to help students consider how to use 4×40 to solve 4×39, developing their knowledge of compensating strategies in multiplication (Fosnot & Dolk, 2001).
- *Solving word problems:* The teacher first launches a word problem to support students in making sense of the problem situation, then monitors while students are working to determine how students are solving the problem, gauges which student strategies are best suited for meeting the instructional goal of an upcoming mathematical discussion, and makes judgments about how to orchestrate the discussion to meet those goals.

The fourth activity, solving word problems, is ubiquitous in elementary mathematics curricula and rarely done in ways that teach important mathematics (Hiebert, Stigler, Jacobs, Givvin, & Garnier, 2005; Kilpatrick, Swafford, & Findell, 2001). The first three activities can be used as warm-ups in the classroom and appear as such in many existing curricula. Typically, however, these activities are not instructionally specified in teachers' guides to the extent that we envision being necessary for novices. By choosing warm-ups that can be routinely used, we have also built in the opportunity for novices to use them more than once, supporting a cycle of preparation, enactment, analysis, and reenactment.

We hypothesize that the instructional activities we are using with novices can provide a mental schema for an instructional "chunk" that can routinely be utilized by adapting it across content and grade levels to achieve instructional objectives (Leinhardt & Greeno, 1986). It is this adaptability, in part, that we contend makes work on instructional activities generative of novices learning both practical skills and professional judgment. In order to support ambitious mathematics teaching, instructional activities need to be structured to generate the variety of skills and knowledge that display to teachers what students can do and what they still need to learn. They also need to leave room for teachers to create teaching in response to what is displayed. At the same time, they structure what teachers and students do with the content to bring about an intended learning goal. They organize teacher and student interactions with the material resources of instruction, including texts, representations, and furniture. They are sequences of coordinated operations that can be mastered by teachers and students and repeated with different materials so that students can learn different aspects of the content at different levels of proficiency. They are grounded in experience, continually evolving in their design as they are used by ambitious practitioners.

While specifying instructional activities that we believe are generative of novices' learning, we are simultaneously developing "Pedagogies of Practice"[3] for teacher educators to use in preparing novices to engage in the activities with elementary-level students. These pedagogies are enacted in recurrent cycles during which teacher educators support novice teachers to analyze and observe, to plan and rehearse, and to experiment with the instructional activities, cycling between a phase in which the activities are taught and studied in a university classroom setting and a phase where beginners use them in interaction with children in actual classroom contexts. We believe that creating a pedagogical structure for novice teacher education in elementary mathematics that links coursework tightly with fieldwork and instructional investigation with enactment will be a substantial contribution of our work (Grossman & McDonald, 2008). The tightly integrated cycle of "Pedagogies of Practice" is designed to counter common problems of inert knowledge, mechanical skill implementation, and principles that are espoused but not enacted (e.g., Borko et al., 1992; Eisenhart et al., 1993; Ensor, 2001).

The Pedagogies of Practice we are developing for working with instructional activities built of what Leinhardt and Steele (2005) call "exchange routines" will

[3]We see Pedagogies of Practice as a cyclic integration of what Grossman et al. (2009) have identified as Pedagogies of Investigation and Pedagogies of Enactment.

guide novice teachers' planning and enactment, helping them learn how to introduce an activity, manage materials and student participation, manage discussion toward an instructional goal, work with mathematical representations, and respond to student error. We are specifying particular routines and having novices rehearse them in ways that are integrated with developing their judgment about responding to students' learning. We are reviewing their use of the routines in classrooms and attending to what students are learning from engaging in them, and we are adjusting the activities based on what we learn from their enactment. In all of this work, we are indebted to Gaea Leinhardt for paving the way.

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Part III
Instructional Explanations in the Teaching and Learning of the Humanities

Chapter 10
Learning History and Learning Language: Focusing on Language in Historical Explanations to Support English Language Learners

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History is a language-based discipline. In this discipline, language plays a central role in understanding, reasoning, and explanation. Doing history entails engaging in close reading and evaluation of particular texts, reading across texts to establish intertextual links, constructing meaning by juxtaposing a series of texts, and writing arguments to support a particular interpretation of events, structures, themes, or metasystems (Leinhardt, Stainton, Virji, & Odoroff, 1994, *Cognitive and instructional processes in the social sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates). Learning history requires teachers and students to engage with multiple kinds of texts deeply, fluently, and analytically.

The demands of engaging with history in a rigorous and analytic way are formidable for any student. For students who are English language learners (ELLs), the intellectual challenges are greatly compounded. As educators interested in supporting history students from multiple language backgrounds, we have collaborated to develop ways in assisting teachers charged with the task of teaching a linguistically diverse classroom. The growing number of ELLs in US schools,[1] along with high rates of low literacy among students for whom English is their first language (Wineburg, 2006), suggests the magnitude of the problem.

This paper draws on research on expert reading in history, and on the teaching and learning of history that stems from cognitive sciences and applied linguistics (e.g., Martin, 2002; Leinhardt & Young, 1996; Schleppegrell, 2004; Wineburg, 2001) to expand the concept of Leinhardt's instructional explanations (2001) to include metalinguistic explanations. Explicit discussions about the role of language in history provide opportunities for modeling the ways historians approach texts and enable a more subtle understanding of historical issues. The argument is that reading like a historian can deepen historical understanding and build disciplinary literacy. By making visible and explicit the practices of expert readers in history, teachers can engage in authentic disciplinary activities and deepen historical understanding.

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[1]Between 1991 and 2001 the ELL population in public schools increased 105% (Kindler, 2002).

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Instruction is influenced by teachers' knowledge of the content and also by their knowledge of the way to teach it. "Knowing a lot about the subject [...], suggests to the teachers different kinds of activities, different kinds of tasks, and different kinds of talk" (Leinhardt, 2001, p. 338). Deep knowledge also affects competence in structuring explanations. Instructional explanation is an important part of teaching because it models the form and content of the discipline for the student, making a difference in the type of educational experience that is constructed (Leinhardt, 1993; 2001). Deepening teachers' historical knowledge influences practice; our position is that such knowledge also includes understanding about the role of language and ways of working with texts favored by the discipline.

The fine-grained analyses of historians and teachers' practices and thinking in history have identified core features that characterize expert behavior in this discipline (e.g., the work of Leinhardt and Wineburg among others). Similarly, detailed discourse analysis of the language used in history texts and classrooms has described some of the linguistic characteristics of history (Coffin, 2004, Martin, 2002, Schleppegrell, 2004). Building on this research, we have identified a series of guiding principles to make visible some of historians' practices, thinking processes, and language-use patterns. We have used these guiding principles to design content-focused professional development (PD) modules to build teachers' metalanguage to reflect and talk about the ways in which texts are approached and meanings are made from texts in history. These PD units were designed for high school history teachers in districts with high numbers of ELLs. We have seen that with guidance, teachers can develop a metalanguage to think about and analyze language as well as design instructional explanations that point to the role of language in the construction of historical meaning.

This paper presents our approach to making explicit the role of language within history instruction to support teachers' construction of deeper historical understanding and the development of disciplinary literacy. We present the theoretical model framing our work and describe one of the PD units we produced for history/social studies teachers in a session on disciplinary literacy. The goal is to scaffold the teachers' ability to construct historical explanations through engaging in text analysis and also to assist them to diagnose the linguistic challenges historical texts pose for ELLs. Our work integrates the scientific study of history and language learning with educational practice to develop instructional models that can improve the teaching and learning of history.

Learning and Teaching History

Learning is a situated process of knowledge construction that has to respond to the implicit standards of a community. History teaching must incorporate opportunities to engage directly with the content and practices that are accepted in the discipline. There are particular ways of integrating content and language through practices typical of the discipline. In history, knowledge, reasoning, and language are inextricably linked.

Instructional Explanations and Language in History

One role of the teacher is to mediate the distance and differences between the experience and practices of the expert (i.e., historian) and those of the novice/non-expert (i.e., learner). In this process, instructional explanations have a key function. Explanations help to convey a sense of both the content and the domain (Leinhardt, 2001). Pedagogical discourse recontextualizes professional knowledge and discursive practices to respond to students' needs and schooling situation constraints. The way history is practiced in the classroom responds to levels of expertise in history content (i.e., experts vs. novices), orientation to historical tasks (i.e., anthropological, humanistic, sociological), and conceptions of history (i.e., facts vs. human construction). Teaching history requires a transformation of the discipline to adapt it to the goals and possibilities that the school context affords and demands. The history teacher's goal is to create new understandings in learners, not to create new knowledge in the discipline (Leinhardt, Stainton & Virji, 1994; Wineburg & Wilson, 1991). Hence, even though the questions explored in instructional explanations emerge from the discipline, teachers need to bridge the gap between the common explanations students come with and the explanations valued by the disciplinary community.

In instructional explanations, teachers and students negotiate historical meanings and academic uses of language to construct historical understanding. The scaffolding of meaning in instructional explanations develops academic discourse, building form, and meaning simultaneously (Mohan & Beckett, 2001).

Instructional explanations play a key role in the recontextualization of the discipline of history in school contexts. They are locations for communicating valued knowledge about the discipline as well as modeling reasoning through language within the discipline (Leinhardt, 1993). Instructional explanations are important because they make explicit statements of and about ideas in the field and how they are constructed (Leinhardt, 1994). These explanations are used to clarify concepts and rhetorical forms providing opportunities to support inductive reasoning.

Instructional explanations are designed to teach. According to Leinhardt (1993, 2001) these explanations can be opportunities where new information is presented, questions are answered, confusions are clarified, or where arguments are made. Instructional explanations can be given by teachers, students, or be co-constructed. The classroom activities in which instructional explanations take place include tasks (e.g., joint reading of a text, discussions) and classroom talk. There are occasions that prompt explanations; these teachable moments are determined by epistemic structures of the discipline and the challenges students face when learning this discipline (Leinhardt, 2001). For example, learning about historical structures poses more challenges than learning about events (Young & Leinhardt, 1996). According to Leinhardt (2001) in history, there are four moments that trigger historical explanations: events (e.g., short narrative episodes, wars, treaties, biographies, causal connections), structures (e.g., long expository systems, government, economy, relational connections), themes (e.g., power vs. freedom, interpretive cohesive devices), and metasystems (e.g., tools, analysis, synthesis, interpretation strategies). The form of the explanation given varies accordingly in terms of the language used and the type of examples selected.

The enactment of instructional explanations usually includes "an instance of something to be explained, an example of it; a set of discussions that connect what is being explained to particular rules or principles; and finally, a set of discussions that bound it or limit its applicability, thus distinguishing it from other closely allied ideas or practices" (Leinhardt, 2001, p. 341). Leinhardt's theoretical model (1993, 2001) can be used to describe the actions and goals present in an explanation of how language constructs historical meanings.

We are interested in expanding this model to explore the uses and effects of metalinguistic explanations, focusing on accessing disciplinary principles related to reading practices and text analysis techniques to work with historical documents. We explore a particular kind of explanation that includes the development of metalinguistic awareness in the service of historical thinking. Explicit discussions about the role of language in history provide opportunities to flag how representation, orientation, and organization of texts construct accounts, perspective, bias, and explanations. The core of a language-focused instructional explanation emerges from the close reading of texts using linguistic tools to get to historically relevant questions focused on the content. The teaching actions include analyzing texts, creating questions to guide participants' close reading, coming up with examples to make explicit and visible the analysis and inferences made by an expert reader, and showing the interconnections to previous discussions and shared background knowledge.

Explaining the Role of Language in History

An important line of work on the role of language in history has been conducted by several researchers working with Systemic Functional Linguistics (e.g., Coffin, 2006; Eggins, Wignell & Martin, 1993; Martin, 1997, 2002; Unsworth, 1999; Veel & Coffin, 1996). This research has analyzed the text types and language features students encounter when learning history. Focusing mostly on the analysis of secondary sources, this work has described the discourse produced by textbook writers of history and students learning history (in classrooms).

Coffin (2004) and Martin (2002) propose a taxonomy of history text types typical of those used in history textbooks and students of history in schools. Included in this taxonomy are *recounts*, *accounts*, *descriptions*, *explanations*, and *arguments*, among other genres. Some of the key linguistic features identified as characteristic of these historical genres include nominalization, reasoning within the clause through verb choices, and the ambiguous use of conjunctions (Martin, 1991; Unsworth, 1999). *Nominalizations* are typically used to represent a series of events as a single abstract participant (e.g., Reconstruction, slavery, the South) or to represent human actors by presenting them as classes of people (e.g., plantation owners, voters). Reasoning within the clause occurs mostly through verb choices or text-level patterns instead of using conjunctions. For example, causal relations are typically constructed through verb choices, such as *caused* or *resulted in* instead of through conjunctions such as *since* or *because*, (e.g., “The general’s field orders *resulted* in the redistribution of land to former slaves”/“*Since* former slaves were following the army, Sherman wrote the Field Orders”).

In addition, causality is constructed in history texts through other more indirect linguistic choices, such as using subordinate clauses with nonconjugated verbs that function as nouns, adjectives, or adverbs (non-finite clauses) to signal the motivation of actions. An example of such a clause comes from Achugar and Schleppegrell (2005, p. 307) “*With President Jackson refusing to enforce the Supreme Court decision*, many Cherokee saw the removal as unavoidable.” When conjunctions are used to signal logical relationships in these history texts, there is usually a conflation of time and cause (e.g., *when* implies a temporal as well as a conditional relation between events). An example of such usage occurs in Martin Luther King Jr.’s *Letter from a Birmingham Jail* (1963), “Perhaps it is easy for those who have never felt the stinging darts of segregation to say, “Wait.” But *when* you have seen vicious mobs lynch your mothers and fathers at will. . .*then* you will understand why we find it difficult to wait.” Here the conjunctions *when* and *then* link the clauses chronologically by specifying the movement in time, but they also function as connectors in support of a conditional relationship – *if this happens the result is we cannot wait*.

The particular characteristics of the language of history, such as those just described, pose challenges in the teaching and learning of history that are different from reading in other content areas. Grappling with these complexities are part of the learning to read process for all history students, regardless of their facility with using academic English. History is also demanding because the texts historians and students read and analyze (i.e., primary sources) are not examples of the historical discourse they have to produce (Coffin, 2006). History requires students to read critically and write persuasively at advanced levels (Schleppegrell, 2004). Enabling teachers and, later, students to recognize and appreciate these nuances of meaning foregrounds the importance of focusing on the role of language in this discipline.

Multilingual Learners in the History Classroom

Learning history depends heavily on language and cultural references that students supposedly already know, although even some native speakers of English that belong to mainstream culture do not always understand these references (e.g., McKeown & Beck, 1990; Young & Leinhardt, 1998). For those who come from different cultural and linguistic backgrounds than mainstream students in US schools, acquiring disciplinary literacy poses a fundamental problem. To ensure that all students have opportunities to learn history, teachers need to create a learning context that explicitly addresses the role of language in the construction of historical meanings while at the same time tapping into the previous experience and knowledge that *all* students bring to the classroom. The challenge in a multilingual classroom is therefore to scaffold reading comprehension of historical documents, make visible the role language plays in the discipline, and tap into learners' relevant background knowledge.

In the following paragraphs we present three approaches to the teaching of disciplinary literacy addressing ELLs and other language minority needs: content-based instruction, cultural modeling, and functional approach. These three approaches foreground the importance of explicitly focusing on language in content area classrooms but they have different conceptualizations of the relationship between language and content and of what students bring to the classroom learning experience.

Previous work on history instruction for ELLs has usually focused on recommending the use of hands-on activities, cooperative learning techniques, and vocabulary-building activities (e.g., Short, 1991; 1993). To make texts more readily accessible to ELLs, these approaches put a major emphasis on visual representation of information, and integration of language and content goals for lessons. More recently, Echevarria, Vogt, and Short (2004) developed the Sheltered Instruction Observation Protocol (SIOP model) to meet the needs of ELLs. This model views a language focus as an added component to content lessons in a discipline. Content specialists are trained to recognize language-learning opportunities by reflecting on and designing lessons that incorporate language objectives in terms of key vocabulary, grammar points, reading comprehension strategies, process writing, and oral communication focused on using language to negotiate meaning or make hypotheses (Echevarria et al., 2004). These teaching strategies proved successful for beginning to intermediate-level ELLs (Echevarria, Short, & Powers, 2006), but effectiveness for advanced learners has not been established.

Another model of disciplinary literacy development for language minority students is the Cultural Modeling Approach (Lee, 1995, 2004), which focuses on tapping into the learners' cultural funds of knowledge to develop advanced academic literacy. By establishing analogies between vernacular language practices and academic language, Lee's work shows how students' background knowledge can be incorporated into the classroom to build academic knowledge. In the case of ELLs, even though there might not be a common vernacular language practice to connect to because of the diversity of the population, there is a bilingual linguistic reservoir (Genesee, Lindholm-Leary, Saunders & Christian, 2006). This reservoir can be integrated into the development of a critical language awareness that focuses on language's role in the construction of disciplinary knowledge. While language and content are linked in all of these approaches, the definitions of language and content used are not the same.

More recently Schleppegrell and her collaborators have engaged history teachers in language analysis to support ELLs academic language development using a functional approach.[2] This approach assumes the notion that language and context

[2]This approach is based on M.A.K. Halliday's Systemic Functional Grammar.

are inextricable. To develop history literacy, students need to work in authentic curriculum contexts where the concept of genre[3] highlights the way language is used to write history. Considering grammar to be a meaning-making resource provides new opportunities to discuss and critique texts. The California History Project disciplinary literacy work (http://historyproject.ucdavis.edu/) used summer PD institutes to integrate functional linguistic goals and literacy with history curriculum (see Achugar, Schleppegrell & Oteiza, 2007; Schleppegrell & Achugar, 2003; Schleppegrell, Achugar & Oteiza, 2004; Schleppegrell, Greer & Taylor, 2008; Schleppegrell & de Oliveira, 2006). An outside evaluation of these teachers' work showed that their students made significant gains in language and history learning compared to other students (Gargani, 2006; Schleppegrell, Gargani, Berman, de Oliveira, & McTygue, 2006).

We build on this functional approach by integrating it with work on explanation in order to design experiences that can help teachers become aware of the complexities of disciplinary literacy and in turn assist their students in learning history and language. The goal is to design PD that integrates academic rigor and language development while apprenticing participants into the ways of *doing history*. These experiences tap into teachers' (and students') implicit language knowledge, make connections to contextual knowledge, and develop metacognitive skills through engagement in discipline-specific practices.

Our work targets teachers serving ELL students who have been mainstreamed into the regular history classroom. These students are the most vulnerable in the history classroom because although they have developed the oral conversational skills to effectively communicate in English, they have few experiences with English in academic situations. ELLs have difficulty developing the academic language that is necessary to participate and succeed in schools (August & Shanahan, 2006; Collier, 1992; Davison & Williams, 2001). Even after ELLs have been redesignated as fluent in English they tend to lag behind in academic achievement (National Center for Education Statistics, 2002; Slavin & Cheung, 2005). When placed in mainstream classes, their language needs are not explicitly addressed and mere exposure to academic language is not enough to support their academic language development and content learning. For these learners, the main challenge is *reading to learn*. For teachers serving these mainstreamed students, the challenge is to ensure access to grade-level content material by providing scaffolding for reading comprehension and language development.

The following section describes the theoretical framework we use to design the PD workshops for history teachers serving ELLs. We then illustrate this language-focused instructional explanation model with a particular case – a unit on Reconstruction.

[3]By genre we mean the different forms texts take in connection to the social purpose they are fulfilling. Genres are usually described in terms of their rhetorical, discursive, and grammatical features.

Theoretical Framework for Teaching History

We recognize the discipline of history as different from other disciplines because there are continuities and patterns of practice associated with representing the past from a historian's position. Knowledge of history is neither static nor merely a body of facts. Historical knowledge is constructed, which implies that learning in the discipline is a dynamic process in which the learner engages with the material by transforming it and her/his understanding in the process. The constructed nature of historical knowledge enables creativity and change in understanding. However, this creative aspect is constrained by what the disciplinary community accepts as valid. There are distinctive ways of using language and constructing knowledge in this discipline that produce a historical understanding of experience.

Learning the discipline implies learning new information and new ways of thinking that are realized in new ways of using language. A traditional view of the relationship between language and content does not offer a way to theorize the manner in which meaning and knowledge are constructed in and through language (Mohan & Slater, 2005). On the other hand, a functional view of language and a language-based theory of learning enable us to think of language as a meaning-making resource, providing tools to analyze and critique how language is involved in the construction of disciplinary meaning (Halliday, 1994, 1993; Vygotsky, 1978).

The development of an awareness of how language works to construct history supports a deeper understanding of the discipline and the content. Descriptions of the reading and document analysis practices of historians revealed that they engage in close readings – analyzing not only *what* texts say but also *how* they say it (Leinhardt & Young, 1996; Wineburg, 1998). Particular reading practices are associated with the way of approaching knowing in history. For example, when reading primary source documents the historian not only decodes texts to extract information s/he also interprets them to establish their historical meaning and significance. In history expert readers classify, corroborate, source, and contextualize a document as part of the reading process (Leinhardt & Young, 1996). This close reading of the text involves word-level and rhetorical analysis to construct a sense of *what* the text means. There is also a deeper level of reading that interprets the text historically, driven by a particular perspective in order to make a link to other disciplinary dialogs and to construct an explanation or argument that fulfills a theoretical purpose. By evaluating sources, organizing information in terms of chronology, causality and perspective, and making connections to other texts, historians engage in a kind of reading that is unique to the discipline. The ways texts are approached, evaluated, and classified in history highlight the importance of being able to work with complex ideas and sort through layers of information to reach reasoned conclusions (Wineburg,1998). The deconstruction of the habitual ways in which historians engage with texts makes visible the role of metalinguistic knowledge in reading within the discipline. Reading like a historian implies developing a metacognitive awareness and a metalanguage to describe documents. By doing close textual analysis of documents, teachers (and students) can engage in legitimate historical practices.

To learn from documents, readers need tools to think about language and history in more abstract ways. Developing a meaning-based metalanguage allows teachers (and students) to be reflective about the meaning and power of the choices authors make. By engaging in multiple readings and reading in multiple ways, readers unpack the content encoded in the text, the inferences that can be made from the information present in the text, and the relationship of that document to other relevant documents. These readings flag the information, perspective, and historical context used to interpret the meaning and meaningfulness of the document. Understanding the complex meaning-making practices of reading historically enables teachers to anticipate the potential challenges students encounter when learning history.

Designing Professional Development for History Teachers Serving ELLs

This section describes the professional development program that has provided the forum for this work to contextualize the language-focused explanation. History teachers from several school districts around the country are exposed to the theoretical framework and practical application of linguistics as a history teaching tool during the course of their regular sessions on Disciplinary Literacy. These districts have been participating in a 3-year PD curriculum in history, from the Institute for Learning (IFL, http://www.instituteforlearning.org), which includes two sessions that explicitly address the role of linguistics in history instruction and how understanding it can serve both the ELLs and English speakers in their classrooms.

The following four principles inform our work on language-focused instructional explanations with history teachers:

- Disciplinary literacy in history needs to address content and language simultaneously.
- Making visible the ways in which language is used in history provides teachers and students with tools to engage in historical reading.
- Engagement in practices such as close reading, sourcing, contextualization, and corroboration contribute to the development of historical understanding.
- Teachers apprentice students into historical habits of thinking by giving them opportunities to engage in text analysis and by providing scaffolding through inquiry, direct instruction, modeling, and coaching.

These principles serve as guidelines to develop educational experiences in which teachers can directly engage in text analysis activities, reflect about the role of language in the discipline, and develop a metalanguage to think and work with language in history.

The IFL PD model engages teachers in lesson-based experiences as learners, asks them to reflect on their experience during and after the session, and makes explicit the connections with current, relevant research to help teachers create professional learning communities and to develop an identity as historians. The lesson-based experiences designed for these PD sessions are built around the following components: (a) sets of guiding inquiries that frame the units, (b) multiple texts from different genres, (c) tools to analyze these texts presented through modeling, (d) small group and individual work, and (e) formative assessment. By metacognitively marking their learning at different points, participants step out of the learner role in order to analyze and come to understand the architecture of the unit. This pattern of reasoning and analysis allows them to understand the process of creating their own units for use in their districts. These participants receive support on site where coaching and professional learning communities are put in place to sustain the work on disciplinary literacy begun in the PD sessions.

An ongoing activity of the IFL history team includes evaluation of these professional development sessions and the particular and evolving needs of participating teachers and the realities and challenges of their districts. An enduring concern has been the growing numbers of ELLs in district classrooms and the issues faced by the teachers responsible for them. We have explored the challenges ELLs face when reading history texts written in English. ELL students who are developing academic language may not have sufficient vocabulary, experience with grammar, and background knowledge to construct meaning from these texts in order to engage in high-level text-based discussions. Since these are the same hurdles shared by other students, whose first language is English (though to a lesser degree), our collaboration thus concentrated on designing units with the capacity to serve the needs of *both* kinds of students, including those with multilingual language histories. Addressing the needs of all students with one linguistic approach honors teachers' responsibility to serve a student population with diverse language backgrounds in a pragmatic way when they have had no particular past training in teaching ELLS.

Case Study: Understanding the Reconstruction Period in US History

We designed a model unit that focuses on the period of Reconstruction in US history and in the construction and deconstruction of historical arguments. One intended learning of the unit is that all historical arguments are constructed and authored and in this instance, we explore the construction of historical argument through historical narrative.[4]

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[4]We are using the term historical narrative following historian Tom Holt's work. In *Thinking Historically* (1990) Holt says "history is fundamentally and inescapably narrative in its basic structure, even when it is not reported in a narrative form" (pp. 12–13). This use of narrative differs from its use in linguistics where it refers only to a particular genre among many (see for example Coffin, 2006).

To design our text analysis lesson, we followed a five-part process. First, we identified the key historical issues/questions. Then, we selected relevant documents based on their historical significance as assessed by historians. Third, we performed a linguistic text analysis of these documents to identify potential challenges for students. Fourth, we designed a task for whole group reading of the text focusing on making visible the role of language in constructing historical meanings. Finally, we designed assessment of participants' learning.

The Reconstruction Unit

Identifying Key Historical Questions

Commonly understood as "the period of time after the Civil War," we chose Reconstruction as the content for a unit because, in addition to being a significant historical topic covered in most US history courses, it offers an ideal opportunity to explore the notion of periodicity in history. Despite the characterization made in numerous social studies textbooks, the Reconstruction period is anything but a specific set of events that can be neatly delineated by a pair of dates. This feature invites discussion of what issues the period represents and when they occurred and serves to show students how history is seldom cut and dried in terms of boundaries. This lack of consensus is borne out in the debates amongst the historians of this period – indeed, it is their job to take this on – and serves as an entry point into considering why it matters how and when a period in history is framed. Further, the arguments made in support of different framings will look quite different from each other. But current (e.g. by Congress in July, 2008) and ongoing discussions of apologies and reparations for slavery and remediation of broken promises, such as "40 acres and a mule," offer a very different framing of Reconstruction as remaining an unfinished enterprise.[5] As a historical construct, Reconstruction allows a great deal of leeway in terms of the range and kinds of evidence available to form arguments for framing the period, lending itself to the historical narrative structure (Holt, 1990). Creating a historical narrative allows the author to freely select the pieces and arrange them causally, a form of argumentation that illuminates the constructed nature of history and illustrates the process for novices to do it themselves.

After reviewing the historical scholarship of the period, from the array of perspectives on it, we formulated the set of guiding inquiries that serve as the

[5]The situation of African Americans today reveals how this historical period is still relevant to comprehend the current social and economic conditions of this group. According to the U.S. census special report on American communities (2007) Black workers are less likely to be employed in management, profession and related occupations. The poverty rate for Blacks is higher than for other groups: one of every four lives below the poverty level. Blacks also have a lower median income and are more likely to rent their homes.

Table 10.1 Guiding questions for the reconstruction unit

• When did Reconstruction begin?
• Who were the main historical actors, or characters, who shaped Reconstruction?
• What challenges, problems and conflicts did these various actors face? In particular, how were they confronted by economic issues related to land, labor, and citizenship?
• What viewpoints did these various actors express, and what actions did they take, as they struggled to "reconstruct" the nation?
• When and in what ways were the problems of Reconstruction "resolved"? What problems or issues were left unresolved, and why?
• What about the daily lives of blacks and whites in the South changed during Reconstruction? What remained the same?
• How might we finish this sentence: in the end, "Reconstruction was the story of ________."

intellectual thread running through all the materials that are used in the unit (Table 10.1).

Selecting Document Set

From Holt's (1990) work on Reconstruction, we did the first selection of the primary source documents for our unit. We conducted a linguistic analysis of these documents to assess the level of linguistic and background knowledge the texts posed for students. To scaffold ELLs' (and students in general) reading of the documents, entering into documents, reading of conflicting arguments, and questioning evidence to pursue historical questions we selected two key documents to do in-depth work in the classroom reading and discussing primary sources: Sherman's Special Field Orders #15 and the Letter from Edisto Island. These two documents provide relevant historical information to understand the meaning of Reconstruction and also offer different genres and linguistic features for students to explore and learn to unpack texts.

Doing a Detailed Text Analysis of Key Documents

The detailed text analysis serves to identify the textual cues that can help readers to understand the historical issues and select portions of the text to work on in the lesson. In addition, a clear idea of what the characteristics of the text are can help predict potential comprehension challenges the text might pose for less-experienced readers. This information will be used later on to construct the language-focused instructional explanation.

The document analysis activity uses as guiding questions the goals of the instructional conversations around the text. These goals are connected to particular language analysis actions and provide knowledge about the linguistic characteristics of the text that are relevant to its historical understanding. The analysis moves from a macro-level focus on genre and rhetorical features to a micro-level analysis that focuses on more discrete lexical and grammatical features to explain the ways in which language functions in the text to construct historical meanings. Table 10.2

Table 10.2 Language-focused instructional explanation

Goals	Actions	Knowledge
What is the social purpose of the document?	Analysis of moves in the text, layout and comparison to other similar texts	Social purpose of the document
What is going on in the text?	Analysis of text to identify processes, participants, and circumstances Word chains	Main events, key social actors, and context
What is the perspective constructed in the text?	Analysis of text to identify words that express degrees of probability, frequency, obligation, and evaluative vocabulary Identifying type of speech function (declarative, interrogative, clause mood: imperative), use of terms of address, pronouns	Construction of social roles and power differences Orientation of the writer to information and audience
How is information organized?	Analysis of text to identify connectors, circumstances of time, referrers, word chains, organization of message in terms of time, cause or reason, nominalizations, Theme/Rheme	Purpose of the text and development of the argument

presents a summary of the key components of a language-focused explanation in history.

The analysis begins by identifying the type of historical document it is (genre[6]), establishing its social purpose, and identifying patterns of language use (lexico-grammatical features used to construct the representation, orientation, and organization of events in the text). We illustrate this text analysis process with Sherman's Special Field Orders #14.

Sherman's Field Orders[7] belong to the genre of procedures, an official military document detailing how to go about a particular task. The social purpose of this text

[6]"Groups of people who use language for similar purposes develop, over time, common types of spoken and written texts which achieve their common goals. People who share an understanding of how the common purposes of a culture are achieved with language will therefore be able to predict, to a large extent, the structure and language of the texts they encounter." Droga & Humphrey (2002: 2–3). Genre is a term used in literacy pedagogy to connect the different forms texts take with variations in social purpose. Texts are different because they do different things. (Cope & Kalantzis, 1993:7)

[7]See appendix.

is to instruct officers on how to proceed regarding Negro freedmen.[8] The generic moves that functionally support the achievement of this social purpose include the statement of the goal (what the field orders are for: to set apart land for the freedmen) followed by a number of steps that result in the creation of a particular institutional position to oversee the achievement of the orders and a description of the scope of their validity (they exclude the Beaufort Island settlement).

The topic of the orders is revealed through vocabulary choices that highlight "freedmen" and "settlements" as the main theme. The document's topic cohesion is achieved by word chains that foreground the main social actors and the events discussed in the text. For example, there is a chain that refers to the "freedmen" including terms such as "blacks," "negroes," "negroes now made free," and "freed people." There is also a word chain that highlights the main purpose of the orders: the granting of land and property rights. For example, actors and actions are represented using terms such as "settlement," "title," "land and labor," "land rights," "settlers." This semantic taxonomy links words that occur sequentially through synonymy and repetition constructing textual cohesion, and information focus.

There is also a particular representation of the events, participants, and circumstances constructed through choices of verbs, nouns, and adverbial phrases of time, manner, and place. "*The islands from Charleston, south, the abandoned rice fields along the rivers for thirty miles back from the sea, and the country bordering the St. Johns river, Florida (participant:goal)*, **are reserved** (action verb in passive) //and **set apart** (action verb in passive) *for the settlement of the negroes now made free by the acts of war and the proclamation of the President of the United States" (circumstance of purpose)*. The events represented include the distribution of land (goal) for a particular reason (circumstance), but does not directly identify the actors doing the actions (verbs in passive voice). The beneficiaries of these actions, "the negroes," appear indirectly mentioned through references to the purpose of this land distribution, but their representation does not present them as active social agents in the process.

The Field Orders document also offers an opportunity to explore how social relations and roles are established through language. The text reveals a difference in power between the author and the document's intended audience through the use of statements that indicate high degrees of obligation and probability. For example, "The negro is free and *must be dealt* with as such" or "He *cannot be subjected* to conscription or forced military service...". These statements reveal that the author has the power to direct others' actions and state the extent to which the interpretation of the situation is open to negotiation.

The organization of the text shows it was written to be read aloud and followed. Since the interlocutors are not face to face, the channel of communication affects the type of language that is being used. For example, the following highlights the fact

[8]Lacking instructions from D.C. Washington, the field orders were written by Sherman to solve the problem of having newly freed slaves following his army. By settling them on reclaimed land he removed refugees from his operations and created a potential way to allow them to join the military service in the future.

that to understand these orders the reader needs to look for clues in the text and not in the immediate context, "The inspector of settlements and plantations will [. . .] give *them* a license to settle." To recover the meaning of "them" the reader has to go back in the text to retrieve the information encoded in the referrer,[9] "three respectable negroes, heads of families." The organization of the text is also centered mostly around circumstances of place, time, and purpose. For example, "At Beaufort, Hilton Head, Savannah, Fernandina, St. Augustine and Jacksonville" or "on the islands, and in the settlements hereafter to be established."

Some of the challenges students may face when reading this document include (1) the representation of events, without identifying main participants, through the use of passive voice, which makes it difficult to identify key social actors that function as agents; (2) the organization of the text around circumstances, using subordination and point of departure of clauses, which foreground circumstances over events or participants; and, finally, (3) the construction of unequal power relationship between reader and writer by using modals[10] to show varying degrees of probability and obligation. These linguistic features of the document pose certain challenges and opportunities to explore the ways in which language contributes to the construction of historical meaning.

The combination of the historical and linguistic analysis guided us to rethink the design of the lesson in ways that would support participants' deeper understanding of the Reconstruction period as well as provide them with opportunities to develop text analysis skills to support the type of work with documents that characterizes expert historians.

Text Analysis Lesson

The lesson begins with the exploration of prior knowledge using guiding questions:

- *When did the Reconstruction begin?*
- *Who are the key characters in the Reconstruction period?*
- *When did the Reconstruction end?*
- *How might we finish the sentence: In the end, the Reconstruction was the story of. . .?*

Participants discuss these guiding inquiries in small groups then, as a large group, reflect on how to get from this brainstorm to historical "narrative" or history. In this section, there is also an opportunity to explore what students know about the end

[9]Referrers are pointing words. A participant or circumstance introduced in one part of the text can be taken as a reference point for something that follows. This means that something can appear again (before or after) or is the basis of comparison. These 'pointing' words link outwards to a person or thing in the environment or inwards to something in the text. In English the main categories of reference words include: pronouns, demonstrative (time and place), and comparatives.

[10]Modals are helping verbs that encode various meanings of necessity, obligation, possibility, permission, etc.

of slavery in other countries, tapping into their previous knowledge, and giving a comparative historical perspective to the issue.

The lesson-based experience begins by choosing a starting point and a key focus document, Sherman's Special Field Orders #15, written in January 1865. Participants read three secondary sources[11] referring to this document and discuss the historical conditions of the Civil War and its aftermath to build their background knowledge and contextualize the document. The facilitator moves the whole group into a guided analysis by modeling a way to read the Sherman text and make sense of what the source is saying and doing. The group focuses on identifying the author's intent, the document's intended audience, its agenda, and the context in which the document is produced.

In the next session, participants reconsider the same documents, but now the group's goal is to use a linguistic lens to read the texts closely to understand how the language that comprises them constructs their historical meanings. By explaining how a text means what it says, we make visible the linguistic and background information we rely on to make the historical reading. We unpack the text by pointing to the linguistic cues that enable readers to get to the historical content.

The language-focused instructional explanation is introduced here in the unit and helps participants focus on unpacking the text and giving teachers tools to understand how historical meanings are constructed through particular language choices. The integrated analysis of content and form make visible how historical meanings are constructed in texts. The analysis moves back and forth between the two sets of parallel questions: linguistic and historical. This allows participants to see how the linguistic analysis supports the historical understanding. Figure 10.1 shows the model text and the guiding questions used to do a close text analysis of Sherman's orders.

An Example of a Language-Focused Instructional Explanation of Sherman's Field Orders

The following example provides a more detailed description of how we approach the explanation of the role of language in history. We offer the general description of the event to give a sense of the components and focus of this type language-focused instructional explanation. When reading the first paragraph of the text, the facilitator has participants notice how the purpose of the text is constructed in these few lines as an issue of land distribution and property rights. The facilitator puts up an overhead of the document with the first sentence of the document with different

[11] These excerpts are from: PBS, American Experience, "Reconstruction: The Second Civil War." http://www.pbs.org/wgbh/amex/reconstruction/40acres/ps_so15.html,: Holt, T. (1990). *Thinking historically: Narrative, imagination, and understanding*. New York: College Entrance Examination Board. pp. 23–25; and Danzer, G.A., et. al. (2003). *The Americans*. Evanston, IL: McDougal Littell. p. 390.

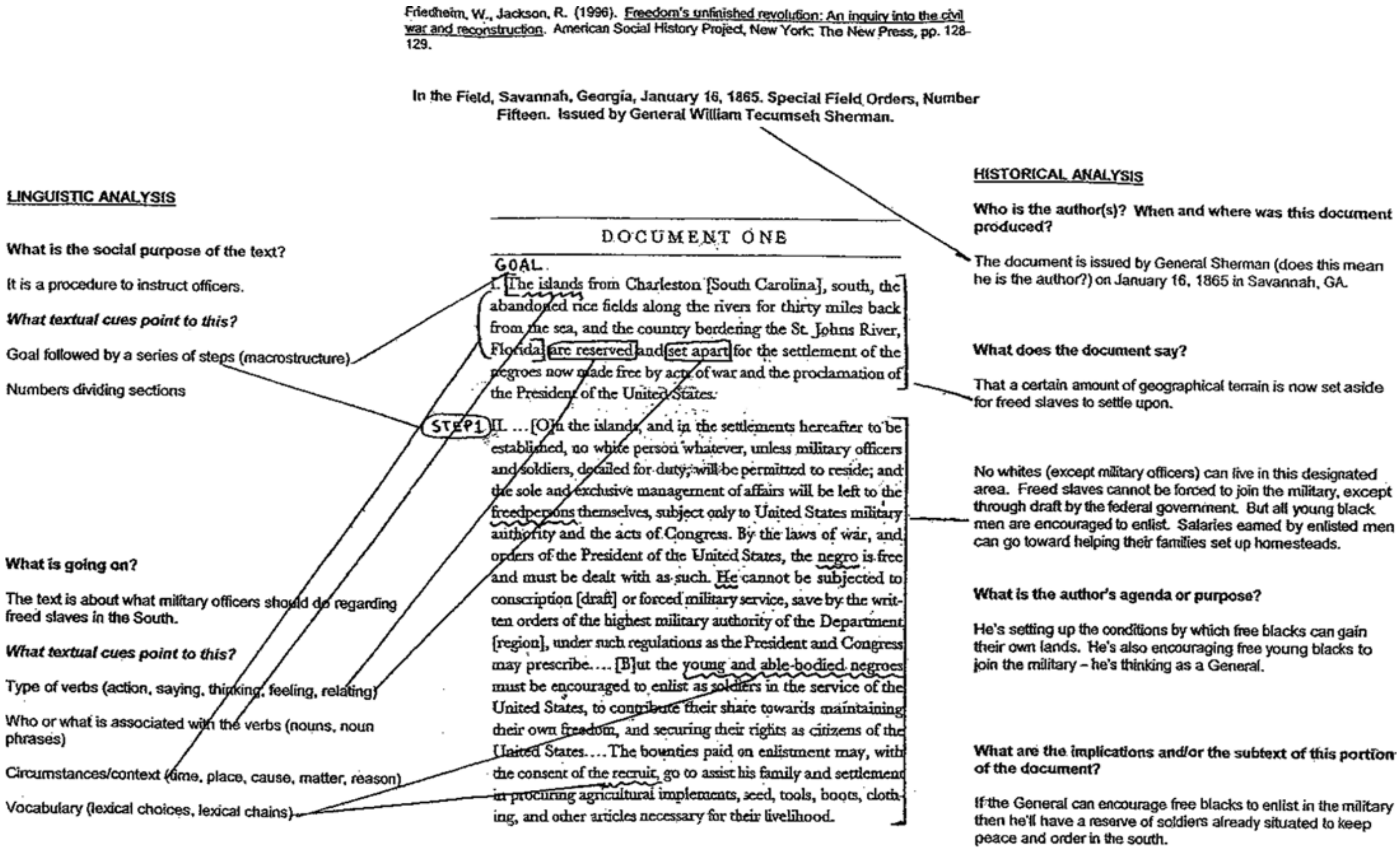
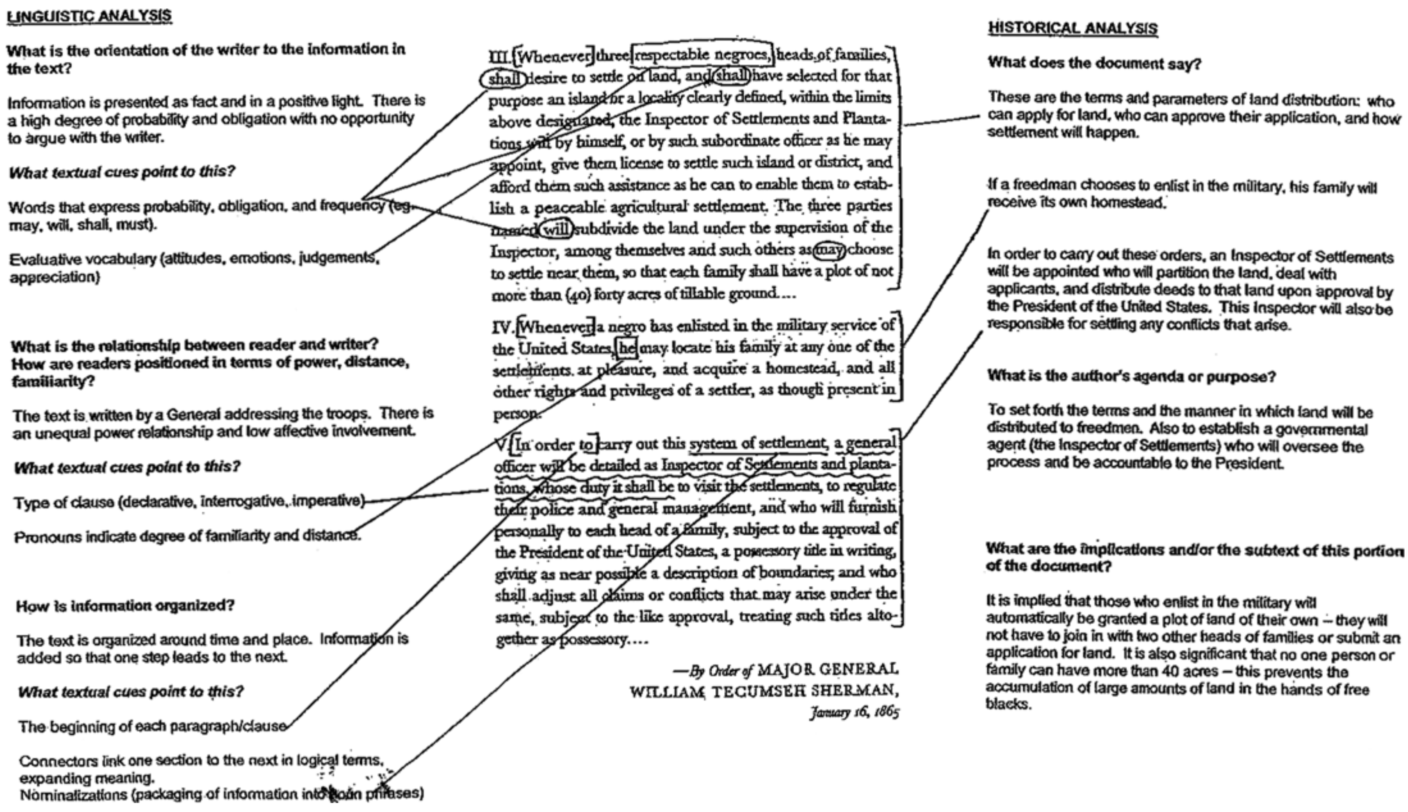


Fig. 10.1 Analysis of Sherman's Field Orders



LINGUISTIC ANALYSIS

What is the orientation of the writer to the information in the text?

Information is presented as fact and in a positive light. There is a high degree of probability and obligation with no opportunity to argue with the writer.

What textual cues point to this?

Words that express probability, obligation, and frequency (eg. may, will, shall, must).

Evaluative vocabulary (attitudes, emotions, judgements, appreciation)

What is the relationship between reader and writer? How are readers positioned in terms of power, distance, familiarity?

The text is written by a General addressing the troops. There is an unequal power relationship and low affective involvement.

What textual cues point to this?

Type of clause (declarative, interrogative, imperative)

Pronouns indicate degree of familiarity and distance.

How is information organized?

The text is organized around time and place. Information is added so that one step leads to the next.

What textual cues point to this?

The beginning of each paragraph/clause

Connectors link one section to the next in logical terms, expanding meaning.
Nominalizations (packaging of information into noun phrases)

III. Whenever three respectable negroes, heads of families, shall desire to settle on land, and shall have selected for that purpose an island or a locality clearly defined, within the limits above designated, the Inspector of Settlements and Plantations will by himself, or by such subordinate officer as he may appoint, give them license to settle such island or district, and afford them such assistance as he can to enable them to establish a peaceable agricultural settlement. The three parties named will subdivide the land under the supervision of the Inspector, among themselves and such others as may choose to settle near them, so that each family shall have a plot of not more than (40) forty acres of tillable ground....

IV. Whenever a negro has enlisted in the military service of the United States, he may locate his family at any one of the settlements at pleasure, and acquire a homestead, and all other rights and privileges of a settler, as though present in person.

V. In order to carry out this system of settlement, a general officer will be detailed as Inspector of Settlements and plantations, whose duty it shall be to visit the settlements, to regulate their police and general management, and who will furnish personally to each head of a family, subject to the approval of the President of the United States, a possessory title in writing, giving as near possible a description of boundaries; and who shall adjust all claims or conflicts that may arise under the same, subject to the like approval, treating such titles altogether as possessory....

—*By Order of* MAJOR GENERAL
WILLIAM TECUMSEH SHERMAN,
January 16, 1865

HISTORICAL ANALYSIS

What does the document say?

These are the terms and parameters of land distribution: who can apply for land, who can approve their application, and how settlement will happen.

If a freedman chooses to enlist in the military, his family will receive its own homestead.

In order to carry out these orders, an Inspector of Settlements will be appointed who will partition the land, deal with applicants, and distribute deeds to that land upon approval by the President of the United States. This Inspector will also be responsible for settling any conflicts that arise.

What is the author's agenda or purpose?

To set forth the terms and the manner in which land will be distributed to freedmen. Also to establish a governmental agent (the Inspector of Settlements) who will oversee the process and be accountable to the President.

What are the implications and/or the subtext of this portion of the document?

It is implied that those who enlist in the military will automatically be granted a plot of land of their own – they will not have to join in with two other heads of families or submit an application for land. It is also significant that no one person or family can have more than 40 acres – this prevents the accumulation of large amounts of land in the hands of free blacks.

Fig. 10.1 (continued)

> ***The islands from Charleston [South Carolina], south, the abandoned rice fields along the rivers for thirty miles back from the sea, and the country bordering the St Johns River, Florida*** **are reserved and set apart for the settlement of the negroes now made free by acts of war and the proclamation of the President of the United States.**

Fig. 10.2 Sherman's Field Orders analysis of processes, participants, and circumstances

parts highlighted (see Fig. 10.2), in order to help teachers notice how different parts of the clause serve to construct historical meanings. The goal of this instructional moment is to begin a discussion about what is going on in the text by identifying the language patterns that help to represent the events depicted in the document. By identifying the main processes (verbs), participants, and circumstances we get a sense of how the historical events are represented. The activity is conducted as a collaborative think-aloud where the facilitator questions the text and voices her thinking while requesting the teachers' participation and interpretation also.

In Fig. 10.2 the key verbs represent what is going on as something that has to do with distributing land: "are reserved and set apart." Although the participants (military actors) who will carry out these actions are not identified explicitly in the text, one can infer that they belong to the military because the author is a general. There is also a link to the government's possible connection to these actions because they are mentioned as being responsible for the freeing of those slaves who will benefit from this land distribution. But that connection is something the reader needs to make by inferring, because it is not explicitly stated in the document. There is also a particular place, which is the territory that will be set apart, that identifies the context where these actions are to take place: the Georgia coast. This geographic information allows us to reflect about the meaning of the particular location and value of this space as something worth acting on. Looking at a map in conjunction with the text prompts us to discuss other historical questions that are not directly answered by the text such as: *What type of land was it? Whose land was it? Was it prime real state property, was it farm land or swamps? Who benefits and who is penalized by this redistribution of land?* Then teachers are asked to think about what Reconstruction was in terms of property distribution and why that was a key aspect of the discussion at the time. This conceptualization allows teachers to expand the meaning of Reconstruction in a way that moves beyond the moral dilemma of individual freedom and reparations of social and cultural life into economic terms: *Who has the right to own property? What is the role of the state in the allocation of property? Is private property a core principle of this society that overrides all other democratic considerations? Is the daily living of the freed slaves very different if they are not given the opportunity to own property?*

The language-focused instructional explanation is followed by an assessment activity where participants are asked to explain what and how the close reading of the document contributed to their historical understanding of the document.

Summary

Instructional explanation focused on language requires a particular type of activity and scaffolding to support deep comprehension of historical texts. According to Leinhardt (2001), there are a variety of elements that are common to explanations: a query, the use, and generation of examples, the use of intermediate representations such as analogies and models, and a system to limit or bound explanations (p. 344). The core of an instructional explanation includes a system of interrelated goals and the supporting actions and knowledge required to achieve them. In the previous language-focused instructional explanation, we can observe there are particular queries to be explored: *How are events and participants represented in the text? What is the text about?* But these queries are also connected to larger historical questions that are explored in a series of lessons, not just in this instance. The larger question is what is the meaning of the Reconstruction period and how is citizenship defined in connection to economic issues related to land and labor as nineteenth century US society struggled to move beyond (or maintain) the system of slavery. The pedagogical actions that support the exploration of these queries include the close reading of the document, analyzing word choices, and questioning them by presenting possible alternatives. Probing alternatives requires having a list of examples of other possible linguistic choices to represent the same events. To coordinate and support the joint construction of a language-focused instructional explanation, the facilitator has to tap into participants' background knowledge and make explicit inferences to provide a model and a space to question the text. The instructional explanation is completed by identifying the core meanings established in the text and generating new questions to explore that which is not in the text.

Text-based historical explanations focus deeply on how language functions to construct historical meanings. The close look at language from a functional perspective has the potential to develop deeper historical understandings and a critical language awareness that can be used to engage with texts in ways that facilitate learning.

These instructional explanations include activities in which the facilitator takes the lead in guiding participants' close reading of the text to model the type of text analysis described above. This line-by-line reading and continuing questioning of the text provide a way to engage with language in historically meaningful ways. The whole group discussions around and about text provide an opportunity for all participants to engage with historical content material and historical questions at their level.

In thinking about how instructional explanations can translate into the classroom, we can add another element: the modeling and scaffolding of the ways to approach text to explore historical questions can provide ELLs, struggling readers, and fluent readers with visible and explicit strategies to read historically. The role of leader in the explanations is first taken by the teacher, but later can be offered to students with support from the teacher. Throughout a semester, there is ideally movement from teacher-led text analysis toward more independent students activities in which the teacher becomes a guide and support.

Conclusions

We have presented the theoretical framework and guiding principles that inform our work with history teachers to develop language-focused instructional explanations to deepen their understanding of the subject matter and the role of language in learning the discipline. Our goal is to contribute to teachers' professional development by giving them a metalanguage to develop a critical language awareness to support the work they do with texts in the classroom. The more detailed work with and around historical texts will also deepen the teachers' historical understanding.

Research on subject matter teaching and learning has demonstrated that the way teachers understand their discipline and their subject matter knowledge affects their ability to teach for understanding and students' opportunities to learn (Shulman, 1986). Being able to select meaningful activities, give explanations, respond to students' questions, and assess their learning require that teachers be knowledgeable and comfortable with both the content and the practices associated with working within the discipline. Engaging in concrete experiences that model the activities of experts in the field provides teachers with the opportunity to learn subject matter and the professional practices associated with it. Designing instructional explanations that highlight the role of language in the construction and interpretation of history provides an opportunity to explicitly focus teachers' (and students) attention on disciplinary literacy and its connection to historical understanding.

This model language-focused instructional explanation exemplifies the functional language approach to disciplinary literacy we are using. We begin by an exploration of the topic to build historical understanding starting from the knowledge participants already have, move into a close reading phase of documents guided by key historical inquiries designed to highlight important historical issues, then revisit the texts to focus on how language constructs those historical meanings to see how we can use primary documents as evidence of particular interpretations and positions. Finally, we bring together the different readings and layers of text analysis to construct a historical argument that responds to the guiding inquiries presented at the beginning of the unit. The learning–teaching model is cyclical and implies going over one piece of text several times to mine it. This entails that the text selection phase of lesson planning is of outmost importance. The focus text needs to be historically relevant and linguistically interesting to justify the amount of time devoted to it in class.

Through the careful introspection of meaning and form in a text participants develop a heuristic for analyzing the relationship of text and social purpose to understand how simultaneously considering social context and textual patterns supports deeper historical understanding. Our work also contributes to the development of a metalanguage to think and talk about language in history. Being mindful of how language functions in history can impact the selection of historical documents for lesson design and deepen historical understanding. A careful analysis of documents produces awareness of the important historical meanings present or absent in texts and the potential linkages between texts to construct a historical argument. Knowing what information can be mined from a text also prompts instructors to search for information that the text does not provide, examine the authors' intent, poke holes in the assertions or reliability of the document, and notice discrepancies between sources.

Our work also requires an active role of teachers in constructing instructional explanations that present content and model authentic disciplinary practices. By modeling and explicitly articulating ways to engage with text to construct historical arguments, we make visible the reading practices that are typical of professional historians. These practices are valuable because they are authentic to the field, and because the construction of knowledge in history is embedded in particular ways of engaging and approaching texts. To understand and engage in multilayered readings and interpretations, teachers (and learners) need opportunities to perform close reading and text analysis activities. Continued and sustained practice of these text analysis activities provides opportunities to move from more supported to more independent work with historical documents.

Our collaboration between history teachers, educational researchers, and applied linguists creates a space to think about learning and teaching history in ways that integrate transdisciplinary views of disciplinary literacy. Having to explain the terms we use, noticing the black holes in our field's view of history, and searching for functional ways to integrate the knowledge base of different disciplines have transformed our approach to disciplinary literacy and PD in significant ways. These changes go from shifting the focus of the lesson and the document selection to rethinking the role of language in the discipline as a social practice. The analytic work with documents resulted also in a reconsideration of historical inquires and key areas to focus that emerged from viewing documents differently. Documentation of this work will hopefully contribute to the improvement of the teaching and learning of history. This collaboration has provided an opportunity to solidify the bases of applied linguistics work in the teaching of language in history by providing a more solid sense of disciplinary learning and teaching. At the same time, the work of educational researchers, such as Gaea Leinhardt, can be extended to integrate knowledge about language learning that can expand our views of the role of language in teaching and learning.

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Chapter 11
Instructional Explanations in a Legal Classroom: Are Students' Argument Diagrams of Hypothetical Reasoning Diagnostic?

Kevin D. Ashley and Collin Lynch

Introduction

Much instruction in the first year of American legal education focuses on argumentation. Paradoxically, however, comparatively little of the instructional explanation in legal classrooms is *about* the process of argumentation. Instead, instructors teach law students the process of argumentation primarily by engaging them in argumentation about the issues, problems, and examples in the casebook. Instructors also use these arguments to teach law students lessons about the substantive rules of a legal area (e.g., contracts or torts) and about the applications, ambiguities, and limitations of those rules. In this sense, the instructor's and students' interactive argument dialogs *are* the instructional explanations of the argument process and an important component of the instructional explanations of the substantive law (Leinhardt, 2001).

My research colleagues and I have long been interested in designing computational tutoring systems to support law students in acquiring skills of legal argumentation. Argumentation lies at the heart of reasoning about and solving ill-structured problems (Voss & Means, 1991, p. 342; Voss, 2006, p. 305f). Legal problems are ill-structured in the sense that they seldom have uniquely right answers as may occur with comparatively well-structured problems in high school mathematics or science. Instead, there are reasonable arguments on competing sides of an issue. In past work my former student, now colleague, Vincent Aleven, and I designed and evaluated programs that could actually make legal arguments and engage students in arguments analogizing legal problems to past cases (Aleven, 2006; Ashley, 1990).

In this work, however, we focus on a different approach: helping students reconstruct examples of experts' arguments using argument diagrams. The examples illustrate a particular kind of reasoning that is important in law, hypothetical reasoning. Judges, advocates, law professors, and students practice hypothetical reasoning

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when they participate in a process of critiquing a proposed test for deciding a case by posing hypothetical examples, or hypotheticals. A hypothetical challenges the proposed test as too broad or too narrow. It invites responses either to distinguish the hypothetical from the case at hand, modify the test to account for the hypothetical, or abandon the test in favor of a different one. Oral arguments before the Supreme Court of the United States (SCOTUS) provide the expert examples of hypothetical reasoning. They are real-world examples of a kind of reasoning in which legal instructors engage law students in class. Hence, the students' reconstructions of the examples using argument diagrams are intended to help them better understand legal argumentation as a form of instructional explanation.

What Law Students Need to Learn About Legal Argumentation

Solving legal problems has certain domain-specific constraints that distinguish it from other ill-structured problem-solving domains. For instance, a proposed solution needs to be justified in terms of a special kind of warrant: a legal rule (also known as a test) that is authoritative, in the sense that it issues from a legally competent source, and that is relevant to and decides the case at hand. Ideally, the rule decides the case in a manner that reconciles the resolution of this dispute with the decisions of relevantly similar past cases and with underlying legal policies and principles.

The central importance of rules in legal problem-solving, however, may mislead law students. They need to learn that attorneys and judges do not just reason *with* legal rules; they reason *about* legal rules. In other words, law students need to learn that legal argumentation is not just a matter of applying rules deductively. Like other warrants, the rules have sources and backing (Toulmin, 1958), for instance, past cases or precedents in which a court adopted the rule. There likely will be an argument about the nature and appropriateness of this backing (e.g., is the precedent relevant or binding?), and even about the correct formulation of the rule given the facts of the precedent.

Law students must also learn that applying a legal rule is an interpretive step. Lawyers argue about whether and how the rule applies to a fact situation and about what the rule's terms really mean. Frequently, the terms are not adequately defined, and one must determine whether they apply to the problem's facts by analogy to those of past cases where the terms were applied or not. The problem is exacerbated by the fact that the terms' technical legal meanings often diverge from their common sense meanings.

Finally, law students need to learn that applying a legal rule involves a normative conclusion. Lawyers argue about what policies and principles underlie the rule, about how well the result of applying the rule "fits" those policies and principles, the past cases, and, as explained below, relevant hypothetical examples, about what similarities and differences among these are relevant, and about how much weight these similarities and differences should be accorded.

Example of Arguments About Ill-Structured Legal Problem

A sample argument about an ill-structured legal problem helps to illustrate what law students need to learn. It also presents an opportunity to introduce various argument models and diagrams that could be useful to varying degrees in teaching legal reasoning. In the case of *California v. Carney*, the Supreme Court had to decide if, under the Fourth Amendment of the US Constitution, police required a warrant to search a parked motor home. As usual, the oral argument occurred after the parties had submitted briefs but (presumably) before the Justices decided the case or drafted an opinion; each side's advocate had one half hour to press his case before the nine Justices. According to the facts, police suspected defendant Carney of trading drugs for sex in his motor home located in a downtown San Diego parking lot. After questioning a boy leaving Carney's motor home, agents entered without a warrant or consent, observed drugs, and arrested Carney. Carney moved to suppress the drug evidence, the State Supreme Court agreed, but the State of California appealed to the US Supreme Court. The issue involved three conflicting policies or principles. On the one hand, there are law enforcement policy concerns: (1) to prevent the loss of evidence in an emergency situation where the vehicle could flee and (2) to provide a bright-line rule that police can apply efficiently. On the other hand, (3) there is a constitutional right of privacy and autonomy in one's home.

Clearly, deductive argument plays a role in analyzing such a problem. If, as illustrated in Fig. 11.1, there were an authoritative rule that vehicles can be excepted from the requirement of a search warrant, and given that motor homes are vehicles, one could logically conclude that motor homes can be excepted from the requirement, too.

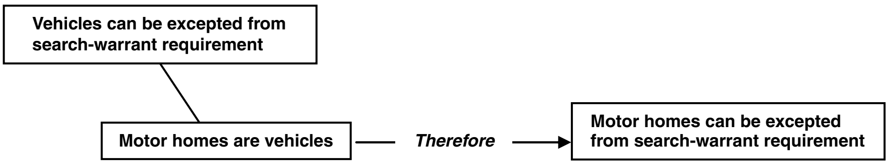

Fig. 11.1 Deductive argument model

Deductive argument is not enough, however. Questions will naturally arise in legal argument, such as "How does one know that's the rule?" and "How does one know that a motor home is a 'vehicle' for purposes of that rule?" The former question asks what backing the asserted rule has: what statutes or precedents give rise to it? One way to answer is to cite a precedent where the court said that was the rule, or at least, where the rule could be inferred from the facts of the case and the court's conclusion. Toulmin diagrams were designed to represent such warrants and backing and the flow of evidential support from a datum through a warrant that has backing to a claim or conclusion, as in Fig. 11.2 (Toulmin, 1958; Newman & Marshall, 1992). Here, the case of *U.S. v. Ross* is cited as the backing for the asserted rule.

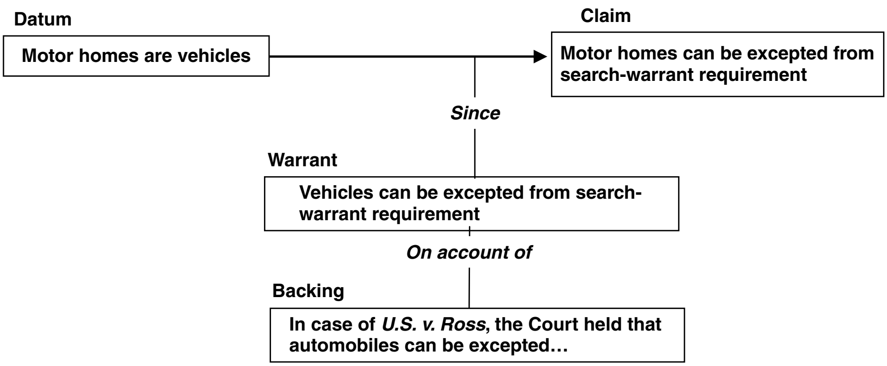

Fig. 11.2 Toulmin structure for legal argument

The latter question goes to what the terms of the rule really mean. Given the source case of the rule, is "vehicle" being used in its ordinary sense or in a more technical sense? In the context of the *Ross* case, would a motor home be treated as a "vehicle"? After all, the argument might proceed, "Didn't the *Ross* case involve automobiles? Didn't the court hold that automobiles can be excepted from the requirement of a search warrant? Given the case's facts, even if the court's rule used the term 'vehicles', it must have meant automobiles. Motor homes are not automobiles, and they should not be treated as 'automobiles' or 'vehicles' for purposes of the search-warrant exception. Motor homes are more like homes that people dwell in. In the *Payton* case, homes were not be excepted from the search-warrant requirement."

Toulmin diagrams can illustrate this kind of legal argument with rebuttals, or contrary claims, as in Fig. 11.3 (Newman & Marshall, 1992). Proponents of Toulmin or related argument diagrams might debate just how the rebuttal or contrary claim should be represented and where it should hook into the diagram, but the dueling claims, warrants, and backing will be represented in some manner like Fig. 11.3.

Which claim should prevail? In pressing toward a conclusion, the arguers would need to address the question of whether, for purposes of the search-warrant requirement, a motor home is essentially more like an automobile/vehicle or a home. Conceivably, a Toulmin diagram could represent an argument for the position that a motor home is essentially more like an automobile (Newman & Marshall, 1992) as in Fig. 11.4.

The asserted warrant that autos and motor homes are essentially similar would be subject to argument. How does one know that they are essentially similar for purposes of the judicial warrant exception? The backing lists relevant similarities, for example, both are mobile, can move quickly, are subject to motor vehicle inspections, etc., but how does one know the backing matters? One could cite the *U.S. v. Ross* case where the court focused on the importance of automobiles' ability to move quickly, but why does that matter? Surely, it is not just because the court said so.

In justifying assertions that particular facts, or that factual similarities or differences, matter legally, one expects to see an argument grounded in the legal policies

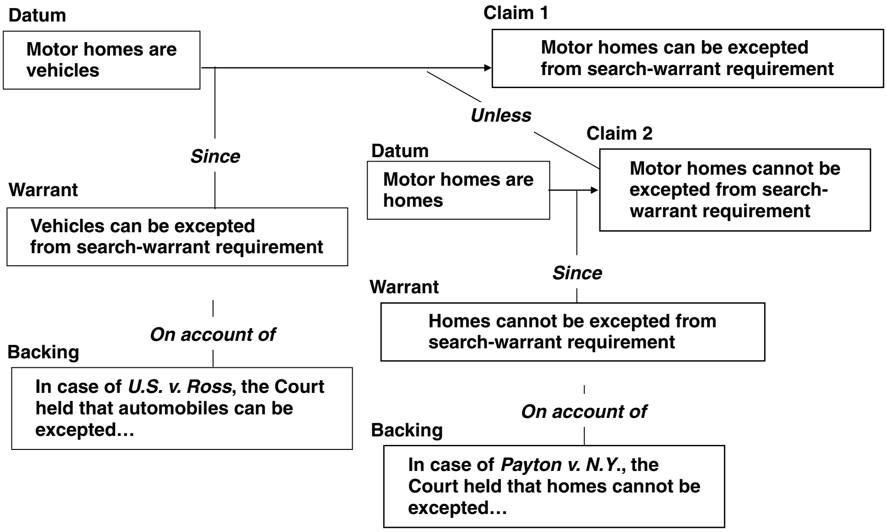

Fig. 11.3 Toulmin legal argument with rebuttals

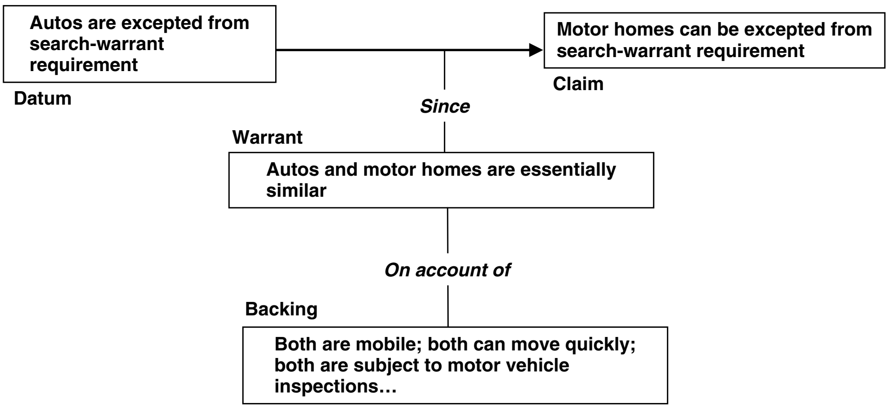

Fig. 11.4 Toulmin structure for analogy

or principles underlying the rule. For instance, one could argue that the mobility matters because evidence could easily be lost in a fleeing automobile, or that motor vehicle inspections matter because they indicate a diminished expectation of privacy in an automobile or motor home. Indeed, any proposed decision rule or test applied to a set of facts works a tradeoff of the often competing policies and principles, and a court must satisfy itself that this tradeoff is acceptable in the current case and in foreseeable circumstances. That is where hypothetical reasoning comes in to play.

As shown in Fig. 11.5, the State's advocate, Mr. Hanoian (Mr. H) proposed a test that, he argued, would serve the principles at stake: if the place-to-be-searched

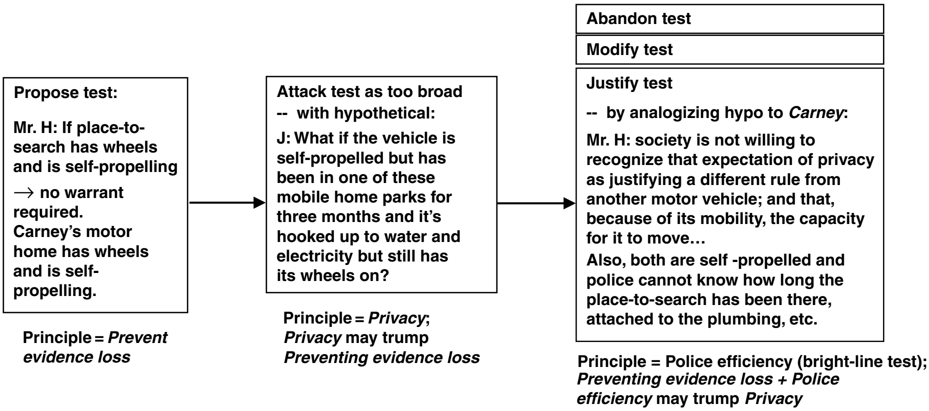

Fig. 11.5 Process diagram for arguing with tests and hypotheticals

has wheels and is self-propelling, then no warrant should be required. This test would prevent the loss of evidence in an emergency situation and would be a "bright line" rule that the police could easily apply. Subsequently, a Justice attacked Mr. Hanoian's proposed test as too broad, posing a hypothetical. The hypothetical rooted the motor home more permanently in a mobile home park with utilities hook-ups. The change in facts might seem unimportant, but it has a significant effect; it emphasizes the motor home's similarity to a house and deemphasizes the likelihood of the vehicle's being driven away along with the evidence. In these circumstances, the hypothetical implies, protecting privacy in one's home supersedes protecting against evidence loss.

In responding to a hypothetical, the advocate has three basic choices. He may concede by abandoning his test and proposing another. He may modify his test to accommodate the hypothetical while still reaching the desired result in the case at hand. Or, like Mr. H, he may stick with his test and analogize the hypothetical to the case at hand, here emphasizing the potential mobility of the motor home and arguing that the proposed test reaches the normatively right result in the hypothetical. In Fig. 11.5, Mr. H argues that the police cannot know if the motor home has been rooted long enough or permanently enough not to threaten loss of evidence, implying that the policies of preventing evidence loss and police efficiency trump privacy concerns.

Teaching with a Process Model of Hypothetical Reasoning

Our process model of hypothetical reasoning formalizes and explains such examples. Figure 11.6 illustrates the part of the model for critiquing a proposed test as too broad.

→ **1. Propose test for deciding the current fact situation (cfs):** Construct a proposed test that leads to a favorable decision in the cfs and is consistent with applicable underlying legal principles/policies and important past cases, and give reasons.

← **2. Pose hypothetical to probe if proposed test is too *broad*:** Construct a hypothetical example that:

(a) emphasizes some normatively relevant aspect of the cfs and

(b) to which the proposed test applies and assigns the same result as to the cfs, but

(c) where, given the legal principles/policies, that result is normatively wrong in the hypothetical.

→ **3. Respond to hypothetical example:**

(3.a) Save the proposed test: Analogize the hypothetical example and the cfs and argue that they both should have the result assigned by the proposed test. *Or*

(3.b) Modify the proposed test: Distinguish the hypothetical example from the cfs, argue that they should have different results and that the proposed test yields the right result in the cfs, and add a condition or limit a concept definition so that the narrowed test still applies to the cfs but does not apply to, or leads to a different result for, the hypothetical example. *Or*

(3.c) Abandon the proposed test and return to (1) (i.e., construct a different proposed test that leads to a favorable decision in the cfs and is consistent with applicable underlying legal principles/policies, important past cases, and hypotheticals…)

Fig. 11.6 Process model of hypothetical argument (excerpts)

A judge may pose a hypothetical to critique a proposed test as too narrow or to explore its meaning for both of which there are variations on the three responses (not shown).

The process model of hypothetical argument of Fig. 11.6 is partially based on Lakatos' mathematical reasoning method of proof and refutations (Lakatos, 1976, p. 50). The SCOTUS oral arguments can be seen as working examples of reasoners' employing hypothetical counterexamples similar to those of the Socratic tutorial dialog Lakatos reconstructed from decades-long communications of mathematicians. Lakatos' dialog exemplifies a kind of interactive instructional explanation, variations of which one could observe in classes teaching law, professional ethics, public policy, history, and indeed any domain where ill-structured problems are routinely confronted. Hypothetical reasoning plays an important role in instructional explanations in all of these domains.

While a process model of hypothetical argument may be useful as the basis for instructional explanation, how best to use it is still a question. As noted, legal instructors rarely introduce models as “meta” explanations of legal reasoning. Law students may encounter some general process descriptions of legal reasoning and argumentation in introductory texts, but these are seldom specific or illustrated systematically with examples; instead, classroom discussion engages students directly in argument.

Law students encounter hypothetical reasoning primarily as part of Socratic dialogs in law school classrooms. In the course casebook, students read cases pertinent to a particular legal issue. In classroom discussion, the instructor may ask a student to formulate the test that courts appear to employ to decide such issues. Like the Justices, the instructor may then pose hypotheticals to critique the student’s proposed test. The instructor’s scenarios may present predictable variations of a precedent’s facts, realistic new scenarios, unanticipated when the precedents were decided due to societal or technological changes, or artifacts designed especially to tease out the questions and ambiguities implicit in the rule given the policies and principles.

Early in law school education, the goal is to teach students an implicit process model of hypothetical reasoning to illustrate the nature of legal rules. Later, the instructors assume students’ familiarity with this mode of reasoning and use it to teach substantive lessons about particular areas of law (e.g., product liability or copyright). It is not clear, however, whether all students succeed in internalizing a process model of hypothetical reasoning, or that they learn it efficiently. Unlike the SCOTUS oral arguments, the classroom exchanges have no official transcript. Students take notes, but the exchanges are fleeting and the students are more likely to focus on annotating the resulting rules and qualifications than on the process that led to them.

For this reason, we believe, it may be pedagogically valuable for law students to encounter a more explicit process model of hypothetical reasoning, but there is still a question of how. As noted above, computational models have not been developed to engage students in arguments involving hypothetical reasoning, certainly not well enough to power an intelligent tutoring system. We hypothesized that students could learn the process by reconstructing examples of it in SCOTUS oral arguments in cases relevant to the legal issues students studied. Our approach enables students to reconstruct such examples by representing them diagrammatically; a computational implementation of the process model helps students to improve and reflect on their argument diagrams.

For a number of reasons, it makes sense to believe that computer-supported argument diagrams could help students learn a model of argument. One is reification; making an argument model explicit is likely to help students understand what it is they need to learn. As Fig. 11.3 illustrates, argument diagrams make it easier for students to track the support and attack relations among evidence and claims. Computer-supported argument diagrams also give students additional opportunities to practice analyzing arguments or engaging in argumentation, and to do so collaboratively with other students. Finally, recording an argument should help students to reflect on the meaning of the argument's components and how to evaluate the argument.

Despite this promise, instruction with computer-supported Toulmin argument diagrams has not yet been shown to be an effective mode of teaching (see, e.g., van den Braak, van Oostendorp, Prakken, & Vreeswijk, 2006; Carr, 2003; Suthers & Hundhausen, 2001; Twardy, 2004; van Gelder, 2007). We draw at least two lessons from this prior work. First, it is worth distinguishing between pedagogical strategies that employ computer-supported argument diagramming to guide students in (a) reconstructing experts' argumentation examples and (b) constructing and recording their own arguments as they make them. We focus on the former. Second, Toulmin diagrams have some disadvantages. On the plus side, as shown in Figs. 11.2, 11.3, and 11.4, Toulmin diagrams capture an argument's functional or "propositional" structure, they go beyond logical deductive inference in making explicit the backings of warrants, they are extendable to case-based and analogical warrants and backings, and they accommodate not only rebuttals but also argument chains, hierarchical argument structure, and conjunctive arguments (not shown) (Newman & Marshall, 1992). All of these features are useful in representing legal arguments.

On the minus side, there is a question of where law students need more help. Is it to keep track of the relations among claims and data or to formulate and interpret warrants? In the legal classroom, and as suggested above, in the SCOTUS oral arguments, most of the interesting "action" involves the latter: formulating and interpreting the warrants. This is what makes the SCOTUS examples particularly useful for law students. It is not clear, however, that Toulmin diagrams are well-suited to keep track of dynamic interpretations of warrants, and it remains an open problem how best to do so, especially since these arguments frequently involve hypothetical reasoning and the warrant and interpretation change dynamically as the argument proceeds. Toulmin diagrams lack a means to represent strategic argument processes like hypothetical reasoning diagrammatically. It is also hard to imagine how Toulmin diagrams of complex legal arguments involving dynamic interpretations of warrants would accommodate the recursive structures between arguments about claims and arguments about warrants; one suspects that may quickly degenerate into "spaghetti."

Our Approach: LARGO (Legal ARgument Graph Observer)

The LARGO program is intended to assist law students in reconstructing and reflecting on the hypothetical reasoning in SCOTUS oral arguments. A student's diagram

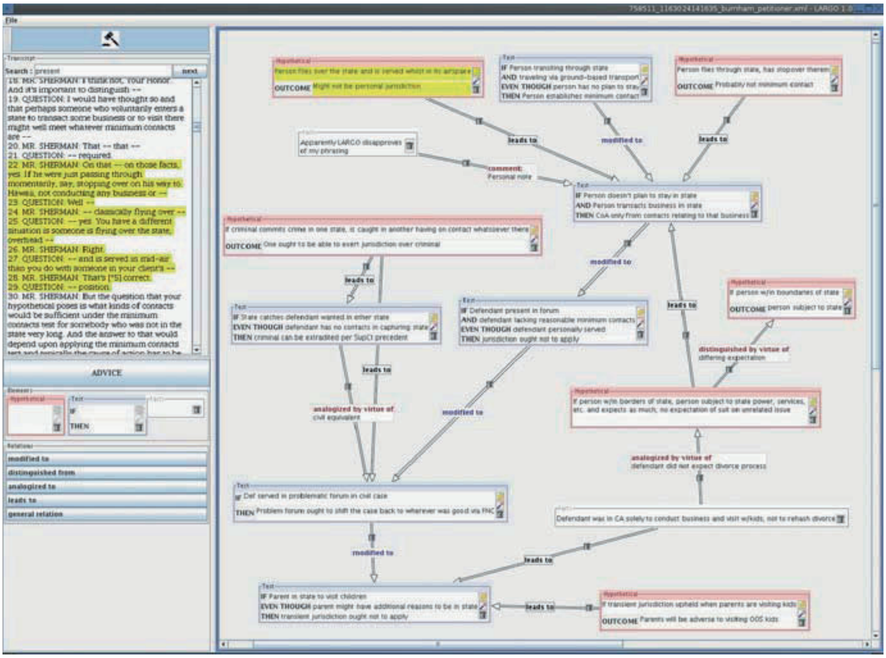

Fig. 11.7 LARGO screen with student's argument diagram

of such an argument is shown in Fig. 11.7. The transcript of the oral argument (here from a case called *Burnham v. Superior Court of California*) appears in a scrollable pane along the left side of the LARGO screen. Students prepare diagrams in the workspace at the right side. A student diagrams the argument by selecting from the palette at the bottom left a node or link, representing an element or relation in the argument, dragging and dropping it into the workspace, connecting it into the developing diagram, and filling it out. Students can also link the diagram's elements to passages in the transcript.

The diagrams are based on the process model of hypothetical reasoning. The nodes/elements represent proposed tests, hypotheticals, and the current fact situation. The links/relations include modifying a test, distinguishing or analogizing a hypothetical, a hypothetical's leading to a test or test modification, and a generic relation. The test element is structured to encourage students to prepare a logical formulation of the test (i.e., with slots for "if," "then," "and," "unless," and "even though").

LARGO provides advice on a student's developing diagram based on the process model of hypothetical reasoning. When a student selects the Advice button at the left side of the screen, the program responds with three hints on improving the current diagram or reflecting on its significance. The program advises students where to look in the argument transcript for passages that should be represented in the diagram, how to improve parts of the diagram that appear inconsistent with the process model, and what parts of the diagram appear to be worth reflecting about in terms of the process model.

Of necessity, LARGO's advice is couched as recommendations for consideration, not as hard and fast assertions that something in a diagram is wrong or must be improved. Since the students are interpreting and representing a textual argument concerning an ill-structured problem, there are no guarantees that all parts of the oral argument are coherent (e.g., there are interruptions, abrupt changes in topic, etc.) A program cannot be sure if a representation is right or wrong. The instructor's markup of the argument transcript indicates where important elements related to the process model are located, but it is not a detailed or "definitive" argument representation.

To produce its advice, the program has a "graph grammar," a set of rules that enforces the expectations embodied in the process model. The rules apply classification concepts to the diagram in order to flag such conditions; Table 11.1 shows some of the concepts and their definitions. Thus, a student's diagram may omit particular elements or relations (No_facts, Isolated_hypo), fail to link elements into the argument text (Unlinked_hypo, Unlinked_test), use inapt relations (Test_facts_relation_specific), include patterns that are worthy of reflection (Discuss_hypo_multiple_tests), or need a better test (Test_revision_suggested). At any point in the construction of the diagram, the graph grammar indicates all such mistakes and opportunities and then prioritizes the associated help in order to pick the "top" three. The ordering criteria include whether the advice applies to a part of the transcript or the workspace where the student is currently working, whether the advice duplicates recent advice, and in which of five localized "phases" the student appears to be in that part of the diagram: (1) orientation, (2) text markup, (3) diagram creation, (4) analysis, or (5) reflection (Pinkwart, Ashley, Aleven, & Lynch, 2008).

Table 11.1 Selected LARGO diagram classification concepts

Classification concept	Meaning	Phase
No_facts	No current fact situation element in diagram	1. Orientation
Unlinked_hypo	Hypothetical element not linked to argument text	2. Text Markup
Unlinked_test	Test element not linked to argument text	2. Text Markup
Isolated_hypo	Hypothetical element not related to other elements in diagram	3. Diagram creation
Test_facts_relation_specific	Test element related to facts element by non-generic relation	4. Analysis
Discuss_hypo_multiple_tests	Hypothetical element related to facts and more than one test	5. Reflection
Test_revision_suggested	Collaborative filtering suggests test formulation could be improved	5. Reflection

Does the LARGO Approach to Supporting Instructional Explanation Work?

We ran a series of experiments comparing learning of first-year law students using LARGO to diagram oral argument examples with those who were taught the process model of hypothetical reasoning but only took notes as they studied the same examples. Unfortunately, as with other computer-supported argument diagramming systems, the evidence that students learn better with the LARGO approach is suggestive but inconclusive (Pinkwart, Aleven, Ashley, & Lynch, 2007; Pinkwart, Lynch, Ashley, & Aleven, 2008). We found evidence that the use of LARGO's advice functions was correlated with higher posttest scores, but students did not use the advice feature frequently enough. We did find evidence that students in the diagramming condition were more successful in finding relevant portions of the oral argument texts than those in the note-taking condition (Lynch, Ashley, Pinkwart, & Aleven, 2007).

On the other hand, there is evidence that characteristics of students' argument diagrams made with LARGO are correlated with and predict information about students' abilities, skills, and progress in law school. In comparing students' diagrams, we noted that students produced very different diagrams for the same oral arguments. For instance, Fig. 11.8 shows the detail of the student's argument diagram in Fig. 11.7; it happens to have been prepared by a 1L. Figure 11.9 shows the detail of another 1L's diagram of the same oral argument. The circled L's indicate that the student has linked the element into the oral argument text. (Fact elements are not linkable to the text.)

In Fig. 11.8, every element that can be linked to the text is linked. The diagram shows numerous tests and hypotheticals and the relationships between them; tests are modified into new test versions, and hypotheticals lead to the modifications. Generally, the fact boxes are used to record the facts of the case at hand, and in a number of places hypotheticals are distinguished or analogized to case facts or to other hypotheticals.

By contrast, in Fig. 11.9, there are only one test and one hypothetical, and only the test element has been linked into the argument text. No tests are marked as having been modified into new versions, and the hypothetical remains isolated; it does not lead to a new test and it is not analogized to or distinguished from the facts at hand. Indeed, the Facts boxes are not used to record facts of the case but rather to record notes about the argument. None of this is necessarily wrong, but it clearly does not show an understanding of the process model of hypothetical reasoning.

We asked third-year (3L) students to perform the same tasks with LARGO as the first-year (1L) students and, using statistical analysis, compared the diagrams with respect to subject population characteristics (i.e., volunteer 1Ls, nonvolunteer 1Ls, 3Ls, LSAT scores, and posttest scores.) The Law School Admission Test (LSAT) is a standardized test taken prior to applying for law school "designed to measure skills that are considered essential for success in law school" including "the ability to think critically; and the analysis and evaluation of the reasoning and arguments of others" (About the LSAT, n.d.).

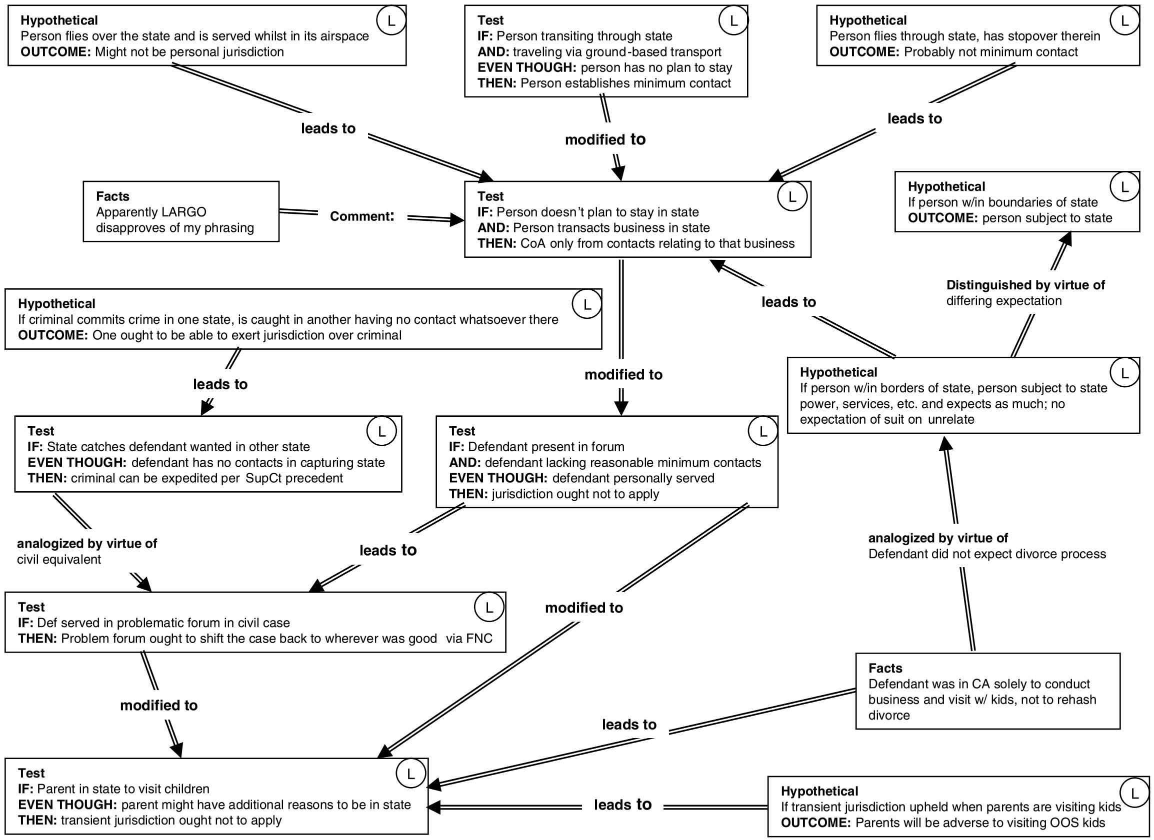

Fig. 11.8 First-year student's diagram of Burnham oral argument

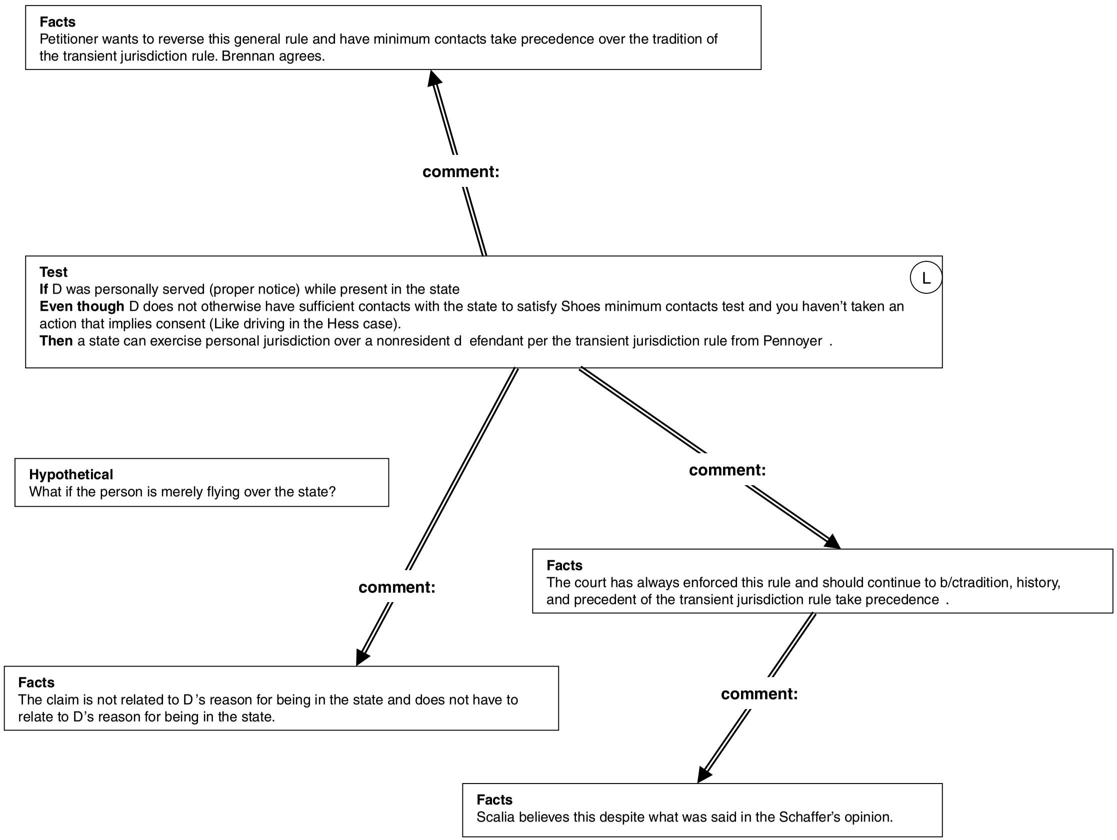

Fig. 11.9 Another first-year student's diagram of Burnham oral argument

We found that the argument diagrams differed systematically across students of different experience and abilities (Lynch, Pinkwart, Ashley, & Aleven, 2008). Regarding LSATs (in a 2007 experiment) the relations-to-node ratio, a measure of how connected the nodes in the diagrams were to other nodes, correlated positively with 1L's LSAT scores ($r = 0.32$, $p < 0.05$) as did the number of relations ($r = 0.32$, $p < 0.05$). (A similar trend occurred in a 2006 experiment with 1Ls, but not with respect to the 3Ls in a 2008 experiment, for whom more time had passed since having taken the LSAT exams.)

With respect to 1Ls versus 3Ls, according to a post-hoc Tukey test, the diagrams of third-year students had statistically significantly:

- more relations than those of volunteer 1Ls who produced significantly more than nonvolunteer 1Ls,
- more elements (i.e., nodes and relations) than those of 1Ls, and 1L volunteers' diagrams had significantly more elements than 1L nonvolunteers, and
- larger relations-to-node ratios than 1Ls.

For purposes of advice-giving, as noted, LARGO's graph grammar applies classification concepts to determine in which phase a student is in a particular part of the diagram. In comparing the diagrams in terms of these concepts, we found that whether a student has linked the hypothetical or test elements in the student's diagram to the corresponding portions of the oral argument text is a good predictor. Another good predictor, Test-revision-suggested, is characteristic of the fifth phase, reflection; it is triggered when the student has rated other students' test formulations using collaborative filtering and his own formulation was rated poorly, indicating that a change might be needed. Its main significance in predicting posttest performance may be that it only happens in highly developed diagrams, some of whose parts are in the reflection phase.

Certain classification concepts (defined in Table 11.1) correlated with whether a student is a first-year student or a third-year student. Test_revision_suggested (indicating that the test formulation could be improved) and Test_facts_relation_specific (indicating that the student has constructed a specific relation between a test and the facts of the case that does not fit, such as "modified to") were good indicators of diagrams by third-year students. Both are characteristic of the last two of LARGO's advice phases, analysis and reflection. If third-year students, knowing more about legal argument, produce more complex diagrams, this makes sense. By contrast, No-facts (i.e., a failure to include a Fact box) and Unlinked-test (a failure to link a test to the text) were good indicators of diagrams by first-year students. Since law school inculcates a respect for the text and a focus on comparing the facts of the case at hand with hypotheticals and past cases, it also makes sense that 1Ls would be relatively deficient in this regard. These differences in attending to argument texts, identifying more elements and relations in the oral arguments, and focusing on the tests and the facts of the case in relation to the hypotheticals are all characteristic of "thinking like a lawyer" (Stuckey et al., 2007, p. 278), an important goal of legal education

Thus, argument diagrams made with LARGO appear to provide a snapshot of a student's understanding of at least some aspects of legal argumentation that are included in the skills of thinking like a lawyer, and as the discussion above illustrates, they are susceptible to objective empirical methods. In other words, it appears that the argument diagrams may provide legal pedagogy with new empirical tools to track students' understanding of legal argumentation and to investigate when law students learn to think like a lawyer. Legal instructors could use LARGO diagrams to identify early on the students who do not understand this kind of instructional explanation or who have some misconceptions about legal arguments as evidenced by their ineffective attempts at reconstructing legal argument texts. LARGO could employ the diagram classifications to identify such students more effectively and better tailor its advice, for example, by insisting that students address certain failings in the diagrams. And researchers could employ LARGO diagrams as an easy-to-apply metric for investigating questions, such as when do law students learn certain legal reasoning and argumentation skills and what factors influence whether they are likely to do so successfully and efficiently. It would be interesting to study, for instance, whether there are any interesting stages in students' learning to express legal tests in a logical format or to compare the facts of hypotheticals and the case at hand.

Since legal arguments with hypotheticals like those illustrated in the SCOTUS examples constitute law school instructional explanations, it follows that legal instructors have some difficulty in determining whether students understand the explanations. Students actively participate in such arguments only intermittently. As a result, instructors do not have much data on which to base an assessment of whether a student understands hypothetical reasoning. If one student's argument gets bogged down, instructors move on to another. Given the pressure to generate a fairly coherent explanation of the classroom material using the unwieldy tool of Socratic discussion, presumably instructors often miss subtle errors in one student's understanding as long as some other student is able to continue the thread of the argument.

For this reason, the diagnostic utility of argument diagrams made with LARGO is important. This is especially so because the instructor's lesson almost never is about hypothetical reasoning; instead, it is about some area of substantive law. Instructors use legal argument with hypotheticals as a medium of instructional explanation to teach contract law, torts, intellectual property or whatever area of substantive law the course is about. The instructors assume that students have quickly developed an understanding of legal argumentation. For many law students, this assumption is often correct, but there usually are some students who do not pick it up. Diagnostic argument diagrams could help ensure that instructors do not have to wait until the final (and often only) examination to find out that a student is lost.

In order to confirm and expand on this evidence of the diagnostic utility of LARGO argument diagrams, we are conducting an experiment in which legal instructors evaluate the diagrams, blinded as to whether they are from first- or third-year students. The graders formulated pedagogical criteria and appear to have identified new diagrammatic patterns for evaluating the diagrams and assessing what the diagrams can tell instructors about the students' understanding of legal arguments. We also plan to investigate any systematic changes in students' diagrams over the six-week LARGO instructional periods and will try to relate those to posttest performance. We will also compare diagrams that students prepared earlier versus later in the course of the instruction and analyze the relation of help usage to changes in the diagrams.

Conclusions

To summarize, argumentation with hypotheticals is a mode of instructional explanation in law school that explores and communicates the meanings and limitations of legal rules. It is an essential tool for students to learn in dealing with typically ill-structured legal problems. Computer-supported argument diagrams may help students to learn these skills of reasoning about rules as warrants, but Toulmin-style argument diagrams may not be ideal representations for that task. We focus instead on a process model of hypothetical reasoning that informs the argument diagramming in LARGO. Our program is intended to teach law students about hypothetical reasoning as an argument strategy for reasoning about warrants. Students use LARGO's diagramming support and advice to reconstruct examples of hypothetical reasoning in Supreme Court oral arguments. The diagrammatic support, in turn, embodies and operationalizes the process model. Evidence supports the utility of LARGO's argument diagrams as correlated with students' argument ability and progress in law school, and thus as a potentially valuable diagnostic tool.

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Chapter 12
Connecting with Art: How Families Talk About Art in a Museum Setting

Karen Knutson and Kevin Crowley

In this chapter we explore the question of what families learn about art during visits to an art museum. Museums are informal learning environments that can be designed to provide experiences that reflect disciplinary thinking and support explanatory engagement (National Academy of Sciences, 2009). Conversation is a natural part of a museum visit, and researchers have discovered that analyzing these conversations provides access to the processes of learning that take place in informal settings (Leinhardt, Crowley, & Knutson, 2002; Crowley & Jacobs 2002; Ash, 2002). Studying conversations allows researchers to explore the ways in which prior knowledge, motivation, and the specifics of a particular moment create a context in which a learning experience transpires. Science museums in particular have looked closely at the ways in which mediation helps to shape more fruitful learning experiences, and they have designed environments to support the learning of particular concepts or learning behaviors (Borun, Dritsas et al., 1998; Humphrey, Gutwill et al., 2005).

But, historically, the issue of learning in art museums has been a more complex undertaking. This is because, at its core, there is a dual purpose for the art museum. On the one hand, art museums are meant to preserve and protect a culture's riches and to promote an aesthetic experience of these treasures. On the other hand, museums profess an educational mission that is based in the belief that art is a discipline that connects us to the human condition and to the world's history and cultures. While these two purposes need not be mutually exclusive, traditionally there have been two camps: those who believe the object should speak for itself and those who believe that the museum should provide additional interpretive support (Zeller, 1989). Some believe that an aesthetic experience is best served by the display of artworks with minimal or no interpretive signage. And those who favor a more educational approach feel that interpretive signage is essential to help the average visitor understand the meaning and importance of the work.

Of course, this dichotomy need not be so starkly expressed. Art museums vary widely in how they perceive and value their educational role. Many art museums

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have a long history of creating innovative ways of mediating visitor experience in the galleries. From handheld devices to extended labels, computer kiosks and family guides, there is no shortage of effort directed at engaging visitors in the museum experience. But, for those museums that have decided to provide mediation for visitors, they must make hard choices about the information that is to be provided. Each artwork might be used to explain issues of culture history, patronage, geography, techniques, artist intention, or theories of beauty, among other things.

Theoretical developments within the discipline of art history and museology have also complicated the role of interpretation in museums. The advent of postmodernism questioned the possibility of having a single, authoritative interpretation, and several high-profile museum controversies around issues of interpretation resulted in the culture wars and the re-examination of authority and whose interpretation is privileged in museum settings. For example, an interpretation of the Enola Gay that recognized the immediate impact of dropping the bomb was heavily criticized by American World War II veterans (Wallace, 1996), the display of Serrano's *Piss Christ* marked the beginning caused a major public debate about the funding of controversial artworks by the NEA (Bolton, 1992). During this period minority cultures and groups also began to clamor for representation in museum displays (e.g., Karp & Levine, 1991).

At the same time that museum curators were worrying about their authoritative voice, there was a growing interest in constructivism within museum education circles. Art museum educators were focusing on making museums more welcoming to visitors, and found the constructivist emphasis on individual meaning making a powerful idea. Among the most influential of these theories have been Gardner's (1993) concept of multiple intelligences and the entry point approach (Davis, 1996); Hein's (1998) constructivist focus on the role of prior experience on personal knowledge; and Housen's stage model for aesthetic development, and the visual thinking strategies approach (Housen, 2007). These educational theories also conveniently took the postmodern pressure off of the museum – if good learning principles dictated that visitors should make their own interpretations, there was no need to decide what the museum needed to say about the art.

Meszaros (2006) labels the resulting trend in museums as the "evil of the 'whatever' interpretation." She argues that too many art museums have allowed their galleries to become an interpretive free-for-all. Art insiders may still know the value and meaning of artworks in the galleries. But what of average visitors? They are often left on their own without much in the way of explicit mediation.

In this chapter, we start with an assumption. While there are complex issues at play in art museum practice, learning about art is a desirable outcome for art museum visitors. We believe that art museums are places where disciplinary practices in art history are enacted and promoted. But to what extent does that inform and enrich the visitor experience? Are visitors talking about and learning about art and art history during typical art museum visits?

Compared to the extensive literature on learning in science or children's museums, there have been relatively few studies of learning in art museums. When research has been conducted in art museums it has tended to focus on the evaluation of school-based or adult programs (e.g., Luke, Stein et al., 2007), or on marketing research that captures the demographics and habits of visitors (e.g., Sterry & Beaumont, 2006). We still know relatively little about the learning experiences of average visitors who visit exhibitions in an art museum.

The Study

The visitors we focus on in this study are families with children. We focus on families for the practical reason that many art museums are interested in cultivating and supporting family audiences. Art museums have traditionally been challenging museum environments for families, as they have often been designed by default to support adults who want to contemplate beautiful objects in a quiet environment. But families typically come to museums with learning as a primary motivation (Swartz & Crowley, 2004). In response, art museums have begun to develop creative ways to engage family audiences, such as providing family guides and programs. One of the more recent developments has been the inclusion of specially-designed rooms that contain materials and experiences directed at helping families with young children have a meaningful (and fun) learning experience at the museum. These areas typically provide a series of hands-on activities, combined with visual representations (usually not originals) of artworks in the museum's collection.

To explore the question, "What does family learning look like in an art museum?" we analyzed family conversations at two art objects and at two related discovery room stations. One object was an 18th century bed from France. The huge canopy bed dominates its gallery. It is ostentatious and very detailed – complete with ostrich feather plumes, swags and tassels, and elaborately carved details. The bed's sheer size and the stunning level of craftsmanship involved attract visitors. The other object was a large-scale narrative painting of a crowd scene with caricature-like figures, some of whom wear masks. The painting was done in a highly expressive style with lots of details to notice.

The study involved 50 pairs, consisting of a parent and a child (8–11 years old), viewing artworks in a large survey museum with works from many historical periods. Participants were pre-recruited and screened in order to include families who had visited an art museum together at least once, but who were not frequent museum-goers, or art experts. When families came to the museum, researchers explained the study and obtained signed informed consent to participate. Both parent and child were asked to wear cordless microphones. All families began by testing their equipment while looking at an artwork that was not included in analysis. After ensuring that families were comfortable, researchers led the family to the gallery in which the first target object was located, and pointing to the object said, "Please take a look at that and talk about it together as you normally would. Let me know when you're finished and we'll go to the next stop." Parents also completed an interview and survey about art museum habits at the conclusion of the study.

In the remainder of the chapter we first present an example of what family conversations sound like in art museums. We then develop and apply a framework for considering the disciplinary content of art talk. Finally, we examine whether one common mediation strategy – interactive discovery rooms – impacts family learning in the galleries.

An Example

This is an example of a parent and child in our study talking about the large-scale narrative painting. It is a good example that illustrates the breadth of conversational topics and tactics that we saw across our data set. This colorful expressionistic painting depicts a crowded street scene where many of the figures are caricatures or wearing masks and costumes. A figure of Jesus riding a donkey is at the middle of a parade coming down the street. Amidst the onlookers, there is a large banner that reads "Vive la sociale." There are many details to be noticed and discussed, and a bench in front of the painting allows visitors to stay and sit awhile to take it all in. A text panel (on the adjacent wall) provides some detail of the political and personal context of the work. The family walks up to the painting, pauses to take in the view, and the parent turns to the child and says:

P: Wow, so what do you think that says?
C: Viva la sociale.
C: Viva Jesus. . .1880. (Humming to self)
P: It's a very interesting style because it's not as realistic as a lot of the French painters were.
C: And it looks like its. . .
P: Hang on, let me look at the tag. Oh, so this painting is called Christ's Entry into Brussels in 19- in 1880 something.
C: 1889.
P: Yeah, well where's Christ?
C: Well, it says Vive Jesus.
P: Yeah? Which means what?
C: Oh, see him in that sombrero back there?
P: Yeah. Do you think that's a sombrero or do you think that's like a halo of light around him?
C: Probably a halo.
P: Is he walking?
C: Yeah.
P: No look. Look closer.
C: It looks like he's floating. No, he's riding a donkey.
P: Yeah.
P: Paintings like this, you know, they're really deceiving because what happens is when you first look at them, you see certain things and if you look longer then you can see more things, and more things, and more things.
P: Oh yeah, he used that same technique to make things look like they're farther off in the distance by making them smaller. The same thing your teacher taught you.
C: (inaudible sentence)
C: Hey look, there's a skeleton. Green and blue.
P: You know what I find really interesting about this painting is the colors.
C: Yeah. It looks Mexican.
P: They're all light, bright colors. Do you know what I mean? Bright primary colors.
C: Except for the dark blue.
P: Do you like this painting?

C: It's funny.
P: What makes it interesting?
C: What- who- how all this stuff is going on and then the marching band is like walking through the middle and everybody's crazy like, shoving into the streets to get out and get away and then in the background you can see two clowns fighting.
P: I don't see the clowns fighting, where do you see that?
C: See the red and blue? Yeah, right there and there.
C: Then there's a girl holding like a giant zebra.
P: Wow.
C: And there's a skeleton.
C: Right in the middle of all the marching band there's like a soldier and he has all these badges that look like they're from a war.
P: Hmm…and all the flags in the background there. It looks like some people are wearing masks…and some people… you know, like there's this skeleton looking one, and that one with the, I don't know what you call him, beside the needle or the…it's probably a marching baton the guy is carrying. Do you know how they do that…?
C: No that girl. Not the guy, the girl, in the very front? That blue thing? That dark blue thing?
P: What do you think that guy is over there?
C: An Indian.
P: Because he's got a tall pointed hat?
C: Uh, he looks Indian or something.
P: Do you know where Brussels is?
C: Nope.
P: Brussels is in a country called Belgium. Belgium is on the coast, you know how England is here and then you go across to France, you work your way up, there's Belgium, it's very small. Do you know what language they speak there? You can read it in the painting. Well, French. They just have a different- they speak French with a slightly different accent than in France.
C: Ok.
P: Belgium is known for- they have really good Belgian chocolate and beer and other things. (Family 34, Painting)

What is there to notice about this conversation? First, they are actively involved in discussing the object. They notice a lot of details in the composition. What is that guy doing? What does that say? Where is the painting from? But all of that noticing does not lead to a great deal of interpretive art talk. At one point the parent comments about the use of perspective and connects this experience to an art class the child apparently had in school. But the talk steers quickly back to listing details, as the child notices a character wearing a skeleton mask in the foreground. As the interaction winds down, the parent looks for another avenue of discussion and comes up with some facts about the artist's homeland. It was the third time the parent tried to offer a more interpretive or contextual comment – first noting the style relative to French painters, second perspective, and finally the language, beer, and chocolate of Belgium. But the offer is not taken up by the child and the adult did not have either the tools or the interest in using these attempts to inform their analysis of the painting. It was as if the adult knew that you were supposed to talk about some bigger ideas, but was not quite sure where to start or how to make it work.

This is a fairly typical example of how visitors talk about art in a museum. In prior work, researchers have focused in on structural aspects of such talk and paid less attention to understanding the disciplinary content. For example, Silverman

(1990) grouped visitor talk into categories that included establishing joint attention, expressing a preference or judgment, describing object features, connecting with relevant personal experience, and relating “special knowledge” about the object. Similarly, in our own prior work (Leinhardt & Knutson, 2004), we proposed a hierarchy that broke talk into listing features, comparing across features, connecting objects to prior knowledge, making personal connections, and, finally, constructing explanations around the object. A second level of coding looked at thematic knowledge. In both of these cases, the content categories “special knowledge” and “thematic” were general – a black box with little differentiation of the kinds of disciplinary knowledge, skills, and concepts that might lie within. This work on the structure of visitor talk has been important, but, as we have worked with museums to put this descriptive research into designed experience, we are discovering that the black box of content needs to be unpacked, debated, and explicitly scaffolded for the visitor. Simply encouraging visitors to talk about objects does not result in richer learning if they do not have sufficient disciplinary knowledge to produce good explanations (Kim, 2009). In order to design mediation for learning, art museums need help deciding *what* it is that visitors should be talking about, not just *how* they should be talking about it.

A Framework for Coding the Disciplinary Content of Art Talk

The field of art education has grappled with a similar dichotomy to the one occurring in art museums as described in the introduction to this chapter. Creative expression has been the backbone of art education since the 1960s, but historically the pendulum has swung back and forth between art education being an outlet for creative individual expression and art education that serves cultural and humanistic education goals (Burton, 2004). Recently, arts educators have been returning to a more contextual position, looking for ways to support the teaching of art using a more rigorous academic framework that supports the humanistic goals of art education as well as the individualistic expressive and technical skills studio side.

Discipline-Based Art Education (DBAE), a curriculum model that focuses on four disciplines in art education (studio, art criticism, aesthetics, and art history), has had a large impact on the development of curriculum standards across the United States and Canada, including a set of National Standards developed in 1994 (Eisner & Day, 2004). These standards for art education hope to ensure that students develop a foundation in understanding not only the studio-based processes of making art but also the means for understanding how to talk about, assess, and appreciate art, and understand its role across time and culture. The DBAE framework was based on the idea that there are four main professional lines of work in the visual arts that could be aligned with a field of study (studio, art criticism, aesthetics, art history). While the standards have worked to identify potential academically rigorous strands upon which a curriculum might be built, there is still much disagreement about how to proceed. First, research that documents the specifics of what should be taught has focused primarily on studio components and not on the contextual components of the curriculum (Burton, 2004). Second, researchers have noted that one of the challenges of including these non-studio disciplines in the classroom is a lack of models for curriculum and instruction (Hagaman, 1988).

Third we believe there is a great deal of crossover between skills and concepts across each of the proposed strands. For example, take the idea of aesthetics. There is typically confusion around the use of the term. Sometimes it is used as an adjective that relates to a kind of art criticism, while other times it is used as a noun to mean the philosophy of art. Aesthetics, as the "why" of art, relates to art history because the understanding of why something was celebrated and preserved in a particular time is a contextual discussion.

In terms of art history, Addiss and Erikson (1993) propose that there might be four possible orientations to the study of art history in the formal system – studying the work (formal analysis), the artist (biographical), the audience (patronage), and the culture. This model suggests that art history relies heavily on aspects of art criticism, and indeed, the discipline of art history has been built on the concept of connoisseurship. But it importantly brings to bear aspects of the time in which the art was produced, the context in which the piece is seen or has been judged. It connects the visual with the historical and cultural to understand and explain the human condition. Museum curators – developing exhibitions and researching collections – are active disciplinary experts producing new knowledge for the field.

Finally, there is art criticism. Art criticism is the analysis and evaluation of works of art. The use of art criticism can stand alone as its own pursuit, but it is also an essential part of the other art disciplines of studio, art history, and aesthetics. Art criticism is typically taught via a variation of Edmund Feldman's model – Describe, Analyze, Interpret, Judge (Feldman, 1967; Barrett, 1994). In the describe stage the viewer looks at the piece and notices details (shapes, colors, subject matter, media, etc.). The next stage involves analysis, which considers the ways in which the various elements of the work fit together. Analysis involves thinking more carefully about the artist's choices in creating the composition. How do colors work together? How does the artist create a sense of balance, proportion, rhythm, etc? These first two stages of art criticism come directly from observation of the work. The next two stages, interpret and judge, can involve some kind of external reference. Both interpretations and judgments can be made from a personal point of view, but they are stronger and defensible when they draw upon knowledge, criteria, opinions, or references beyond the viewer and the work itself.

In art criticism, being able to distinguish the nuances of a brushstroke, a line, or a stylistic anomaly form the basis of connoisseurship. The ability to distinguish and compare, to describe and notice are important visual skills to be developed. Yet criticism as it appears across the art disciplines is not considered within a vacuum. Context is required – understanding how the visual has been shaped by the creator, how the work fit into its time, why we should care about it. Art criticism is interpretive and theoretically based, and it makes an effort to understand the significance of a work of art in the history of art.

Much of the recent work on art talk in museums has focused primarily on formal criticism (what do you see?) and interpretation (what does it mean?) to the exclusion of other core conceptual aspects that surround the display and interpretation of artworks in museums (i.e., how was it made, why is it here?). Additionally, while interpretation is actually a very complex area of academic interest, and an important disciplinary practice, much recent museum work might be characterized as leaning too heavily on "What does it mean, *to you?*"

In fact, if you ask families about it, they are much more interested in turning that question around to the museum. At the end of this study we interviewed parents about why they bring their children to art museums and what museums could do to support their visiting agendas. A clear finding emerged: Parents told us that they go to art museums to help their children learn about art and that they feel ill-equipped to help with this learning without explicit support from the museum. For example, when asked to rate a number of different reasons why they visit art museums on a 5-point scale, parents rated "learning about art" as being "very important" (M=4.2 of 5). Parents generally rated their art knowledge as being just below average (M=2.8 of 5) and told us that they did not know enough about art to answer all of their children's questions in art museums. It is not surprising, then, that when we asked parents what art museums could do to improve the family visiting experience, they asked for more interpretive information specific to the artwork, including "what the art means" (M=4.32), "how the art was created" (M=4.44), and "the life of the artist" (M=4.6). Parents strongly agreed that museums should provide such information in ways that help them talk about the art while viewing it in the galleries (M=4.54).

A Disciplinary Lens for Art Museum Conversation

Drawing from these broader discussions about the nature of disciplinary knowledge, we developed a coding scheme to distinguish between four categories of visitor art talk. We describe each below, followed by examples drawn from our data.

1. *Personal Connections*. The role of prior knowledge and experience has emerged as a key indicator for learning in informal settings (e.g., Leinhardt et al., 2002; Falk & Dierking, 2000).

> How would you like to sleep in a bed like that?
>
> I think it would be cool. (Family 22, Bed)
>
> Remember when we went to the field trip and they had all those paintings of people of that – oh, not paintings but um – what do they call them? Prints! Of, of skeleton people? (Family 5, Painting)
>
> Do you remember- have you seen any artwork on the Beatles uh not the Beatles- The Yellow Submarine and Beatles animated movie? Did we rent that yet? That guy right in the center with the big round eyes- see the mayor and the mayor's hat- his yellow hat?
>
> Yeah.
>
> And it's pointing right up to the guy wearing the green shirt? He looks like one of the Blue Meanies. Except he's not blue. But the style- I'll show you. We'll rent it. It's a cool movie. (Family 2, Painting).

Sharing personal connections is a common museum activity (Leinhardt et al., 2002). While these conversations do not necessarily align with the disciplinary agenda of the informal learning environment, these conversations are important in the context of a family's everyday learning experience. Museum visits are often about reinforcing group identities, and an effective way to do that might be, for example, talking about a past family trip.

2. *Criticism*. This is talk about what can be directly observed in the artwork. Visitors might describe or direct their partner to attend to specific details. Visitors might offer a local analysis or interpretation that attempts to develop or connect their observations in more detail. The key piece of evidence in assigning a criticism code was that visitors were using only the information directly at hand in the object and that they were talking about the object without considering how or why it was created.

> Oh, look at this. Did you – I didn't see this at all. It's like, it looks like a cornucopia of, with different fruits and things coming out of it. (Family 14, Bed)

> Oh, there's a decorated man in there too. Army guy, military. So that's a band, like a military band? (Family 43, Painting)

These examples show common segments in this category, where families are describing visual aspects of a work. Whereas art criticism is a broad disciplinary practice, in this coding scheme we use it very simply to mark the direct observations of visitors. When families begin to connect visual components – to analyze the composition and choices of the artist – we place that talk into the creation category.

3. *Creation*. These were comments that attended to the object as an artwork. These conversations included attention to the artist in some way, whether directly referencing who made the artwork or through an observation of skill or technique. This talk could sound similar at times to *criticism*, but we created this category to distinguish conversations where visitors were noting or interpreting artistic process vs. treating the artwork as on object on its own terms. The inclusion of this category allowed us to make more fine-grained distinctions between conversations that noted a formal element and those that noted a formal element and referenced it as such. We were able then to code those meta-level comments about the art-ness of the artwork, alluding to the creative forces behind the creation of the artwork or using vocabulary that indicated some sense of awareness of the artist's process.[1] While this category includes conversations that would be considered a part of normal art criticism practices, we differentiate it to emphasize the importance of visitors' considering the decisions, motivations, and techniques of the artist.

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[1] Callaghan (1997) found that it is uncommon for average adult art viewers to refer to either the artist or the viewer when asked to justify a classification of an artwork. Most focused on the qualities of marks made (50%), one-third focused on the subject matter and only 2% made an explicit reference to artist or viewer. This suggests that visitors need more help to think about the intention and the interpretive process.

> Come on this side. Look at how intricate this is, how it's all carved out. Can you imagine carving that out of wood? (Family 29, Bed)
>
> This one has a lot of paint.
>
> Yeah, it almost seems like he spent more time doing that. (Family 23, Painting)
>
> These, the big people up here? See how it gets smaller, smaller, smaller, smaller, smaller, all the way to the back? (Family 23, Painting)
>
> Yeah, do you see where- see where the two lines of that- going back to the perspective, going back to your focal point in the back corner right up there?
>
> Want to hear something I noticed? Look back on that street between the pink building and the white building. It looks like the road is curving that way. (Family 9, Painting)

These examples show talk coded as creation. The first two examples show families directly referencing the artist, while the other examples are more indirect references to the artist and the choices he/she made in the creation of the artwork. Creation talk includes specific vocabulary about how the work was put together (i.e., perspective, texture, medium, composition, etc.). Creation talk indicates some evidence that the family is thinking about the artwork as an intentionally designed object, where choices were made to create a specific effect. This distinction separates criticism from creation codes. Criticism codes show perceptual attention to visual aspects but do not reference the creative process. By attending specifically to the process of creation, creation codes provide a way to move art conversations from strictly personal observations to conversations based in specific art content.

4. *Context*. This category was created to capture talk about the historical, geographic, or cultural context of an object. Although the surface content of this talk could sometimes sound similar to *criticism* or *creation*, it was coded as *context* if there was evidence that visitors were learning about details or interpretations that make the object meaningful as part of a museum collection. This is a large part of the work of curators and represents the vast knowledge bank housed within a museum in its staff. This is the way in which we can understand the value of art for humanity. This is an area of conversation that is not accessible through visual thinking strategies alone. Accordingly, visitors, without bringing prior knowledge to the museum, have a very difficult time with this kind of talk:

> That's immediately what I thought of as soon as I walked in here and saw this bed. I thought of Marie Antoinette. (Family 22, Bed)
>
> Yeah. It looks like a hat.
>
> {laughs} Yeah, it does look like a hat. But it's actually supposed to be kind of a – you see it in a lot of paintings as this holy symbol. You know, they'll have it on angels and Christ and the Madonna or Mary. Right? (Family 2, Painting)
>
> Look at that little animal that the person with the sombrero is wearing.
>
> That's Jesus.
>
> I know.

My poor religiously uneducated child.

I know. I forgot for a minute. (Family 5, Painting)

The way to think about the relation of the art codes is that *criticism* refers to the object by itself, *create* refers to the object and its creator, and *context* refers to the object and the creator in the context of who they were, where and when they were created, or why it is meaningful in the history of art and culture. All three of these are core disciplinary practices forming the cornerstones of collecting and interpreting art in museums. By thinking about visitor conversations in these three discipline-specific categories we might begin to think about ways in which conversations could be prompted, supported, or moved toward more concrete art learning goals by museum educators.

Family talk at the Painting and the Bed was transcribed and then segmented by idea unit, defined as a new topic being raised by either the adult or child in the ongoing conversation. Within each idea unit there could be multiple turns by both parents and children. Each idea unit was then assigned one of the four codes or, if the unit did not focus on the art object (e.g., navigation or social management talk), it did not receive a code. Each unit was assigned only one code. It occasionally happened that criticism might overlap with the create and context codes, for example if visitors noticed a detail in the object and wondered about how the artists created it. In these cases, create and context codes, which establish interpretations of the object itself, were used.

Observing Family Conversations

We analyzed the conversations of the 50 families in our study, and, as shown in Fig. 12.1, the most common kind of talk we coded was criticism, both at the Bed and at the Painting. This should not be surprising, as visitors coming upon an object

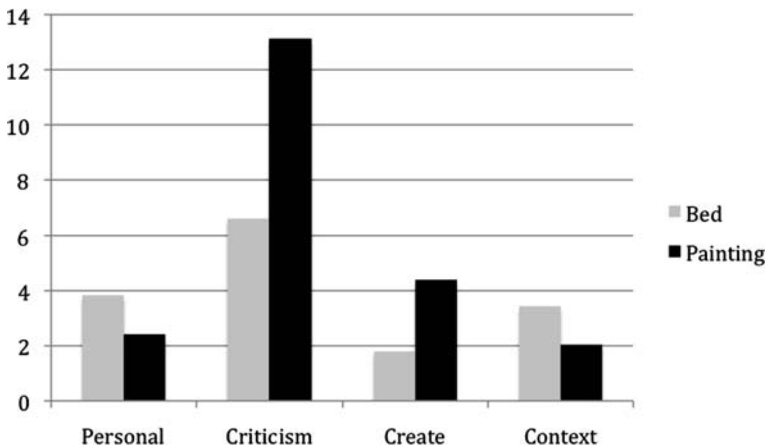

Fig. 12.1 Mean number of exchanges per family coded in each category of art talk

might naturally begin their conversations by noting details within the object and making sense of them with respect to the overall object. It is common in museums to see groups establishing a common understanding of objects as part of building shared interpretations (Leinhardt et al., 2002).

What was more interesting to us was that we also regularly observed families engaging in talk that we coded as being about the creation and context of the object. This talk was significantly less common than criticism, but its existence suggested that families were at least attempting to connect their interpretations to disciplinary constructs beyond criticism. And these attempts were widespread: Every family in the study was coded as having at least one create or context exchange and 93% of families were coded as having done both at least once.

Were there differences in the relative frequency of the kinds of interpretations families constructed at each object? Comparing the raw code counts between the Bed and Painting reveals differences for each of the four categories of talk. However, it is apparent from the figure that there was also an overall difference in how much talk we observed at each object. Combining across the four categories of talk, families were coded as having an average of 22 comments at the Painting compared to 16 at the Bed. This may partially reflect a belief that narrative paintings are easier to talk about (Yenawine, 2003) and it may also be simply due to the simple fact that the painting was just a lot bigger and had more details to notice than the Bed:

A more precise comparison, between-object comparison, requires that we convert the talk codes from counts into proportion of coded talk that fell into each category. Paired t-tests comparing the proportional scores across the bed and painting revealed significant differences for each category of talk (all p's < 0.001). While viewing the painting, families were significantly more likely to engage in criticism talk (60% of coded talk) and create talk (20% of coded talk) than when they were viewing the bed (42 and 11%, respectively). At the bed, families were more often observed using context (22% of coded talk) and personal connections (24% of coded talk) than when they were viewing the painting (9 and 11% of coded talk, respectively). Prior studies of talk in art museums have not distinguished between types of objects and the kinds of talk that is easily supported. The findings here suggest that there are important differences to note. It may be easier to think about the artist while looking at a painting and it may be easier to think about context when faced with a decorative object like the Bed.

It is a promising finding that families used, on average, all of the categories of talk. But the low numbers of creation and context talk bear out what our examples suggested: families need help to interpret art in the galleries. These families tried to get beyond a visual experience, but they did not have the tools to do so.

This finding parallels what has been documented in school-based research, that interpretation is the aspect of art criticism that needs the most help (Barrett, 1994). Criticism has rightly been the focus of museum education work, and in the past few years, common approaches involve getting the viewer to engage with the work, without additional input or evidence beyond what is seen in the work. This may be a useful approach in the development of observation skills, but it leaves the interpretation and judgment aspect of art criticism underdeveloped. There is no way to develop expertise in art without additional information of some kind, as without this supplementary information it is impossible to make a reasoned judgment. One can only make a personal judgment. While postmodernism might have launched a period of anything goes, in fact, some interpretations are better than others. In order to support meaningful conversations about art, we need to be more specific about interpretation and content.

A Common Mediation Strategy: The Discovery Gallery

The museum where we conducted this study had a very popular discovery room that was intended, among other things, to help families learn about the art that was in the permanent collection on the gallery floor. Family room experiences were designed to explicitly refer to objects that the family might encounter in the galleries. The objects we described earlier, the Painting and the French Bed, were the focus of two different interpretive stations in the family room. The Painting-related station allowed visitors to create a mask using paper mask cutouts and crayons, working in front of a large reproduction of the painting. The mask making activity is connected to the Painting because there are characters wearing masks in the painting. The Bed station allowed visitors to sit in a small bed similar in look and feel to the French Bed. Books related to beds are available for families to read together as they sit on the reproduction bed. In two books produced by museum staff, families could read about the materials and processes used to produce the 18^{th} century bed and about different kinds of beds produced around the world.[2]

To test whether using the discovery room changed how families talked about the objects, we asked a subset of the families in our study to visit the discovery room station before they viewed the corresponding object in the gallery. To maximize our chances of observing impact of the discovery room on subsequent gallery talk, we made sure families intended as in understood the intended activity. At the Bed station we said, “Please take a look at this area, and these two books (pointing towards the two museum-created books – one on beds around the world, and one about the French bed). Spend time and talk as you normally would and let me know when you’re finished.” At the Painting-related station we said, “Please take a look at this area. Make a mask together and while you’re working could you talk about

[2] Although most families use the family room as a learning environment, some use it as a playground. The reality is that children sometimes need to take a break from the museum to blow off steam and touch something without getting yelled at by guards. And parents sometimes need a break too. There are always a few who sit off to the side, talk on their cell phones, chat with each other, or glance through pamphlets while their children bounce from activity to activity. It is important for museums to provide this kind of place for families, and these activities serve the outcomes of making the day a pleasant outing, of valuing families’ needs, and even perhaps ensuring, with fun, that children might become lifelong users of museums. However, these goals do not advance the museum’s art-specific learning objectives.

the ways in which artists give their figures a sense of personality. Spend time and talk as you normally would and let me know when you're finished."

When we compared the gallery conversations of families who visited the discovery room before they saw an object with the conversations of families who had not visited the discovery room first, we detected no significant differences in personal connections, criticism, creation, or context talk. We had observed and recorded families as they used the discovery room, so we know that they followed our instructions and completed the activities as designed. The lack of transfer was disappointing to us, but we recognized that it is in general very difficult to get transfer to occur across contexts.

While we didn't find transfer in the disciplinary kinds of talk, we were able to find evidence that the discovery room experience was referenced while families were in the gallery. In looking through the transcripts of family talk, we located 215 instances where families explicitly mentioned prior discovery room experience while looking at an object (an average of a little more than 6 per family). Here are some examples of what these references sound like:

C: Oh mommy this is the stuff we saw that was hand-made, remember?
P: That's right.
C: Oh, look at this. That- this is pretty.
P: So do you remember what this is? What did they call this kind of wood?
C: The- what was it? The. . .
P: Gilded, remember?
C: Gilded, yeah. [Family 8, Bed]

P: Same thing. Remember like that one in the, um, second binder we were looking at where it's-
C: It's holding-
P: Yeah. The canopy is suspended because see you have the four posts right?
C: Yeah.
P: They call it a four-poster bed but um the posts are not supporting the canopy. They'd have to suspend it from the ceiling. [Family 2, Bed]

P: I have to say, you, I think you can see the person- look at the personalities more here.
C: Yeah.
P: I don't know why. Why do you think?
C: Maybe 'cause it's bigger.
P: It's bigger. You can also sort of see the brushstrokes, and it seems more vibrant somehow. The other one was a print. Just a copy. [Family 26, Painting]

P: Don't touch!
C: I can't? I could touch the other one.
P: You didn't touch the other painting.
C: Yes I did.
P: That wasn't a real painting.
C: Oh.

P: That was a reproduction of this painting.
C: You mean this is the real painting?
P: This is the real painting. That was a reproduction of the painting.
C: Oh.
P: You didn't – you don't know the difference that that was a poster of this painting?
C: No.
P: And this is the real painting.
C: No, I didn't know that. I didn't. [Family 15, Painting]

As shown in the examples, most families recognized that they were looking at the authentic object that had been reproduced in the discovery room. But beyond that, we noticed families using two specific approaches to connecting the authentic and reproduced object. The first kind of talk we coded was *Content,* where families explicitly discussed content that they had learned in the discovery room. The second kind of talk was *Compare*, where families compared features of the authentic gallery and reproduced discovery room objects.

There were significant differences in the use of content and compare talk between the two objects, $p<0.001$. At the Bed, families were much more likely to talk about content ($M=4.8$ exchanges) than to compare the authentic object to the discovery room reproduction ($M=0.6$). At the Painting, the pattern was reversed (*M's*=1.7 and 4.0, respectively). The difference between how families referred to the Bed and Painting coves mapped directly onto differences in the learning opportunities that the coves presented. The primary activity in the Bed cove involved the museum-prepared books, and families were able to recall and connect some of the book content as they viewed the Bed. The Painting-related activity was making a mask, and the main content feature was to think about how artists convey a sense of personality in their work. Content codes for the Painting included conversations that discussed how the artist gave his figures a sense of personality or questions about why someone might wear a mask.

The findings at the Bed illustrate the simple concept that interpretive information provided by the museum is used by families. Families recalled what they had read and were interested to relate the information to the real bed, confirming their newly acquired knowledge. Although seemingly straightforward, it is worth pausing to note that this finding confirms what we heard from parents in the surveys and interviews – parents welcome and will use interpretive information in the museum to help their children learn about art.

The prevalence of comparison talk at the Painting is also interesting. Families referred to the reproduction frequently while making their masks in the discovery room. When they went to the gallery to see the real painting, they had their "aha" moment noting that they were seeing the "real thing." But their conversations continued and they spent a great deal of time making comparisons between the real painting and the reproduction in the discovery room. They noticed things like, "the paint is more textured here," or "I didn't see that character in the reproduction," or "the color looks different." Families made very fine-grained comparisons that revealed that they had indeed looked very carefully at both the reproduction and the painting.

There was so much comparison talk that we wonder how a museum might rethink its use of reproductions in the discovery room. It is certainly a goal of museums (and art education, more generally) to help people understand the difference between a reproduction and the real object, yet we wonder if there might be a more productive goal for the use of a reproduction in a museum. Perhaps the museum might show a reproduction of a detail of a work, or similar work by the artist, or related school to explicitly target the desire to compare the original to what was created in the discovery room. In this case, the discovery room seemed mostly to serve as a place for families to encounter the image, and to do so first in the weaker form of the reproduction.

Conclusions

In general, this study suggests that families are quite comfortable looking at and talking about art during museum visits. Families had active conversations that touched upon criticism, creation, context, and personal connections. The problem was not that they couldn't talk about art, the problem appeared to be that they didn't have the knowledge or tools to make their talk richer with respect to the disciplines of art and art history.

At the most specific level, our findings can be used to design mediation strategies to help families learn in art museums, particularly discovery rooms. While we did not see differences in the disciplinary talk in the gallery and the discovery room, it is significant that families did make other connections between the two contexts. It is important to remember that the discovery room we studied was not designed specifically to increase the disciplinary kinds of talk we are interested in. But the appearance of references to the family room experience, both in the visual observations and comparisons and in the transfer of content learned in the family room, suggests that families do pick up and use the mediation strategies offered by the museum. One next step in designing family rooms might be to experiment with the kinds of experiences and conversations that move best across the boundary of discovery room and the gallery floor.[3]

At a more general level, our findings are meant to catalyze debate about what visitors could learn in an art museum and what the appropriate role of the museum is in supporting that learning. There has been a tremendous amount of excitement and experimentation around the idea of helping visitors weave core scientific practices and knowledge into visits to science museums, children's museums, zoos, and

[3]The family room has a lot of advantages as a learning environment, but as a separate space that is not filled with authentic art objects, it will always be encumbered with the transfer problem. Perhaps new technologies (such as PDAs or cell phones) will make it possible to do more "just-in-time" mediation directly on the gallery floors when families are standing in front of the objects.

aquaria (National Academy of Sciences, 2009). We hope our work can be useful in sparking a similar discipline-specific learning movement among art museums. This effort is still very new, and we begin it without a clear agreement around what the core disciplinary practices might be and even disagreement about whether art museums ought to introduce a learning agenda for their visitors. The four outcomes we suggest in this chapter are just one approach to what might be learned in an art museum. We hope that the field will engage with the question and work on the problem of determining what the appropriate kind of art talk should be and to think about what a trajectory for learning in art might look like, across environments and through time.

Art education is still in the early stages of grappling with the effects of the change to a broader curriculum framework. One recent study showed that art teachers have trouble utilizing higher level disciplinary strategies (Erickson & Villeneuve, 2009). It is not obvious, even to experienced teachers, how one might best teach, for example, cultural context in art. Interestingly enough, art museum educators have been at the forefront of trying to assist school teachers in developing experiences that support a standards-based art curriculum. Museums across the country have taken up the challenges set out by the new arts-standards as well as NCLB legislation and have redesigned educational experience to connect directly with school standards. With their longstanding concern for object-based learning, and developing strategies for art appreciation, museums have the expertise to help define the future of art education. We are hoping that our work will help the conversation move from instrumental or structural approaches to engage with a more discipline-specific approach to learning in art museums.

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Chapter 13
Developing Writing Skills Through Students Giving Instructional Explanations

Kwangsu Cho and Christian Schunn

Introduction

Writing skills are considered to be critical for academic and professional success (National Commission on Writing, 2004). However, a large number of students are not writing well. According to National Assessment of Educational Progress (2002), 69% of 8th graders and 77% of 12th graders have only basic writing skills. Moreover, 50% of college students cannot produce texts that are relatively free of errors (ICAS, 2002). This unfortunate situation also permeates government and industry sectors. State government employees are found to have weak writing skills (NCW, 2004). Salaried employees in major US firms also lack writing skills (NCW, 2004).

Writing is a very difficult skill for students to master. Writing is an ill-structured and complex task that requires a number of cognitive processes such as planning, translating, reviewing, and monitoring (Hayes, Flower, Schriver, Stratman, & Carey, 1987). High-quality writing further requires a large amount of situation-specific adaptation, with the features requiring adaptation being relatively abstract and complex constructs like the writing goal, the genre, and the audience. In order to teach these complex and abstract elements of writing effectively, rich instructional explanations are highly likely to be required.

While rich instruction is required, limited instructional attention is the actual situation. There are generally too few writing activities taking place in typical classrooms. While part of the problem may be the significant amount of student time required for each piece of writing, the largest bottleneck standing in the way of more writing in the classroom is instructor time. The complex, open nature of writing makes instruction challenging: reading, commenting on, and grading on student writing easily overwhelms instructors. Together, these two challenges lead to near total neglect of writing, especially in subject matter courses (NCW, 2003).

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To illustrate, we conducted an analysis of writing in undergraduate psychology courses at 12 different universities, covering a range of university ranking, university type (research, teaching), university size (large, medium, small), university funding source (public, private), and tuition costs (high, medium, and low). We obtained all course syllabi (for at least two semesters in most cases), and then coded for the presence of required papers. We also coded for the presence of required multiple drafts, because learning to write is likely to be much weaker without attending to instructor feedback.

Although one might have expected that university size or rank would strongly predict the inclusion of writing, in fact annual tuition was the best predictor. Those with the highest tuition levels were the ones to most commonly require writing in their courses (see Fig. 13.1). Presumably tuition predicts class size (and teaching assistant resources), which in turn predicts inclusion of writing. Interestingly, required drafts were very rare across the board (see Fig. 13.1), and almost nonexistent in the highest tuition category. If psychology instructors primarily see writing in their classes from a writing-to-learn perspective rather than from a learning-to-write perspective, then that would explain why required drafting is so rare, regardless of institutional resources.

Responding to Leinhardt's call for research on the development of higher levels of academic literacy in students (Young & Leinhardt, 1998), one possible solution to including more writing (in the resource poor settings) with revisions (in all settings) is the use of reciprocal peer reviewing (RPR). In RPR, students review each other's writing rather than the traditional model of only receiving feedback from the instructor or a teaching assistant. Through RPR, students are potentially learning from both the feedback they receive and from the task of giving feedback.

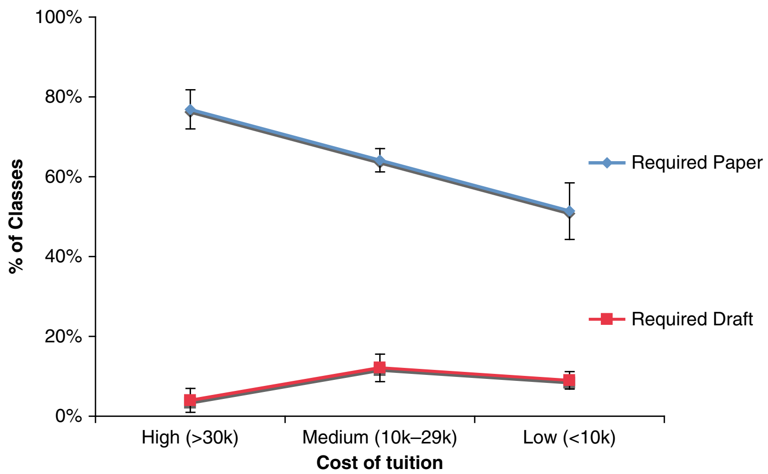

Fig. 13.1 The mean percentage (and standard error) of psychology undergraduate courses that include a required paper or a required draft as a function of annual tuition (in state)

Over the past 25 years, scholars of rhetoric and composition have continually emphasized the importance of assigning multiple drafts for improving students' writing skills (Beach & Friedrich, 2006) and participating in peer review. These pedagogical principles grow out of a long research tradition showing that gains in writing occur in classes that adopt a process-based approach and less teacher-centered classroom (Hillocks, 1984). Not surprisingly, these approaches are consistent with learning theories that promote active learning, including collaborative and cooperative learning, provision of feedback, repeated opportunities to practice, and relevant domain-specific tasks (Ashbaugh, Johnstone, & Warfield, 2002; Cornelius-White, 2007; Palincsar & Brown, 1984; Vygotsky, 1978).

In theory, RPR addresses the bottleneck problem. Regardless of class size, with every increase in the number of authors, a corresponding increase in the number of potential reviewers occurs. Indeed, we have seen RPR used with substantial papers in classes with as many as 300 students.

However, the shift to RPR also marks a very interesting shift from instructor-centric to student-centric writing instruction. This shift involves instructional explanations in two different ways. The obvious shift involves the nature of instructional explanations that students (as authors) receive from their peers. As it turns out, systematic comparisons of instructor-generated vs. peer-generated feedback have found that the feedback that students receive from their peers has many similarities to the feedback that they receive from instructors. While there are some systematic differences, overall the similarities outweigh the differences (Cho, Schunn, & Charney, 2006; Patchan, Charney, & Schunn, 2009) (Fig. 13.2).

The less obvious shift involves the change from students being the *receivers* of instructional explanations to students being the *generators* of instructional explanations. It is this kind of instructional explanation that is the focus herein. A student participating in RPR generates explanations on peer writing through a rich process. In the role of reviewer, a student engages in reading, text analysis, and writing.

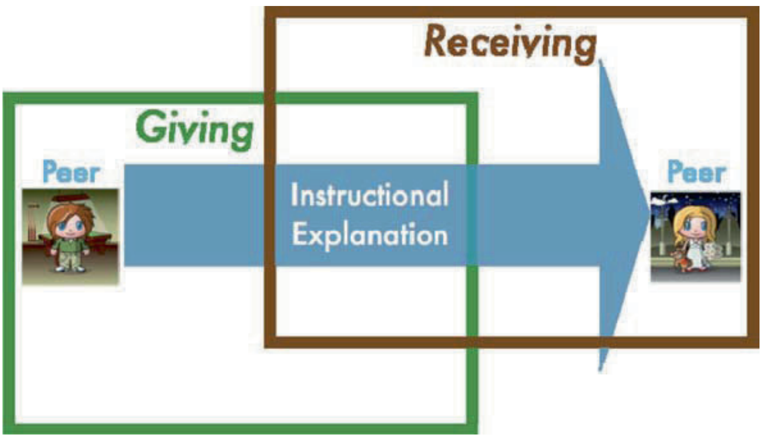

Fig. 13.2 The two sides of instructional explanations in peer review

He or she must carefully read a draft, interpret the evaluative criteria, detect and prioritize problems, make a holistic assessment, and draw on writing skills to formulate comments. Coming to understand the criteria well enough to apply them to another student's paper provides students with the opportunity to improve their own writing and revision activities. More learning gains are possible through a second round of review, in which the same reviewers evaluate the writers' revised drafts and receive feedback on the helpfulness of their comments. We summarize evidence that, indeed, students are benefiting from giving these instructional explanations.

In the next section, we describe a technological support tool that we have created for broadly implementing peer reviewing in small and large classrooms. Then, in later sections we describe research that we have done on the benefits that this system provides for students in learning how to write, both looking at the benefits of *receiving* peer feedback and the benefits of *giving* peer feedback.

A Technological Solution

To fully realize the benefits of reciprocal peer review in many settings, an automatic administration mechanism is required due to the logistical complexity of keeping tracking of scores – if not hundreds – of papers, reviewers, and reviews. A web-based platform for reciprocal peer review offers unique opportunities for improving writing instruction across the board.

We have developed such a system called SWoRD (Cho & Schunn, 2007), for Scaffolded Writing and Rewriting in the Disciplines. SWoRD is a web-based, hybrid intelligent system that implements reciprocal peer reviewing of writing. It was initially developed for use in large undergraduate courses in academic disciplines in which writing is rarely assigned. Since 2002, SWoRD has been used by about 6,000 students from 120 courses at fifteen universities and for 5 courses in secondary schools in the United States. Interestingly, the largest user setting of SWoRD is smaller disciplinary courses in which writing may have happened previously, but in weaker form (e.g., only a single draft or with relatively little feedback).

SWoRD enables instructors to implement a wide range of reciprocal peer review activities. First, students as authors write first drafts in response to any task given by the instructor and submit them online. Then, students are randomly assigned a set of three to six of these first drafts to peer review. As reviewers, they analyze the written texts in detail along several evaluative dimensions in response to prompts that incorporate explicit rubrics. Students submit written comments and ratings online. Figure 13.3 presents an example of the prompts used to guide the ratings and comments students provide on their peers' writing.

After students as authors receive the feedback from their peers, they revise their drafts and re-submit them. SWoRD also asks authors provide comments to the reviewers on the helpfulness of the suggestions. Then the revised drafts are made available to the same set of reviewers who evaluated the first drafts. The reviewers then observe how the revised drafts have changed (or not) in response

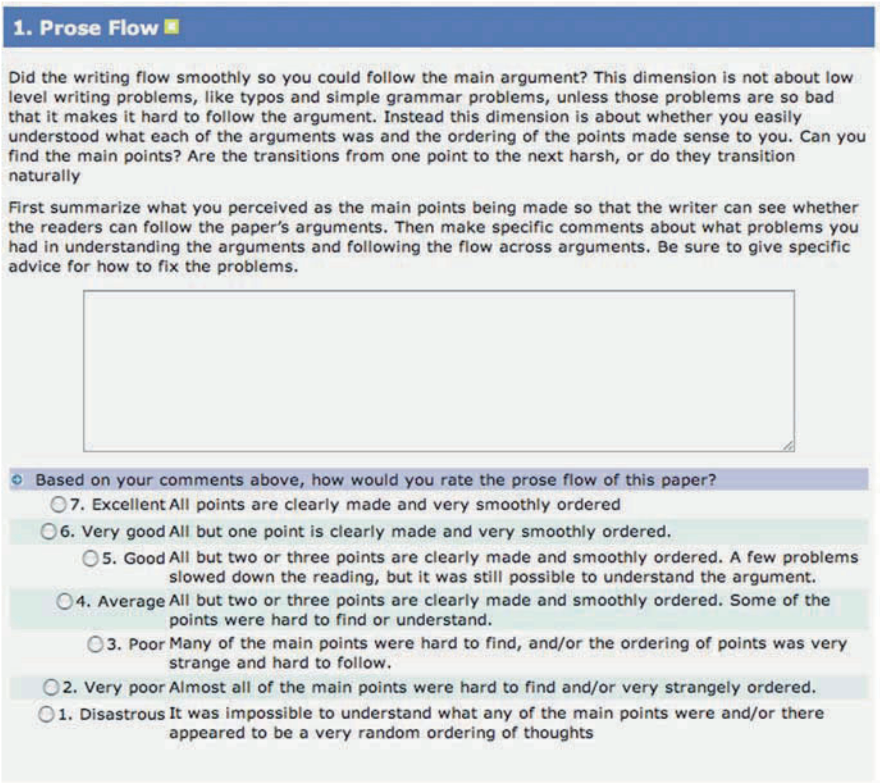

Fig. 13.3 Example writing prompt and evaluation rubrics used in SWoRD

to the full set of reviews. The reviewers rate and comment along with the same dimensions, providing data on gains from the first draft. In this explicit, step-by-step fashion, students are required to go through iterations of writing, reviewing, and revision. We hypothesize that this iterative writing and reviewing help students to develop good models of writing practice, which they may begin to apply to other writing contexts. Once these behaviors become automatized over multiple writing tasks, students can become better self-regulated writers (Zimmerman & Kitsantas, 1999, 2002).

SWoRD's design makes it well suited to overcoming the core obstacles to implementing peer review described above. First, it relieves the logistical burden by automatically administering the collection and exchange of drafts and reviews, monitoring completion of each step, and providing summative statistics on both writing and reviewing activities. Instructors may increase the number of reviews, the number of reviewers, and the rounds of review without additional effort (Rada, Michailidis, & Wang, 1994).

Second, the SWoRD system helps to establish and maintain conducive pedagogical practices with peer review and makes it easier for instructors to design writing assignments and rubrics. SWoRD incorporates a case-based reasoning (CBR) module, storing instances of writing genres and writing evaluation rubrics. The CBR module currently stores 25 types of writing evaluation rubrics that are designed for particular types of writing. For example, there are rubrics for scientific research papers and there are different rubrics for papers that ask students to explain a scientific theory and then apply it to an everyday situation. The former involves longer papers and has rubrics specific to typical sections of a research report (e.g., abstract, introduction, methods), whereas the latter has rubrics for the (shorter) paper as a whole (e.g., the flow, argument transparency, and insight provided in a paper).

Each dimension of the rubric has clear explanations and rating points have a clear anchor – what features a paper should have to deserve the given rating in order to maximize consistency across reviewers. When instructors create their courses in SWoRD, instructors may select existing rubrics for their writing assignments, modify existing rubrics for their purpose, or create new ones. Modified and new rubrics are also stored for the use of other instructors.

Third, to support effective feedback generation, SWoRD helps to provide an atmosphere conducive to collaboration and guides students to produce high-quality reviews. Student papers are randomly assigned to reviewers, with authors and reviewers double-blinded to each other's identity, thereby fostering peer's willingness to provide reviewer that are appropriately critical. In addition, by receiving comments from multiple students (rather than just one or two as in typical classroom practice), the issue of diverse audience becomes very salient. Writing is difficult not just because one must write clearly and persuasively to an individual starting from a different position than the writer, but rather it is especially difficult because one must write clearly and persuasively to different groups of individuals each starting in a different position. Feedback from just one person does not make this diversity of audience problem salient, but feedback from multiple reviewers can. Indeed, our research shows that students benefit from receiving comments from both stronger and weaker writers (Nelson, Melot, Stevens, & Schunn, 2008).

In addition, because authors assess the quality of the reviews, students have incentives to make comments that are constructive and helpful. SWoRD also provides reviewers an interface for self-monitoring, making it easy for reviewers to compare their comments with other reviewers on the same papers. By making it easy for students to view and re-view an explicit evaluative rubric, SWoRD helps students articulate their evaluations and expand their knowledge of discourse structures. Assuming that students review five drafts, they are exposed to the rubric about 14 times per writing assignment – 10 times as reviewer across both drafts, twice as self-assessor across both drafts, and twice as receiver of feedback organized around the rubric.

SWoRD also incorporates a calibration exercise in which students practice reviewing three writing samples (good, mid-level, and poor), with given evaluation rubrics before actually reviewing peer drafts. The exercise module provides feedback on how the instructor would rate each sample on each dimension.

SWoRD provides students with a multimedia module allowing them to hear real student-authors explaining their experiences with helpful and unhelpful feedback.

Empirical Research

In the early research on SWoRD, studies focused on the effectiveness of peers' instructional explanations relative to instructor explanations. We found that peers, on average, generated roughly similar kinds of feedback, although with some differences in relative length, focus on problems, inclusion of solutions, and inclusion of praise (Patchan et al., 2009). Multiple peers produce much more feedback in total than a single instructor; the peers find the comments just as useful as instructor comments (Cho et al., 2006); and more revision behavior results from the multiple peer feedback, producing better final drafts (Cho & Schunn, 2007).

This chapter examines the less-explored aspect of generating instructional explanations: the role of providing peer reviews. In particular, we focus on the question of whether providing peer reviews improves the reviewer's own writing skills. Peer reviewing is an active process that can help the reviewer learn which features of writing are desirable and which features are undesirable. Thus, reviewers are engaged in exercising important skills for writing (Bereiter & Scardamalia, 1987; Fitzgerald, 1987; Flower, Hayes, Carey, Schriver, & Stratman, 1986). These activities may improve the reviewers' own writing skills, by finding strengths and weaknesses, reinforcing successful strategies, and calling attention to unsuccessful strategies that the reviewers have already used in their own writing.

On the other hand, while providing instructional explanations might have opportunities for learning, they might not always involve actual learning. The reviewer may be exposed to problems they themselves do not have or may not be able to generate methods for effective revision. Further, the literature on transfer of skills finds that even when there is clear overlap of underlying skills between the learning environment and the testing environment, transfer is not always observed (Bransford & Schwartz, 2001). For example, the time between generating a possible solution to the time at which it is required in later writing may be so great that the insight is lost. Further, the proposed solution may be framed in the mind of the reviewer in such a specific way that it does not seem applicable to other writing tasks.

Further, assuming there are benefits of reviewing for one's own writing, there is the question about what aspects of generating peer reviews is actually useful for improving ones own learning. Critically for this book, there are three propositions worth considering: (1) participating in generating of instructional explanations per se is useful, (2) simply the task of reading others' papers is sufficient in terms of learning from models (Charney & Carlson, 1995), or (3) practicing detection skills by evaluating others' papers is most useful for learning to write.

Recently, Cho (in preparation) examined the hypothesis that reviewing (evaluating AND generating explanations) is being more helpful than simple reading (i.e., learning from models) in supporting students' development of high-quality writing. Students in a college physics class were randomly assigned to one of the three conditions: After-reviewing, After-reading, and No-reading-or-reviewing. All the students were given three sample lab papers that had the same structure as the papers the students were asked to generate. Students in the After-reviewing condition were asked to review the papers with the given rubric and to generate written comments on and rate the papers. Students in the After-reading condition were asked to read the sample papers twice but were not told to comment on or rate them. The students in the No-reading-or-reviewing condition were not asked to read or review the papers. Instead these students were simply notified that the sample papers were available in the SWoRD system. All the students were then asked to generate a paper of their own. Three physics PhD students evaluated the papers to see which condition produced the strongest quality papers according the given evaluation rubric. That is, the study tested whether students could apply something from the reading or reviewing tasks to improve their own writing.

Figure 13.4 presents the mean first draft quality (averaged across evaluation dimensions). The writing quality in the After-Reviewing condition was significantly higher than in either the After-Reading or No-reading-or-reviewing condition. Furthermore, the After-Reading condition papers were no better than the No-reading-or-reviewing condition papers. These results suggest that reviewing activities do benefit the writer's own writing. Further, these results suggest that the locus of the benefit does not stem (at least in this context) from simply reading the papers of others. However, it is unclear from these results whether evaluating papers or generating comments contribute the writer's learning.

Wooley, Was, Schunn, and Dalton (2008) followed up on this work to examine the relative benefits of evaluating examples vs. providing revision suggestions. In order to populate a complex nested experimental design, this study took place in a large educational psychology undergraduate class (over 180 students). A third of

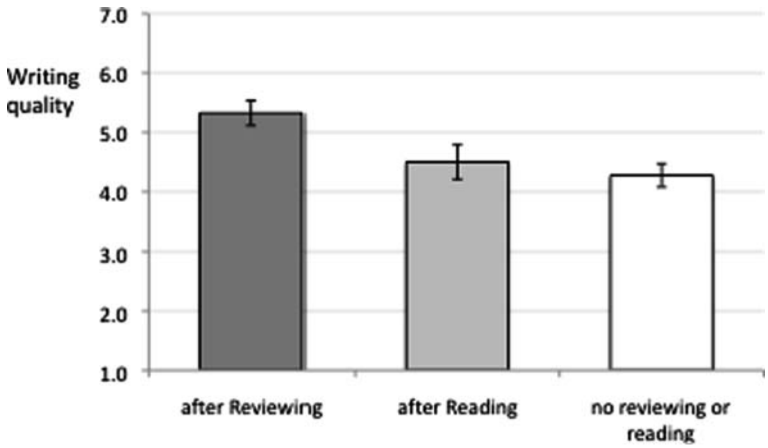

Fig. 13.4 Mean first draft quality (and SE bars) as a function of condition

the students wrote a paper early in the semester. For the purposes of the experiment, they were simply generating materials for the other conditions. Another third of the students (Evaluate-First condition) were asked to evaluate five peer papers, and then write their own paper. The final third of the students (Write-First condition), wrote for the same deadline as the Evaluate-First condition, but did not have to evaluate papers before writing. Students were randomly assigned to one of these conditions.

The Evaluate-First condition was further subdivided into two conditions critical to the question of the efficacy of instructional explanations. The Rate-Only sub-condition had students evaluate five papers using a rubric (three dimensions with 1–7 Likert ratings like those shown in Fig. 13.2). They did not have to generate any comments. The Rate+Comment sub-condition had students rate the papers as well as generate helpful comments. By examining the quality of the students' own writing across these two conditions, we can examine whether the comment generation process confers benefits to the reviewer above and beyond the benefits of simply carefully evaluating models (i.e., practicing error detection skills). Three PhD students blinded to condition evaluated all of the 1st draft papers in the Evaluate-First (Rate-Only and Rate+Comment) and Write-First conditions.

Figure 13.5 presents the mean first draft quality scores in the Rate-Only and Rate+Comment conditions on each of the three writing dimensions. We see that the commenting task did indeed help students in their own writing – generating explanations for others in this instructional setting were indeed instructional, for the author AND for the reviewer. In addition, only the Rate+Comment condition generated papers that were of higher quality than in the Write-First condition, suggesting that simply evaluating papers did not convey much writing benefit to the students.

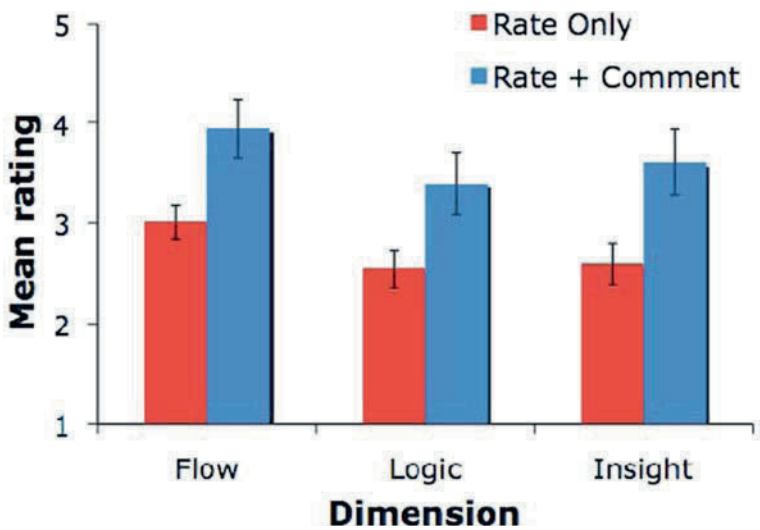

Fig. 13.5 Mean first draft quality (and SE bars) as a function of condition

These two studies suggest that the generation of instructional explanations is critical for learning, rather than just reading or evaluating examples. However, we do not mean to suggest that quality or features of the examples being evaluated play no role at all in student learning. We do not think that generating instructional explanations is a magical learning activity that conveys learning benefits regardless of content, as some kind of exercise for the mind. Rather we think that generating explanations conveys learning benefits because typically generating explanations for peers will produce explanations about problems that the students themselves are struggling with in their own writing. And thus, we predict that the quality of the examples serving as objects of review and commenting will influence what the reviewer takes away from the experience.

Indeed it is here that the instructor can play a critical role in shaping learning that happens in the peer review context: by influencing which papers each peer is asked to review. Instructors often use examples to help students develop understandings on concepts and definitions. Consistently, much research on examples in mathematics and science reveals that examples may enhance knowledge acquisition and problem-solving (Atkinson, Derry, Renkl, & Wortham, 2000; Sweller & Cooper, 1985). Examining examples may help learners to understand general rules and apply the learned rules to given problems whose structural features are similar to the examples (Anderson, Fincham, & Douglass, 1997). Leinhardt (2001) argued "The generation or selection of examples is a fundamental part of constructing a good explanation. But developing, recognizing, or selecting an appropriate example or counterexample is difficult" (p. 347).

Recently, Cho and Cho (2009) examined the role of instructional examples in improving the effect of participating in instructional explanation activities, focusing on the mean quality and diversity of quality of the examples in learning to write from reviewing. In reviewing, peer writing of low quality may have a different role for the reviewer's learning from that of high-quality writing. In mathematics, explaining why correct solutions are correct and why incorrect solutions are incorrect was more effective in learning than explaining only why correct solutions are correct (Siegler, 2002). This prior work suggests that learning from low-quality examples may be different from learning from high-quality examples. An obvious difference between the two types of examples is that low-quality examples include more errors than high-quality examples. There are different perspectives on how errors in low-quality examples influence learning.

High-quality examples may be more beneficial in acquiring knowledge of high-quality writing than low-quality examples. Students can model their writing on the superior features of high-quality examples, whereas errors in low-quality examples can be harmful if students mimic the errors without caution. In addition, revising errors may impose a heavy cognitive load on limited working memory (Paas, Renkl, & Sweller, 2004), which may interfere with abstracting writing principles from examples. In other words, students who review high-quality examples can better concentrate on features of high-quality writing than students who review low-quality examples, which requires paying attention to detecting the many errors contained in the document. Thus, students may understand more about what writing should be and how to write well from high-quality examples.

However, low-quality examples can help students develop knowledge about various constraints on writing and apply the learned constraints to their own writing. Low-quality examples can also provide more opportunities to detect, diagnose, and revise errors than high-quality examples. While revising errors, students may think deeply what errors are critical, why they are harmful, and how to fix them. For instance, Zimmerman and Kitsantas (2002) found that coping models that showed how to revise errors were more beneficial in acquiring writing skill than mastery models that did not include any error. Thus, low-quality examples can help students to improve writing by reducing errors.

Whether low- or high-quality examples are better could further depend on the writing abilities of the reviewer. For example, stronger writers may already know to avoid common errors shown by weaker writers, whereas weaker writers might need to practice detecting and repairing those more basic writing issues found in the writing of weaker writing peers.

Cho and Cho (2009) analyzed data from a class that used SWoRD, placing students analytically into one of four conditions in a 2×2 design. First students were divided into poor and good writers on the basis of first draft scores. Crossed with that dimension was whether or not the papers the students reviewed were low or high in quality. Median splits were used to create these categories. The critical question concerns the average final draft paper scores of students in each reviewing category: that is, who learned the most that could be applied to their own revision work?

Cho and Cho found an interaction between the two conditions (see Fig. 13.6). Poor writers benefited most from seeing low-quality examples. By contrast, good writers benefited equally from reviewing high- and low-quality drafts.

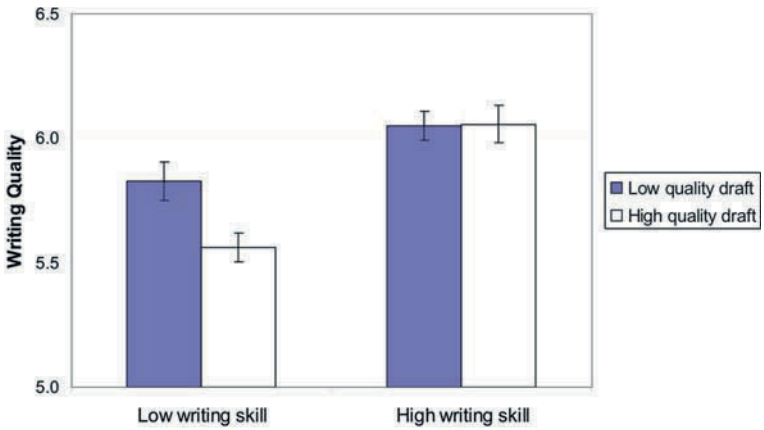

Fig. 13.6 Mean final draft scores (and SE bars) as function of writer skill and whether the papers reviewed were of poor or good average quality

Discussion

In this research, we examined the role of giving reviews as an example of providing instructional explanations. We investigated the gains for reviewers-as-writers rather than the more traditional focus of reviewers-as-surrogate-feedback source. Thus, this research speaks to the pedagogical value of providing the reviews in addition to its practical advantage of making rich feedback available more often to students. Although this research did not focus on the nature of the comments being generated, it is worth noting that, like with peer tutoring, reviewers are expected to provide peer writers with coherent explanations or suggestions for improvement. By writing comments to others, therefore, reviewers may be more engaged in constructing a coherent understanding of writing as a result of developing these coherent explanations (Bargh & Schul, 1980).

Reviewing is a process of problem-solving in which reviewers are engaged in exercising important skills for writing (Bereiter & Scardamalia, 1987; Fitzgerald, 1987; Flower et al., 1986), such as detection, diagnosis, and solution generation along with reading and commenting. These activities may improve reviewers' own writing and revising skills by reinforcing successful strategies and by calling attention to unsuccessful strategies that the reviewers have already used in their own writing.

A structured interview in a large undergraduate course about their experiences with the scaffolded peer review process supports the findings. Here are typical responses from the undergraduate students to the question, "How did giving feedback help your own writing?" Students often mentioned they learned what they should not do in their own writing as well as what they should do. For example, a student said, "Well, I reviewed before I wrote so that definitely helped because I was able to see what other people were doing too and know what to expect and or what was expected and so that helped and then just again seeing, just more writing styles and different ideas." Another student expressed a consistent opinion by saying, "Yeah, I think it helped me in writing; it allows me to see how other people are writing and allows me to see their mistakes and that can only help me better write my papers.... It just shows me what not to do and what to do; gives me a better understanding of how to write a paper." Another student also mentioned, "I think it helped me look out for things that I didn't want to repeat; I didn't want to waste other people's time in effect, so that's what I made sure. I really thought about what I had done to other people and told them what to do, not to use their mom as a reference, that's just point blank common sense that some people just didn't have that so."

In addition, some students mentioned learning about taking an audience perspective to their own writing, especially by learning what others might want to see in writing. For example, a student said, "I guess, maybe, just looking at the flaws other people have in their paper I would make sure I didn't do the same thing. Like, because I had to look for smooth transitions I, you know, I knew that's what they'd be looking for in my paper so I made sure my transitions were ok. *So, I guess, by giving feedback on their papers I knew what they'd be looking at for mine*." Also another student commented on the audience issue, "I think it gave me an idea of what other people look for, it helped me recognize what other problems there could be in writing. It also, I think, helped me learn how to write for a more general audience because I could see what other people think is important and that kind of thing. *It mostly helped me see how other people see writing*." Another student expressed a consistent experience by saying "Oh yeah, *it gave me a better perspective of how my audience is going to be perceiving me* because I was the audience and tried to perceive how other people, saw what to look for, saw to look for things that usually when I'm writing I don't catch. So I tried to reread my own writing as I was one of the students who was going to be grading it which I usually didn't try to do before."

Young and Leinhardt (1998) argued that disciplinary writing skills develop mainly along two dimensions: the content and rhetoric of the discipline. Along the content dimension, students develop more detailed and integrated understandings of disciplinary knowledge. Along with the rhetorical dimension, students develop "disciplinary acts of argument and interpretation, evaluating and qualifying claims and evidence, and using rhetorical and linguistic conventions to support these acts of analysis and synthesis" (p. 56).

In this chapter, we argue that peer reviewing may provide students with valuable opportunities for understanding disciplinary writing skills. In the process of peer reviewing, students read, analyze, and assess peer papers and explain how to improve them in reference to the disciplinary rubric. Unlike troubleshooting their own papers, peer reviewers are asked to construct instructional explanations that are coherent and accurate according to disciplinary rhetoric and content (Leinhardt, 2001).

The findings from the SWoRD research tentatively make a number of suggestions for classroom practice regarding instructional explanations. First, the SWoRD work suggests that having students engage in constructing *instructional* explanations can be useful for learning, rather than just the more typical student activities of self-explanations or explanations to the teacher. Second, the SWoRD work suggests that students can benefit from providing instructional explanations to both weak and strong examples. Furthermore, there is some suggestion that the best examples to provide instructional explanations for may depend on the skill level of the student.

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