Supporting Scientific Reasoning and Conceptual Understanding Through the use of Inscriptions

by

Nicole Wong

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Committee in charge:

Professor Kathleen E. Metz, chair
Professor Judith Warren Little
Professor Eve Sweetser

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Abstract

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While there is a vast body of research on visual representations, the results do not paint a clear picture of how to use inscriptions to support learning. Part of the difficulty stems from the need for research that investigates the use of inscriptions in classroom learning contexts. Toward this end, there is a small body of work that investigates the role of inscriptions in supporting students' engagement in scientific reasoning practices. Through the development of a case study of expert practice, this dissertation contributes to that literature by examining the potential power of inscriptions as resources for science teaching and learning in the context of a teacher professional development course that aims to support 4th grade teachers' content knowledge around the topic of electric circuits. This study examined the curriculum and video record from one enactment of this course to analyze the affordances of particular representations for supporting conceptual understanding and scientific reasoning practices; examine the facilitator's inscriptional practices that supported collaborative learning; and analyze the interactions among the learners, facilitator, and inscriptions that supported conceptual understanding. This exemplary facilitator successfully used inscriptions to engage learners in scientific reasoning practices that supported their conceptual understanding. She used inscriptions to structure and support discussions that were based on learner-generated ideas, yet led to curriculum-directed conceptual and pedagogical goals. The curriculum provided a series of inscriptional resources that were well suited for the conceptual and scientific reasoning activities that they proposed to support. By using curricular inscriptions to shape the content and form of the discussions, the facilitator created opportunities to learn that were 1) contingent on learner contributions and understanding, and 2) congruent with curricular goals. This work identifies several pedagogical content knowledge demands of

supporting scientific reasoning through the use of inscriptions. Beyond knowledge of the conceptual terrain, the facilitator needed to (a) understand the match between particular inscriptions (or types of inscriptions) and the conceptual or scientific reasoning work they can support; (b) understand and interpret learner ideas in relation to the curricular goals; and (c) use inscriptions to make learner ideas available for examination, analysis, revision and discussion in service of the curricular goals.

Table of Contents

List of Figures

List of Tables

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Chapter 1: Introduction

Recently, the National Research Council Committee on Science Learning, Kindergarten through Eighth Grade (NRC) studied the body of work about children's scientific understanding and concluded that the field of education has underestimated the capabilities of elementary school children (National Research Council [NRC], 2007). They claim that, as a result of this underestimation, the education community has set the bar for goals in science education too low. As part of their effort to improve science education, the committee proposed four strands of scientific proficiency that "lay out broad learning goals for students":

1. Know, use and interpret scientific explanations of the natural world.
2. Generate and evaluate scientific evidence and explanations.
3. Understand the nature and development of scientific knowledge.
4. Participate productively in scientific practices and discourse. (NRC, 2007, p. 36)

This is an ambitious agenda, and teachers need support to help students meet those goals. There is little research about how elementary school teachers are prepared to teach science, but a survey of their accreditation standards suggests that the scientific knowledge of K-8 teachers is not very strong (NRC, 2007)[1].

To help teachers support their students in the attainment of the aspects of science proficiency stated above, we need professional development that helps teachers learn about science content, the practices of science, and ways of teaching science. The practices of science include such things as participating in communities of learners who construct and evaluate knowledge claims on the basis of evidence. My research focuses on the use of inscriptions and inscriptional practices to support learning about the content and practices of science.

Inscriptions such as graphs, chart, and diagrams are central to the construction of knowledge in scientific practice (Goodwin, 1994; Latour, 1990; Latour & Woolgar, 1986; Lynch, 1990; Stevens & Hall, 1998). It is valuable for teachers and students to gain expertise with inscriptions because much of scientific inquiry rests on the ability to use and interpret multiple forms of representation (Lemke, 1998; Hapgood, Magnusson, & Palincsar, 2004). By focusing on this central component of scientific practice, my

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[1]Interviews that my collaborators and I conducted with elementary school teachers and teacher professional development leaders participating in the Learning Science for Teaching (LSFT) study suggest that many of these teachers and the teachers they work with feel uncomfortable with their understanding of science, and the professional development opportunities that are available to them severely lack conceptual focus. These data have not yet been analyzed, but we regularly heard from participants that they have never experienced (or led) professional development with as high a level of content as that presented in the LSFT curriculum.

research provides a lens into the way the Learning Science for Teaching professional development course supported teachers' participation in scientific practices. This, in turn, will have implications for how these teachers understand and teach science.

Theoretical Framework

Instructional triangle. Cohen and Ball (1999) propose a view of instruction as a series of interactions that take place between teachers, students, and content within particular environments. Rather than viewing instruction as a direct result of curriculum or teaching, this view contends that teachers, students, and content are potential resources, and learning opportunities are realized through the interaction between elements. Features of all three elements and the interaction between them shape the learning opportunity and affect the effectiveness of instruction.

According to Cohen and Ball (1999), teachers' resources include their knowledge, skills, and dispositions toward content, curricula, and students. These attributes shape the way teachers interpret curricular materials and use them in interaction with students. Students bring with them prior knowledge, previous experiences, and personal interests and habits of mind. All of these factors shape the ways students interpret and respond to teachers and materials. The instructional materials include the texts, problems, and tasks with which students are asked to engage. The opportunities they structure depend on how they are used by teachers and learners. Instruction is the result of the fluid and dynamic interaction between these components in particular contexts over time.

Building from this work, Hiebert et al. (2005) conceptualize instruction as a system of interacting features that create the learning conditions for students. They noted that, while it is impossible to document all of the relevant features that influence any particular learning context, "it is possible to identify a range of teaching features and to consider how individual features work together to reinforce particular kinds of learning conditions" (p. 113).

Although they emphasize the importance of the teachers, the learners, and the content, Cohen and Ball (1999) singled out *the teacher* as having a unique role in mediating all of the relationships within instruction. This dissertation places similar emphasis on the mediating role of the teacher within the instructional triangle.

Inscriptions and inscriptional practices. In this dissertation, I use the term *inscription* to refer to representations that exist in the material world and are publicly available (Latour & Woolgar, 1979; Lehrer & Schauble, 1998, Roth & McGinn, 1998). Following Roth and McGinn, I use the term *inscription* to prioritize their functions as *social objects*. This view stands in contrast to cognitive views of visual representations where the individual cognition is the primary focus (cf., Larkin & Simon, 1987; Paivio, 1990).

Inscription can refer to a wide variety of representations: Latour (1987) includes graphs, tables, lists, photographs, diagrams, spreadsheets, and equations, while Lehrer, Schauble, and Petrosino (2001) include "drawings, maps, diagrams, text, recordings from instruments, mathematical formalisms of various kinds, and even physical models" (p.

259). This framing of visual representations as social objects places research emphasis on their creation, modification, annotation, reference to, discussions about, and appropriation of inscriptions.

Inscriptions are omnipresent in science classrooms as pedagogical devices (e.g., textbook images, chalkboard diagrams, data collection tables and data displays). This dissertation investigates the function of these inscriptions in relation to the instructional triangle. This analysis explores the inscriptional resources provided by the curriculum text and the ways the instructor and the learners made use of those resources to create various learning opportunities.

In the following section, I present and discuss prior work on the use of inscriptions to support learning. The relevant literature includes work on visual representations, graphical displays, and external representations. Though the terminology varies, all of the studies presented here focus on representations that I have previously labeled as inscriptions, or representations that exist in the material world. The finer distinction added by Roth and McGinn's (1998) use of the term *inscription* is an emphasis on the function of external representations as social objects.

Literature Review

Inscriptions and individual cognition. The role of external representations or inscriptions in learning is a complex issue. Despite the existence of a large body of work on the function of external representations, there is no clear, unified picture of how they should be designed and employed to support learning.

Many cognitive studies have focused on describing the mechanisms by which visual representations support individual cognition by deconstructing cognitive tasks into components (e.g., Larkin and Simon's (1987) search, recognition, and inference) and examining the influence of the external representation at each level. This type of task analysis allows researchers to describe the utility of particular features of representations for specific problem-solving purposes.

In a review of literature about the value of graphical displays for learning, Vekiri (2002) found that the research supports three complementary theories for explaining the cognitive function of visual representations for individual learning: dual coding theory, visual argument, and conjoint retention. Dual coding theory (Paivio, 1990) rests on the assumption that there are two separate but interconnected systems for processing information: one that is used for imagery and one that is used for linguistic information. According to this theory, graphical displays aid learning when used in conjunction with text because they provide learners with the opportunity to store the same information in two forms. The visual argument hypothesis (Waller, 1981) attributes the effectiveness of graphical representations to their visuospatial properties. According to this theory, the spatial arrangements of elements make graphical displays computationally efficient by allowing users to make "perceptual inferences." Users extract information about relationships between elements using perceptual mechanisms rather than involving interpretive mechanisms (Larkin & Simon, 1987). The third theory, conjoint retention (Kulhavy, Stock, & Kealy, 1993, 1994), is a theory that uses both the dual coding theory and the visual argument hypothesis to explain how maps facilitate learning. According to this theory, maps are represented in a visual format (dual coding) and facilitate learning because they are computationally efficient (visual argument).

Although there is a large amount of evidence to support these theories, there are also some inconsistencies in the literature. There is conflicting evidence about the influence of learners' prior knowledge on the usefulness of particular representations for learning (Vekiri, 2002), the usefulness of representations for helping individuals make inferences (Scaife & Rogers, 1996; Vekiri, 2002), and the effectiveness of learning environments that use multiple representations (Ainsworth, 1999). In each of these cases, there is evidence supporting claims in both directions. For example, some studies have shown that prior knowledge helps individuals learn with graphical displays (Hegarty & Just, 1989, 1993), while other studies have shown that prior knowledge did *not* help individuals learn with graphical displays (Mayer & Gallini, 1990).

Ainsworth (1999) points to one explanation for why some of these inconsistencies exist. She speaks specifically about multiple representations, but her arguments can be extended to single representations as well. According to Ainsworth, multiple representations serve a number of different purposes. She claims that, in order to better understand the effectiveness of multiple representations in learning, researchers must distinguish between the various functions they are intended to serve. This perspective is echoed by Lewandowsky and Behrens (1999), who contend that the effectiveness of certain graphic characteristics and types of graphics depend on the cognitive task for which the graphics are used. To address these concerns, there have been persistent calls for research that investigates the contexts in which these visual representations are employed (cf., Ainsworth, 1999; Perkins & Unger, 1999; Vekiri 2002).

Social construction of interpretation of inscriptions. Much of the literature on the practice of representation is concerned with how individuals interpret inscriptions. Greeno and Hall (1997) draw attention to the role of interpretation by calling physical notations such as graphs and tables "potential representations" until they have been interpreted. This perspective does not assume that aspects of representations and their interpretations will be obvious or consistent across different viewers. The cognitive literature attributes differences in the interpretation of representations to factors such as domain knowledge (Scaife & Rogers, 1996) and spatial ability (Mayer & Sims, 1994; Scaife & Rogers, 1996). The sociocultural and sociocognitive literature adds a consideration of discipline-specific social negotiation of interpretations.

Within the sociocultural and sociocognitive literature, the mappings between what is represented and the inscription are framed as socially negotiated within a particular community of practice. "Scientists' interpretations of inscriptions emerge from an iterative, dialectical process in which signs and referents are used in a mutually elaborative fashion" (Roth & McGinn 1998, p. 42). Stevens and Hall (1998) and Goodwin (1994) both describe interpretation as a process of social negotiation.

Goodwin (1994) emphasizes the importance of socially organized ways of seeing and understanding in particular groups and the role of interaction in building and contesting professional vision. This vision is socially situated and historically constituted:

> An archaeologist and a farmer see quite different phenomena in the same patch of dirt (e.g., soil that will support particular kinds of crops versus stains, features, and artifact that provide evidence for earlier human activity at this spot). An event being seen, a relevant **object of knowledge**, emerges through the interplay between a domain of scrutiny (a patch of dirt, the images made available by the King videotape, etc.) and a set of **discursive practices** (dividing the domain of scrutiny by highlighting a figure against a ground, applying specific coding schemes for the constitutions and interpretation of relevant events, etc.) being deployed within a **specific activity** (arguing a legal case, mapping a site, planting crops, etc.). The unit of analysis being investigated is thus analogous to what Wittgenstein (1957) called a **language game**, a "whole, consisting of language and the actions into which it is woven." (p. 607; Emphasis in original)

Goodwin (1994) emphasizes the central role that visual representations play in the discourse of any profession. The work of "seeing" in a profession is inseparable from the types of talk, writing, and material artifacts that constitute that profession.

Similarly, Stevens and Hall (1998) propose the notion of a "disciplined perception," where forms of visual interaction with inscriptions are developed through interaction with others in a community and become stabilized. They argue that "the way technoscientists orient to and coordinate visual aspects is fundamentally shaped by their activities with other people and culturally specific artifacts" (p. 139). Through the development of a case study from the field of civil engineering, Stevens and Hall describe the way visual interaction with inscriptions is non-trivial even to those who are familiar with a discipline's visual practices. In this case, a senior engineer helped his more novice colleague develop an interpretation of a set of road plans that attended to the considerations necessary for their road construction project. In this episode, the expert helped the novice develop a disciplined perception though face-to-face interaction around a set of inscriptions.

Community norms of interpretation are also relevant for classrooms. Saxe (2004) describes the contrasting ways a teacher and her student interpreted the same symbol system during a 4^{th} grade lesson about fractions. Mrs. Gates, the teacher, drew two circles on the board to represent two cookies. Though one circle was slightly bigger than the other, Mrs. Gates treated them as idealized forms. She assumed that the circles would be interpreted as two cookies of equal size. She intended to convey the idea that dividing each of the two circles into fourths is equivalent to taking one half of each circle. Lenny, the student, interpreted the representation as two different-sized cookies. Given Lenny's interpretation of the representation, Mrs. Gates' notion of equivalence did not hold. Both the teacher and the student had constructed reasonable interpretations of a particular representation. Saxe argues that although the norm for classroom mathematics might be to interpret these spontaneous, hand-drawn figures as idealized forms, these meanings must be socially negotiated.

The emphasis on the role of socially-negotiated interpretation of inscriptions is particularly relevant to a learner's ability to engage in scientific practices and discourse. Disciplined perception and professional vision describe the use of particular inscriptions by specific communities of practice and the cultivation of particular ways of interpreting those representations that are relevant to knowledge generation within those fields. Individuals learning to participate in scientific activities must learn and use the norms of practice for interpreting scientific inscriptions. As it pertains to the role of classroom teachers as mediators between content and instruction, one might expect to see teachers guiding learners' interpretations of inscriptions as a means of helping them learn how to participate in scientific activities.

One of the analytical implications of this socially-negotiated interpretation is that researchers should treat the interpretation of inscriptions as situated in social context. Aspects of representations should not be treated as features that are obviously salient or have obvious mapping to the things they represent (Roth & McGinn, 1998). Instead, researchers ought to attend to the changing ways individuals interpret inscriptions and the ways classroom communities negotiate their meanings. In some cases, as with some standard forms of inscription, teaching and learning might be considered a process of learning how to use and interpret inscriptions that are tied to the practices of particular scientific communities.

Inscriptions as supports for communication. When considering the social functions of inscriptions, perhaps the most obvious functions are their roles in supporting communication. These communicative functions of inscriptions have been brought to the fore through discussions of inscriptions as boundary objects and tools for communicating understanding between learners and teachers.

Boundary objects are representations that are used to share information across different communities of practice (Star & Griesemer, 1989; Greeno & Hall, 1997; Roth & McGinn, 1998). Boundary objects have the potential to coordinate the activities of many people with many different viewpoints. The same object can be taken up in different ways by different groups of people. In face-to-face interactions, inscriptions can coordinate interaction by providing a common environment to from which to talk (Roth & McGinn, 1998). "The physical layout of the inscription and the wider setting provide the frame within which each member's activities can be perceived by others and thus directly inform the coordination of team activities" (p. 43). Inscriptions can also be used to coordinate the work of people who are temporally and/or physically distant. Roth and McGinn point to the value of standardized forms to coordinate these interactions.

In classrooms, inscriptions can be thought of as boundary objects coordinating between the activities of the scientific community with the learning community; between the curriculum developers, the facilitators, and the learners; or between groups of learners. These boundary objects have the potential to facilitate the interaction between these various groups with differing viewpoints.

Greeno and Hall (1997) identify communication as one purpose of using inscriptions in the classroom. They claim that, when students are asked to present projects to their teachers and other students, they learn to evaluate representations for their usefulness in communicating their findings. Greeno and Hall emphasize the importance of teaching multiple forms of representation to help learners communicate their understanding to others in the community.

Inscriptions as supports for scientific argumentation in the classroom. Classroom studies show that young learners can successfully use inscriptions to support scientific argumentation (Forman & Ansell, 2002; Radinsky, Goldman & Singer, 2008; Roth & McGinn, 1998). Forman and Ansell (2002) found that, elementary school students were able to use inscriptions to advance knowledge claims and evaluate the effectiveness of those inscriptions for supporting their claims in ways that paralleled the work of scientific communities. These students used inscriptions to coordinate their interaction with their peers and support their scientific argumentation.

Roth and McGinn (1998) point to the use of inscriptions to support argumentation as a skill that can be learned by students. They report the results of a study where 8^{th} graders and college graduates were given pairs of measurements and asked to determine whether there was a relationship between the two variables and provide a convincing argument. The eighth graders relied more heavily on sophisticated practices of graphing than the college students. These 8^{th} graders had had experience engaging in research and constructing reports with inscriptions with an explicit focus on their rhetorical qualities, while the college students had not. Roth and McGinn (1998) claim that students can use inscriptions to support scientific arguments, but they must be supported in learning the communicative functions of inscriptions.

Recent work has begun to document the *mechanisms* by which inscriptions support learners' scientific reasoning and argumentation. This work describes the ways that elementary school and middle school students and their teachers can use inscriptions to support scientific (or mathematical) argumentation and reasoning.

In a study of 6^{th} and 7^{th} graders' use of visually-intensive data to support scientific argumentation in an Earth Structures class, Radinsky, Goldman, and Singer (2008) focused on student-to-student interactions that were centered around visual representations of large data sets. These representations took the form of interactive geographic information system (GIS) computer programs and paper maps. Radinsky et al. identified three common ways members of the small groups referred to this visual data: they found that students successfully used talk and gesture around the visual displays to challenge other students' authoritative positioning, used gestures over visual data to participate in argumentation before they had mastered the conceptual vocabulary, and used argumentation about data as a means of co-constructing the goals of the task at hand. This microgenetic analysis gives us insight into the mechanisms by which students employ inscriptions to support scientific argumentation.

McClain (2002) used reflections about her own teaching practice to provide insight into her decision-making processes while using inscriptions as tools for supporting communication in her math lessons. She initially encountered some difficulty separating her own, more advanced, ways of reasoning about the inscriptions from those of her students. This work points to some of the knowledge and skill demands of supporting student use of inscriptions.

Other studies have focused on teacher's use of inscriptions that are generated from student ideas. Cortina, Zhoa, Cobb, and McClain (2004) found that, in contexts where learners participate in the generation of inscriptions, the learners must first see the inscriptions as meaningfully representing their contributions before they can view the inscriptions as resources for mathematical reasoning. Additionally, they found that it was important for the teacher to continually adjust the learning environment according to the teacher's assessment of how the learners were interpreting the activity.

The analytical emphasis on inscriptions' functions as communicative tools in these classroom examples explicitly addresses the role of inscription in supporting learners' engagement in scientific practices and discourse. While these studies show that learners can successfully use inscriptions to support their scientific or mathematical argumentation, they all suggest that instructor mediation is important for the success of these efforts.

Summary. Inscriptions such as graphs, charts, and diagrams are important in science practice, and they are frequently used as instructional tools and topics of instruction in school science. However, while there is a vast body of research on inscriptions and other visual representations, the results do not paint a clear picture of how to optimize their design and use to support teaching and learning.

While the cognitive literature has made a significant contribution to our understanding of the ways visual representations support individual cognition, the task of designing inscriptions and inscriptional practices for supporting learning requires an understanding of how they function in the context of classroom learning.

Social approaches to studying inscriptional use add to our understanding of the role that inscriptions may play in the classroom by emphasizing the social construction of interpretation of inscriptions and their communicative functions.

Current studies of how inscriptions have supported students' scientific argumentation demonstrate that students can effectively use inscriptions to do this ambitious work. These studies highlight the importance of the mediating role of the instructor.

Dissertation Objectives

Through the development of a case study of expert practice, this dissertation examines the potential power of inscriptions as resources for science teaching and learning. The study takes place in the context of an inscription-heavy teacher professional development course, led by an expert facilitator. The purpose of this study is to examine the ways inscriptions were used as resources for supporting learners' conceptual understanding and scientific reasoning practices.

While there is a vast body of research on inscriptions and other visual representations, the results do not paint a clear picture of how to optimize the design of inscriptions and inscriptional activities to support teaching and learning.

Many researchers have identified the need for research that investigates the role of visual representations in learning contexts (Ainsworth, 1999; Ball, 1993, Roth & McGinn, 1998), particularly those that contexts are consistent with constructivist learning approaches (Vekiri, 2002) and where there is the presence of teaching for understanding, a culture of discourse, and authentic inquiry (Perkins & Unger, 1994).

This dissertation attempts to further our understanding about the power of inscriptions for supporting classroom learning by providing a detailed analysis of a case of teaching and learning science with inscriptions, which takes into consideration both the cognitive and social affordances of particular types of inscriptions as they are used in a particular learning context.

The case under analysis is an extreme case that represents particularly strong instruction by an expert facilitator. The goal of this work is to identify the practices that make her use of inscriptions so powerful. The context for this study is a teacher professional development program that is designed to support 4th grade teachers' understanding of content knowledge by engaging them in scientific practices (e.g., data analysis) around the topic of electric circuits. The *Learning Science for Teaching* (LSFT) professional development curriculum has a strong conceptual focus and is inscription-rich. The facilitator leading the course in this case study, Mayumi, is an "expert" in the sense that she has a strong understanding of the electric circuits concepts, a deep understanding of the curriculum, and substantial experience facilitating science professional development for elementary school teachers.

Through the development of this extreme case, I will examine how inscriptions function to support science learning in this teacher professional development program and answer the following questions:

- As it is designed, how does the professional development curriculum employ inscriptions and inscriptional practices as resources for supporting learner understanding?
- How does an expert facilitator recruit inscriptions and inscriptional practices from the curriculum to support learning?
- How do the *interactions* between the learners, the facilitator, and the inscriptions support learning?

This study will analyze the affordances of particular representations for supporting conceptual understanding and scientific reasoning practices, highlight the facilitator's inscriptional practices that support collaborative learning, and identify the pedagogical content knowledge demands of using inscriptions to support learning.

Chapter 2: Methods

Dissertation Overview: Overview of Three Analytic Strands

The purpose of this study is to detail the ways inscriptions supported learning in the context of a learner professional development course. The analysis proceeds in three inter-related strands, corresponding with three chapters, to answer the following questions:

- As it is designed, how does the professional development curriculum employ inscriptions and inscriptional practices as resources for supporting learning?
- In her enactment, how does one expert facilitator recruit inscriptions and inscriptional practices from the curriculum to support learners' conceptual understanding and scientific reasoning practices?
- In this enactment, how does the interaction between the learners, the facilitator, and the inscriptions support learning?

These analyses are built upon the perspective that classroom instruction involves many interactions between teachers and learners around educational material (Cohen & Ball, 1999). The instructional triangle in Figure 2.1 is an adaptation of Cohen and Ball's instructional triangle, which characterizes classroom learning as involving sets of interactions between the facilitator and the learners, the facilitator and the curriculum, the learners and the curriculum, and the learners and each other.

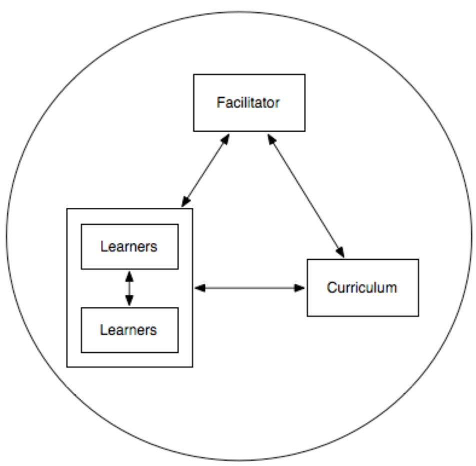

Figure 2.1. Modified instructional triangle.

Given a particular set of curricular resources (the intended curriculum), the learning experience (the enacted curriculum) depends on how those resources are used by the facilitator and the learners. The knowledge and actions of the facilitator and the learners shape the interpretation and appropriation of the curricular materials. The *opportunity to learn* in any given educational setting comes about as a result of the interaction between the elements in the instructional triangle.

This framework suggests that a deep understanding of how inscriptions support learning requires an examination of the interplay between these elements as they pertain to inscriptional use. To provide a more comprehensive understanding of how inscriptions were used to support learning in this professional development course, I present a series of three analyses, each of which prioritizes a different set of relationships within the instructional triangle.

Before delving into the three analyses, chapter 3 provides a brief overview of the science concepts and curriculum activities that will be analyzed in the subsequent chapters.

Chapter 4 takes the professional development curriculum, *Learning Science for Teaching: Electric Circuits* (LSFT), as a place of inquiry. The chapter describes the elements of the curriculum design that support and promote the use of inscriptions for advancing conceptual understanding and supporting scientific reasoning practices by cataloging the inscriptional forms, content, and practices that exist in the written curriculum. The analysis links the inscriptional forms to their intended functions (Figure 2.2).

This analysis helps us understand the curricular context in terms of the conceptual and pedagogical goals of the curriculum and the range of inscriptional tools that are provided to support the facilitator and learners in meeting those goals.

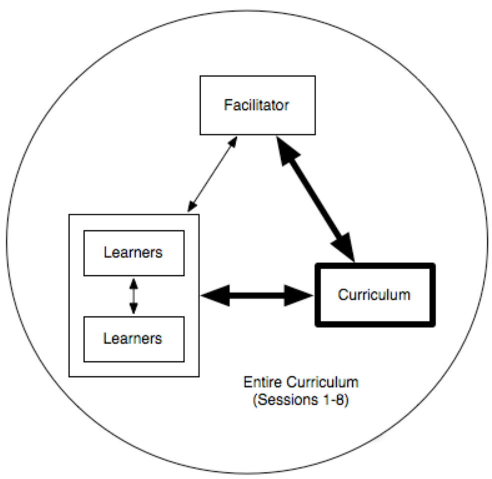

Figure 2.2. Modified instructional triangle. This figure illustrates the emphasis on the curriculum in sessions 1 through 8 for the analysis in chapter 4.

Chapter 5 characterizes the group's opportunities to learn by describing the ways the facilitator used inscriptions to shape the learners' participation in the learning activities. The analysis focuses on how the facilitator guided the learners' inscriptional practices and how and when she strategically employed inscriptions from the curriculum (Figure 2.3).

The facilitator's role is singled out for attention because of her unique role in the classroom. Her actions mediate the interaction among the learners and between the curriculum and the learners. She has the greatest likelihood of influencing the group's opportunities to learn.

This analysis identifies patterns in the facilitator's selection and manipulation of inscriptional use, and her management of the learner's inscriptional practices. Chapter 5 answers the question: How does this expert facilitator recruit the inscriptions from the curriculum to support learning?

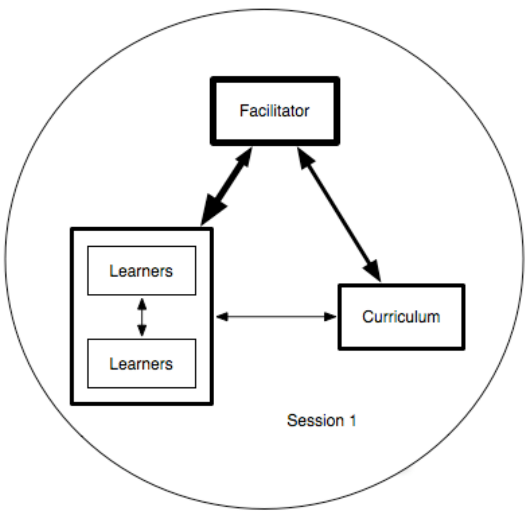

Figure 2.3. Modified instructional triangle. This figure illustrates the emphasis on the facilitator in session 1 for the analysis in Chapter 5.

Chapter 6 investigates the interaction between the facilitator, the learners, and the inscriptions and inscriptional activities in the curriculum to reveal the processes by which inscriptions support learning. This analysis zooms in on a short segment of the enactment to reveal how inscriptions were created and interpreted and how those inscriptions, in turn, affect the participants' talk and thinking about key science concepts. This third analysis helps us understand, on a micro level, how the interaction between the learners, the facilitator, and the inscriptions from the curriculum supported communication and cognition.

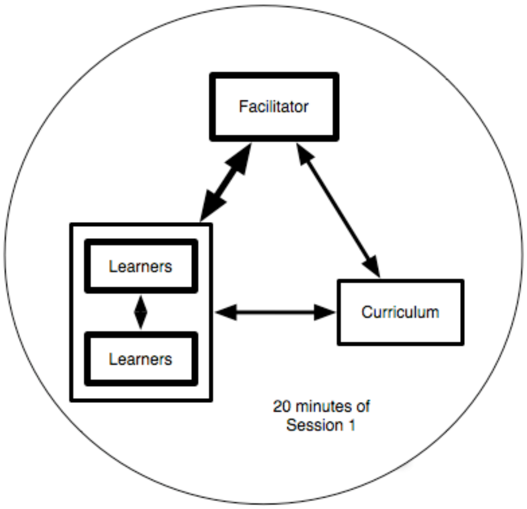

Figure 2.4. Modified instructional triangle. This figure illustrates the emphasis on the relationship between the facilitator, learners, and curriculum in the first 20 minutes of session 1 for the analysis in chapter 6.

In the sections that follow, I describe the context in which the study takes place and outline the methods used in each of the analyses. The methods for Chapter 4 are separated from the methods for chapters 5 and 6 because they differ significantly in data sources, strategy, and scope.

Context of the Study

The larger research project. The current analysis takes place within a large-scale study entitled *Effects of Content-Focused and Practice-Based Professional Development Models on Learner Knowledge, Classroom Practice, and Student Learning* (informally dubbed the Learning Science for Teaching (LSFT) study). The study was a joint project of WestEd, Heller Research Associates and the University of California, Berkeley, funded by the National Science Foundation (NSF 04-568 TPC) and co-directed by Mayumi Shinohara (WestEd), Joan I. Heller (Heller Research Associates), and Judith Warren Little (University of California, Berkeley).

This national study was designed to trace the effects of 3 different models of professional development on learner conceptual understanding, learner pedagogical content knowledge (knowledge of subject matter for purposes of teaching), classroom practice, and student outcomes.

The study included three course designs (Treatments A, B, and C), which represent three common approaches to learner professional development that emphasize different sources of pedagogical content knowledge: A) analysis of pre-designed cases of classroom teaching and learning, B) looking at student work from learners' own classrooms, and C) content immersion. Each course was contained eight 3-hour sessions, a total of 24 in-class hours (Figure 2.5). Each session was composed of two modules: a treatment-specific module that is designed to support learners' pedagogical content knowledge and a "science investigation," which focused on learners' content knowledge and scientific sensemaking. As it is written in the curriculum, the science investigation module is nearly identical across Treatments A, B, and C.[2]

	Part I Science Learning	**Part II Pedagogical Content Knowledge**
Treatment A	Science Investigation	Classroom Cases
Treatment B		Looking at Student Work from Learners' Classrooms
Treatment C		Analysis of Learners' Own Learning
Treatment D	No Intervention	

Figure 2.5. Professional development course configurations.

This dissertation focuses on the science investigation module of the professional development courses, because it has an explicit focus on developing learners' understanding of science content and scientific sensemaking.

A total of 22 facilitators led the *Learning Science for Teaching* (LSFT) professional development courses in 8 sites across the United States. Two of the facilitators, Kirsten Daehler and Mayumi Shinohara, played a special role in the project. In addition to their roles as leaders of learner professional development courses (facilitators), they were also central members of the research team: Ms. Daehler and Ms. Shinohara held the primary responsibility for designing the LSFT course models and they acted as facilitator trainers, teaching the other 20 facilitators in the study how to lead the courses.

[2] Treatment B consistently included one activity within the Science Investigation that the other two treatments did not. In this variation, learners were asked to write down an "inventory of key science ideas" in their notebooks at the end of each investigation.

The *Learning Science for Teaching* curriculum: science investigations. A review of the LSFT course materials and observations of the course sessions showed that inscriptions played a prominent role in the professional development activities. A multitude of diagrams, graphic organizers, summary charts, and data collection tables plaster the walls and populate the participants' investigation guides (the "participant guide").

During the Science Investigation, participants are introduced to electric circuits through small-group investigations and whole-group discussions. In small groups, learners engage in pre-structured investigations using instructions from their participant guides, physical materials (batteries, wires, bulbs, etc.), content notes (including different metaphors, symbols, and other visual representations), and assistance from facilitators. During the whole-group discussions, facilitators encourage learners to work together to make sense of their investigations. Facilitators encourage learners to record their work on whiteboards for "sharing out" and to create diagrams on easel paper during the large group discussion. Inscriptions are prominent in both small-group and whole-group work.

This professional development course is an example of a learning setting where there is a sustained focus on supporting conceptual understanding and the scientific practices of reasoning from evidence. Inscriptions seem to play a major role in structuring and supporting the investigations and discussions, but what is that role? This dissertation is intended to describe that relationship.

Methods for Chapter 4

Chapter 4 investigates the role of inscriptions in the *Learning Science for Teaching: Electric Circuits* curriculum. This chapter uses the facilitator guide as a resource for understanding the elements of the curriculum design that support and promote the use of inscriptions as tools for engaging learners in scientific practices and advancing their conceptual understanding.

Data sources. The facilitator guide is the primary data source for the analysis presented in chapter 4. The LSFT professional development course is structured by two key texts: the facilitator guide and the participant guide. Similar to a teacher's guide, the facilitator guide contains the plans for instruction. These detailed lesson plans include materials and preparation advice, procedures, suggested guiding questions and prompts, and inscriptions for whole-group use. The facilitator guide is the primary resource for structuring whole-group activity in the professional development course.

Like a classroom textbook, the participant guide is intended to guide the individual learners' activity. The participant guide contains instructions and guiding questions for the science investigations, written cases of classroom enactment for the case analysis, content notes to be read before the investigations, and content review sheets to be read after the investigations. While the participant guide and the facilitator guide both contain large numbers of inscriptions for supporting science learning, I have chosen to exclude the participant guide from this analysis of the inscriptional supports for whole-group work because the primary function of the participant guide is to structure individual and small-group activity, whereas the facilitator guide is the primary resource for structuring the whole-group activity.

This analysis examines the 134 pre-designed "wall charts" included in the facilitator guide. Each whole-group discussion centers around these large, poster-sized (24" x 36") inscriptions. Wall charts are the primary tools for structuring whole-group work. Figure 2.6 contains scanned images of two pages from the facilitator guide, showing a few of the recommended charts for session 1.

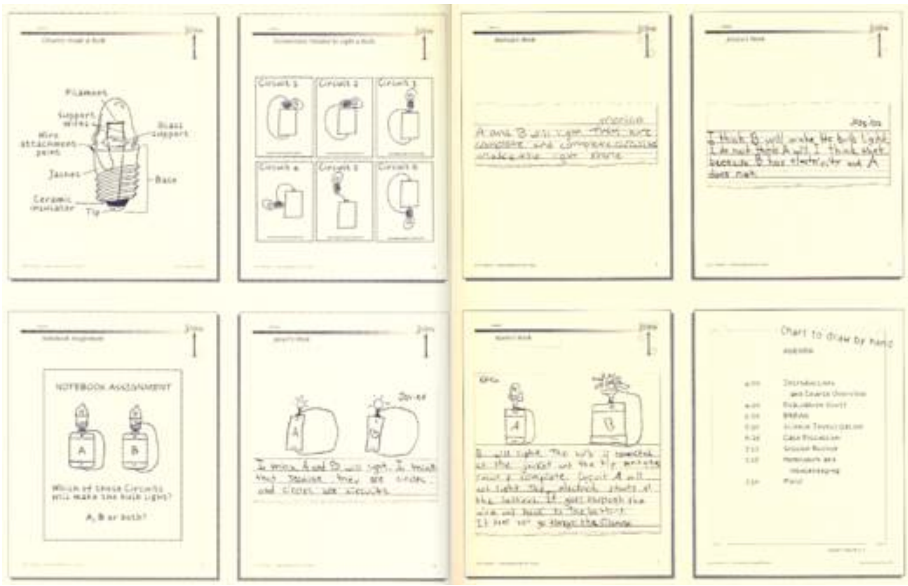

Figure 2.6. Partial list of recommended wall charts from the session 1 facilitator guide.

Some of the charts are pre-drawn and included with the curriculum materials as printable files. The first seven charts shown in Figure 2.6 are examples of these pre-drawn, print-ready charts. The images are made available to the course facilitators in digital format, and it is the responsibility of the facilitator to enlarge and print these charts prior to each session. Other charts, such as the "Agenda" chart on the lower right-hand side of Figure 2.6, are ones to be drawn by hand and customized by the facilitator. The analysis includes both the pre-drawn chart for enlargement and the charts that the facilitators must draw by hand.

Methods. This analysis characterizes the inscriptional forms and the intended functions of the inscriptions recommended by the curriculum. Each wall chart presented in the facilitator guide was coded for the inscriptional form(s) present, such as lists, diagrams, T-charts, concept maps, continuum arrows, prose, and formulas. In cases where multiple forms were present on a single wall chart, primary, secondary, and tertiary forms were assigned according to the differing levels of organizing structure. For example, if a T-chart (a matrix with 2 columns) was used to organize diagrams, the chart was coded as "T-chart" for the primary form, and "diagrams" for the secondary form.

In cases where the charts contained conceptual content (such as sample learner responses), the content was documented and analyzed for themes across inscriptions.

For the analysis of function, all text regarding the inscriptions' intended uses were recorded and analyzed for themes. Using the information explicitly included in the facilitator guide text, each chart was then categorized according to whether it was intended to be modified and the nature of those modifications were analyzed.

The analysis of the facilitator guide spans all 8 session, but the examples presented in Chapter 4 are primarily drawn from session 1 for purposes of continuity, since the analyses in Chapters 5 and 6 both focus on the whole-group discussion from session 1.

Methods for Chapters 5 and 6

Case study: extreme case. Chapters 5 and 6 represent two case studies of one expert facilitator's enactment of the Learning Science for Teaching (LSFT) curriculum. The analyses of Mayumi's lessons in Chapters 5 and 6 are intended as extreme cases (Yin, 2009) that represent an enactment of the professional development curriculum course by a highly skilled facilitator.

Mayumi is considered an expert facilitator due to her high degree of content knowledge, her experience as a developer and facilitator of science professional development, and her experience with the LSFT curriculum. This case explores the purposes for which she employed the inscriptions and the strategies she used for engaging the learners in inscriptional practices. This analysis of *how* inscriptions functioned in Mayumi's enactment helps us to understand the potential power of using inscriptions as a pedagogical tool, and sets a baseline for future work that will compare the practices of expert and novice facilitators.

By choosing to conduct a case study of an expert facilitator, I am investigating a case of strong facilitation to explore the potential power of instruction using these inscription-rich materials. Even without a specific focus on expert facilitation, an examination of the enactment of LSFT courses would present a unique opportunity to investigate the ways learners learn with materials and activities that are inscription-rich and specifically designed to support conceptual understanding and scientific sensemaking. Such a study would contribute to an understanding of how the inscriptions used in this professional development curriculum can support learning. However, strong curriculum does not necessarily entail strong instruction. These chapters foreground the mediational role of an expert facilitator in her use of the LSFT professional development materials. In this analysis, curriculum is not treated as merely a script for teacher action; instead, it is viewed as one resource for the facilitator's professional decision-making.

Participants. The participants in this case study are 1 facilitator (Mayumi) and 8 elementary school learners. There were six 4th-grade teachers, one 5th-grade teacher, and one science specialist. The participating teachers include 2 men and 6 women.

The group was diverse in terms of their experience teaching science. At the time of the study, the learners' years of teaching experience ranged from 2 to 26. Three of the learners had 2 years of science teaching experience, while 4 of the learners had 14 or more years of experience. Only 3 out of the 8 learners had previous experience teaching electric circuits to elementary school students.

Overall, the teachers' pre-service background in science was fairly low, with six of the teachers having only taken one semester of college-level or graduate-level science. However, most of the learners had experienced at least some in-service professional development in science or science teaching during the three years prior to the study.

All of the names used in this report are pseudonyms with the exception of Mayumi Shinohara, who is the facilitator and one of the principal investigators in the LSFT project. Throughout this document, Ms. Shinohara is either referred to as "Mayumi" or "the facilitator." The eight other members of the group are referred to by their pseudonyms, as "teachers" to indicate their role as professionals, as "learners" to indicate their role in the professional development course, or as "participants" to indicate both their role in the course and in the research study.

Focus on content learning during science investigation. Chapters 5 and 6 examine the teacher-learners' opportunities to learn science content, so they specifically focus on the segments within the professional development courses that target teachers' science learning: the science investigation.

In each session of the course, the learners divided their time between two activities: science investigations and case discussions. During the science investigations, teachers are asked to engage in hands-on activities to support their own learning about a specific science topic (e.g., complete and incomplete circuits). During the case discussions, the teachers are asked to analyze pre-structured, written cases that include classroom vignettes and samples of student work as catalysts for discussion about student thinking and instruction. The purpose of the science investigation is to support the teachers' own science understanding (including conceptual understanding and understanding of scientific sensemaking practices). The purpose of the case is to support teachers' discussions about teaching practices and student thinking in relation to the content area that was addressed during the science investigation. I prioritized the teachers' experiences as adult learners of science content by focusing on the science investigation only. I set aside their discussions of the classroom cases in order to de-emphasize their discussions about teaching the topics to 4th graders.

Selection of focal session. Chapters 5 and 6 focus on session 1 of the professional development course (out of 8 sessions total). The narrow focus on one episode allows for an in-depth analysis that accounts for the inscriptional forms and practices *and* the conceptual terrain of the lesson.

Session 1 is comparable to the other seven sessions in terms of the number and types of visual representations made available in the curriculum. (See the chapter 4 for the full analysis). It is representative of the inscriptional environment of the entire course.

For the purposes of understanding how inscriptions were employed to support learning, session 1 stands out as a stronger candidate for inquiry than the subsequent sessions because of its special role as the first meeting of this particular group. Session 1 gives us insight into the ways the norms of interaction were set. It was during this lesson that the facilitator and learners began negotiating the expectations for creating and using inscriptions in this LSFT course. Here, the facilitator introduced the group to the valued ways of interacting with the inscriptions in both explicit and implicit ways.

Secondly, the content of session 1 is representative of the knowledge demands faced by most elementary school learners who teach electric circuits. In this lesson, the learners are given a battery, a bulb, and a piece of wire and asked to find various ways of lighting the light bulb. This primary activity in session 1 is found in many of the most commonly used elementary school electric circuits curricula, including *Full Option Science System* (FOSS), *Science and Technology Concepts* (STC), and *Insights*.

Thirdly, the prevalence of the bulb-lighting activity in elementary school curricula is advantageous for future work because it allows for comparisons between the learners' own learning experiences during the professional development and how they teach those activities in their own classrooms. This lesson was very commonly observed in the classrooms of the learners who participated in the larger LSFT study. The ubiquity of this activity also allows for more general comparisons to circuits lessons in elementary classrooms at large. Session 1 is a stronger candidate for close investigation than the later sessions because, while the bulb-lighting activity is extremely common, only a small number of elementary school students will encounter the broad range of topics that are presented to the learners in the later professional development sessions (e.g., resistance, Ohm's law, and parallel circuits).

The choice to focus on session 1 potentially limits opportunities to see how the facilitator and learners recruit inscriptions to discuss the more complex concepts and the relationships between multiple concepts. However, beginning in session 1, the learners already contend with complex and abstract concepts including the definitions of current, the path of current flow, and direction of current flow. They also discuss the relationships between those concepts.

A second limitation of studying only session 1 is that we cannot trace how the group's inscriptional practices develop over time. It is plausible that, as the group works together over a period of time and with different content, they re-negotiate the norms around inscriptional use. This analysis prioritizes the in-depth analysis of one episode rather than changes in inscriptional use over time.

Focus on whole-group discussion. As with each session in the curriculum, the Science Investigation in session 1 includes both small-group and whole-group work. Learners first work in groups of 2 or 3 to conduct investigations. Guided by a handbook called the *participant guide*, each of the small groups area asked to spend about 30 minutes conducting the "Ways to Light a Bulb" investigation and answering questions. Then, the learners reconvene as a whole group for a discussion. The discussion is designed to last 20 minutes.[3]

I have chosen to focus the analysis on the whole-group discussions because the role of the facilitator is most pronounced during the whole-group porting of the lessons. It gives us a lens into Mayumi's expertise. Facilitators are directed to take on a strong listening role while the learners work in small groups. Facilitators are encouraged to intervene only when the groups seem to be having difficulty or when using prompts that are written in the facilitator guide:

> Remember that your job during the small-group time is primarily to participate as a warm but silent observer. You should also:
>
> 1. Listen carefully for ideas to build on in the whole-group discussion:
>   a. Common areas of interest and confusion
>   b. Ideas that were brought up but not discussed
>   c. Ideas that were discussed in some groups but not others
>   d. Ideas about which groups noticed different evidence or seemed to disagree
> 2. Assist groups that ask for help. Intervene when participants seem stuck, overly frustrated or off-task.
> 3. Encourage participants to observe, compare, and make patterns. Asking questions like the ones shown (in the margin of the facilitator guide) can be particularly helpful.
>
> (p. 14, Session 1, Facilitator Guide)

This type of participation stands in sharp contrast to the more active role that facilitators are asked to play in the whole-group discussions. Here, the facilitators are asked to "customize the whole-group procedure to meet the needs of the group." (p. 14, session 1, Facilitator Guide). This customization requires decision-making and actions that have the potential to reveal the expertise of the facilitator.

[3] These time estimates are the ones provided by the curriculum guide, or the "facilitator guide." The actual times varied. During Mayumi's enactment, the group spent a total of 45 minutes working in small groups and 40 minutes in whole group discussion. The extra time was taken out of the Case Discussion. This distribution of time was characteristic of all 8 sessions of Mayumi's enacted course.

Video analysis. The primary data source for this analysis is the video record of the enactment of the whole-group discussion of the science investigation in session 1. The video was transcribed, resulting in a total of 1115 transcript lines, representing 44 minutes of class time. The transcript includes short pieces of text that include the facilitator's and learners' nonverbal interaction with the inscriptions, such as drawing, writing, and pointing. In some of the analyses, transcript line counts and percentages are reported as rough proxies for the proportional amount of time devoted to certain types of speech.

Close-up photos of the inscriptions were taken at the end of the session and were used in conjunction with the video record in the analysis of the participants' interactions with the inscriptions. When coding, the video, transcript and still images were used in parallel.

The transcript was coded for the conceptual content of the whole-group discussions (e.g., definitions of current, path of current flow, direction of current flow, conductors and insulators). Both the normative and non-normative ideas that surfaced in these discussions were coded. This coding supported the development of claims about the nature of the conceptual work that was done in the episode by allowing me to identify conceptual themes, identify areas of difficulty, and track changes in the sophistication of the group's talk about science concepts.

Note: The transcript margins have been reformatted and the line numbers have been reassigned for ease of reading and ease of reference in this document. The transcript lines in this document do not correspond to the documents that were used for the data analysis. Inferences about the sequencing of transcript excerpts should not be made on the basis of the transcript line numbers presented in this text.

The use of inscriptions during the discussion was also documented in the transcript and coded. The inscriptions themselves were coded for their form and content. This coding informed claims about the affordances of particular inscriptions for particular conceptual purposes. For example, the blank T-chart was coded as a "form: graphic organizer" and "content: observations-lit/unlit." The T-chart afforded the categorization of observations about the presence of light from the group's hands-on work.

With respect to the activity and interactions around the inscriptions, documentation was created for the ways the learners and facilitator created, changed, interpreted, talked about, reasoned with, and referred to the inscriptions. This documentation supported claims about the functions that the inscriptions served during the professional development course, both in terms of how the facilitator structured the activities (reported in chapter 5) and the ways the participants made use of them (reported in chapter 6).

Chapter 6 episode selection. The methods for chapter 6 are the same as those used in chapter 5. One key difference is that chapter 6 shifts the analytic emphasis away from the facilitator's use of inscriptions and toward the interaction between the facilitator, the learners, and the inscriptions. In order to conduct this in-depth analysis of the interaction between these elements of the learning environment, chapter 6 narrows in on 4 episodes within the session presented in chapter 5. These episodes are limited to the first 10 minutes of the 44-minute whole-group discussion. They are chronological, contiguous, situated at the beginning of the discussion, and each one is bounded by the introduction and discussion of a diagram or wall chart.

The episodes are chosen from the beginning of the episode, which allows for an analysis of how the representations and ideas were built up and modified over time, beginning from blank templates set up by the facilitator.

The sequential nature of the episodes allows for an analysis that traces the development of ideas over time. This chapter examines the order in which ideas become aired, what materials support the communication of those ideas, how and when those ideas reappear in the group discussion.

Although they are only taken from the beginning of the episode, the wall charts used in these four episodes still represent a wide range of inscriptional forms as described in the curriculum analysis presented in chapter 4. These episodes include a graphic organizer, a list, and both pre-structured and learner-generated diagrams. The diversity of forms in these four episodes reflects the diversity in the curriculum, and it allows for an analysis of *how* and the circumstances under which different inscriptional forms were employed.

Chapter 3: Content and Lesson Overview

Content Overview

Session 1, the focal lesson in this case study, is designed to support learners' understanding of complete circuits, incomplete circuits, and short circuits. This content and lesson overview is intended to familiarize the reader with the key ideas and activities in session 1.

The key ideas for session 1 are described in the *Learning Science for Teaching* (LSFT) participant guide (p. 29) as follows:

- A bulb will light if there is a continuous path for electrical current to travel from one end of the battery, through the bulb and back into the other end of the battery. For this to happen, the bulb must be connected at two points (the jacket and the tip).
- The connections needed to make a complete circuit differ from those needed to light a bulb. A circuit is complete if there is a continuous path for electrical current to travel from one end of the battery to the other end of the battery.
- A light bulb is constructed so there is only one continuous path for electrical current to flow into the bulb, through the filament, and back out the bulb. The endpoints of this continuous path are at the jacket and tip, which is why the bulb must be connected at these points to light.
- A lit bulb is sure-fire evidence of a complete circuit, but the opposite is not true. An unlit bulb can occur in both incomplete and complete circuits. For example, short circuits are complete yet their bulbs do not light. The fact that an unlit bulb is NOT reliable evidence of an incomplete circuit is an important limitation of using light as evidence of electrical current.

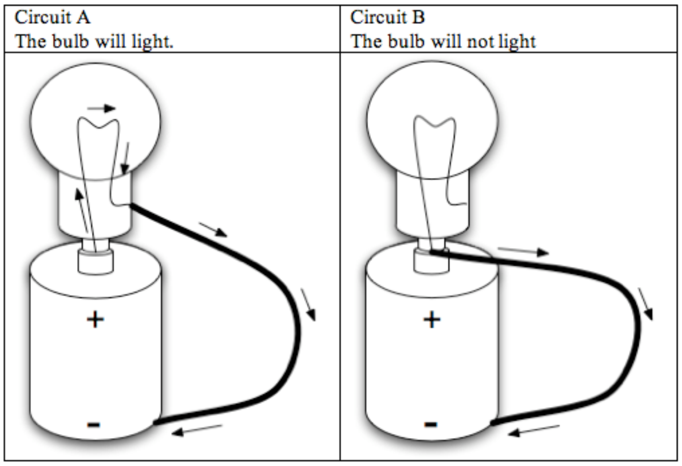

Figure 3.1. Diagrams of two complete circuits. Circuit A will light the bulb while Circuit B does not.

The images in Figure 3.1 show two complete circuits: the one on the left lights the bulb, the one on the right does not. Each diagram shows a battery, a light bulb (with a thin filament wire inside), and a piece of hookup wire (the thick line). Notice that the filament wire inside the bulb is attached at the tip (the very bottom point of the bulb) and the jacket (the metallic sides of the bulb). The bulb's tip and the jacket are both made of conducting materials, and they are separated from each other by non-conducting (insulating) material. The arrows in these diagrams indicate the path and direction of current flow in the circuits. The positive and negative ends of the battery are labeled with "+" and "-" signs.

Consider Circuit A: this circuit lights the bulb. Notice that there is a continuous path for current to flow from the positive end of the battery, through the conducting tip of the light bulb, through the filament wire (inside the bulb), out through the bulb jacket, and through the hookup wire to the negative end of the battery. Light is produced when current flows through the filament wire.

Next, consider Circuit B: this is a complete circuit that will not light the bulb. Notice that there is a complete conducting path for current flow from the positive end of the battery to the negative end, but the path does not include the filament wire because the bulb's jacket is not included in the circuit. Current will flow in this circuit, but the bulb will not light.

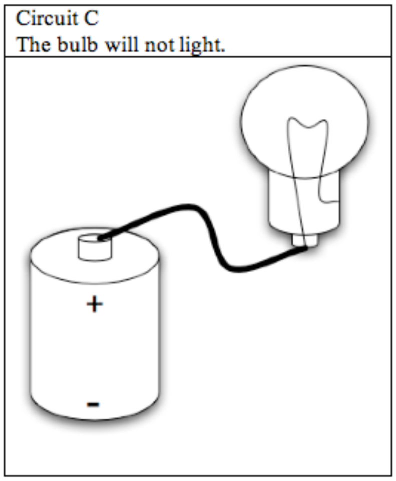

Figure 3.2. Diagram of an incomplete circuit.

The bulb pictured in Figure 3.2, Circuit C, is an incomplete circuit and the bulb will not light. There is no conducting path for current to flow from the positive end of the battery to the negative end. Bulbs in incomplete circuits will never produce light because current is not flowing.

Session 1 Science Investigation Lesson Overview

During the science investigations, learners worked with hands-on materials and participated in small-group and whole-group discussions to develop their understanding of circuits concepts (See Figure 3.3 below). The learners first worked in small groups of 2 or 3 and then convened as a whole group for discussion. This analysis focuses on the whole-group discussion of the science investigation in session 1.

Figure 3.3. Michael, Betty, and Dana work as a small group.

In session 1, each small group was given a light bulb, a battery, and a wire. Figure 3.3 shows Michael, Betty, and Dana working together to light a bulb. Following the directions in their participant guides (the spiral notebooks shown in the Figure 3.3), the learners tried to find as many ways as possible to light the bulb. They recorded their findings by drawing pictures of configurations where the bulb lit and where the bulb did not light. The small groups then answered a series of short-answer questions and True/False statements that summarized their findings.

After the small group work, the learners reconvened as a whole group to discuss their observations. Mayumi facilitated the whole-group work, which included verbal discussion, and visual work on a series of wall charts posted in the front of the room.

There were four main activities in the whole-group discussion:

1) Learners used a T-chart to categorize various circuit drawings as portraying lit or unlit circuits (Figure 3.4, middle).
2) Mayumi recorded summary statements that learners generated about their learning on the “what we’re learning” wall chart (Figure 3.4, right).
3) Learners used the diagrams on the T-chart and the “architecture of the light bulb” wall chart to indicate the connection points required for the bulb to light and trace the path of current flow (Figure 3.4, middle and left).

4) Mayumi and the learners re-categorized the circuit drawings on the T-chart to reflect the relationship between lit, unlit, complete, and incomplete circuits. (Figure 3.4, middle).

By the end of the discussion, the groups had collaboratively produced three wall charts. Figure 3.4 is a compilation of three photos, which approximates the arrangement of the wall charts in the front of the room at the end of whole group discussion. From left to right, the wall charts are: The "architecture of the light bulb" chart, the "lit/unlit T-chart,' and the "what we're learning" chart. These photos were taken at the end of the discussion, after Mayumi and the learners made modifications to blank templates, which were included in the facilitator guide.

Figure 3.4. The arrangement and state of the wall charts after the group discussion.

Chapter 4: Function of Inscriptions in the Curriculum Design

This chapter analyzes the plan for inscriptional use that is designed into the *Learning Science for Teaching: Electric Circuits* (LSFT) curriculum. The larger goal of this work is to reveal the potential pedagogical power that inscriptions can have by characterizing one facilitator's expert use of these visual representations to support learning. I begin the case of Mayumi's inscriptional use with an investigation of the curricular context in which she was working. I consider the curriculum materials to be resources for Mayumi's professional decision-making and for learner action, and this chapter analyzes the inscriptions and inscriptional activities that are provided by the LSFT facilitator guide. This chapter seeks to answer the question:

> As it is designed, how does the LSFT curriculum employ inscriptions and inscriptional practices as resources for supporting learner understanding?

This chapter analyzes the inscriptions and the pedagogical strategies offered in the facilitator guide.   The key argument is that the designed curriculum is rich with inscriptions that are well suited for particular conceptual and pedagogical purposes. They are well matched for a learning environment that values a sustained conceptual focus, a high level of learner participation, and evidence-based discussion. This analysis of the intended curriculum design provides a backdrop for understanding the enactment, which is analyzed in chapters 5 and 6.

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Comment: Eve: How can we judge whether they are well adapted to that intended use?

This chapter is framed by the following analytic questions:

- What inscriptional forms are promoted by the written curriculum documents?
- How are the inscriptions intended to be used?

Analysis and Discussion

Prevalence of inscriptions. The LSFT curriculum calls for an astounding 134 wall charts over the course of 8 sessions. The sheer number of the inscriptions present in the facilitator guide suggests that these pre-structured wall charts play a central role in the LSFT professional development course. Table 4.1 summarizes the number of wall charts given in the facilitator guide. For each session, there are between 13 and 21 suggested wall charts. These totals only include the charts that the facilitator is asked to prepare in advance or in-the-moment to help organize and focus the group's work. This table does not include the individual inscriptions that learners are asked to generate and layer on top of these wall charts, and it does not include inscriptions that the facilitator or learners may choose to create on their own.

	Total number of charts

Session 1	21
Session 2	20
Session 3	16
Session 4	17
Session 5	17
Session 6	17
Session 7	13
Session 8	13
Total	134

Table 4.1

It is not expected that all of the suggested wall charts will be used in any given session. The facilitator is given several options for group discussion and asked to determine which topics would be most helpful for the group. Each of the curricular options corresponds to a set of inscriptions and activities. In session 1, facilitators are asked to choose 2 or 3 out of 4 possible topics to discuss. The other seven sessions follow a similar pattern. The built-in flexibility in the curriculum means that, by design, there are up to three charts per session that will not be used. Even with this caveat, it is still expected that anywhere from 10 to 18 wall charts will be used in each session. As an example of what these large wall charts look like in practice, Figure 4.1 shows some of the inscriptions used during the first half of an enactment of session 1.

Figure 4.1. Wall charts posted on the front wall of a LSFT professional development course midway through session 1. This figure shows the abundance of inscriptions included in the LSFT courses.

Figure 4.1 shows nine wall charts taped to the front wall of the room where the professional development course was held. On the left, there are several hand-drawn charts, layered with learner-generated diagrams and text. On the right, there are several printed charts, which accompany the curriculum as printable files. Resting on the floor, there are three learner-generated representations that were used in the session. The tables in this room are oriented so that all members of the group have visual access to these multiple inscriptions, which serve as the focal point of the group discussion.

Inscriptional forms and uses. There are a wide variety of inscriptional forms represented in the curriculum materials, and they are strategically employed for differing conceptual purposes. With the exception of eight session agendas and one ice breaker, all of the wall charts directly support conceptual understanding. The session agendas provided logistical information about the sequence of the day's activities and the ice breaker chart provided a prompt for facilitating participant introductions. The various ways these remaining 125 charts supported conceptual understanding are outlined in the sections below.

Table 4.2 provides an overview of the types of inscription found in each lesson. The column headings represent the inscriptional form that characterizes the highest level of organization for each wall chart. Each of the forms shown in the column headings are discussed in separate sections below. Although many of the charts involve multiple forms of inscription, only the primary form was used for the categorization in Table 4.2. The layering of multiple forms is addressed in the detailed analyses that follow.

	Lists	Diagrams	Graphic Organizers	Student Work	Total number of charts
Session 1	7	3	7	4	21
Session 2	13	1	3	3	20
Session 3	10	2	1	3	16
Session 4	8	1	3	5	17
Session 5	8	4	2	3	17
Session 6	11	1	2	3	17
Session 7	6	2	2	3	13
Session 8	6	3	0	4	13
Total	68	17	20	28	134

Table 4.2. Breakdown of wall charts in each session according to the primary inscriptional form.

Lists. For the purpose of this analysis, lists are inscriptional forms that either invite or contain a series of written statements about the same topic. Half of the wall charts in the facilitator guide are lists or prompts for lists (68 out of 134).

There are two types of lists in the facilitator guide: ones where the content is predetermined by the curriculum and ones where the content is intended to be generated by the learners. Examples of both types of lists are shown in Figure 4.2. The "Learning Goals" list contains predetermined content, while the "Parking Lot" does not.

About half of the lists (32 out of 68) have predetermined content and are not intended for learner modification. These predetermined lists include session agendas, statements of learning goals, and guiding questions. The agenda helps the learners orient to the day's tasks. The role of these pre-determined lists is to steer the conceptual focus of the discussions by explicitly stating the key ideas and questions in the lesson. The designed curriculum calls for lists be introduced at the beginning of each session and left on display for the entire session.

The remaining 36 lists (36 out of 68) are open-ended and intended as spaces for documenting learner-generated ideas. As suggested by the list titles and instructions in the facilitator guide, the lists are intended as placeholders for "findings" or "what we learning." In other words, they are collections of statements of understanding. While these lists can hold "known" ideas, they have the potential to generate new discussion, since not all of the learners in a given group will share the same understanding. These lists are typically introduced after the learners have had a chance to interact with other inscriptions where they are encouraged to articulate their more tentative ideas (see the sections about diagrams and graphic organizers below). In the guide, it is stated that the facilitator serves as the primary recorder of the information on these lists. The facilitators solicit statements from the group and serve as recorders. The guidelines for what and how they record the learners' contributions, however, are unspecified.

Other lists are intended to hold questions. Some "questions" lists are used in tandem with "findings" lists encourage learner to air their thoughts even when their understanding is not yet complete. The "parking lot" is a prompt for questions that are off-topic at a given time, but might become relevant for future conversations.

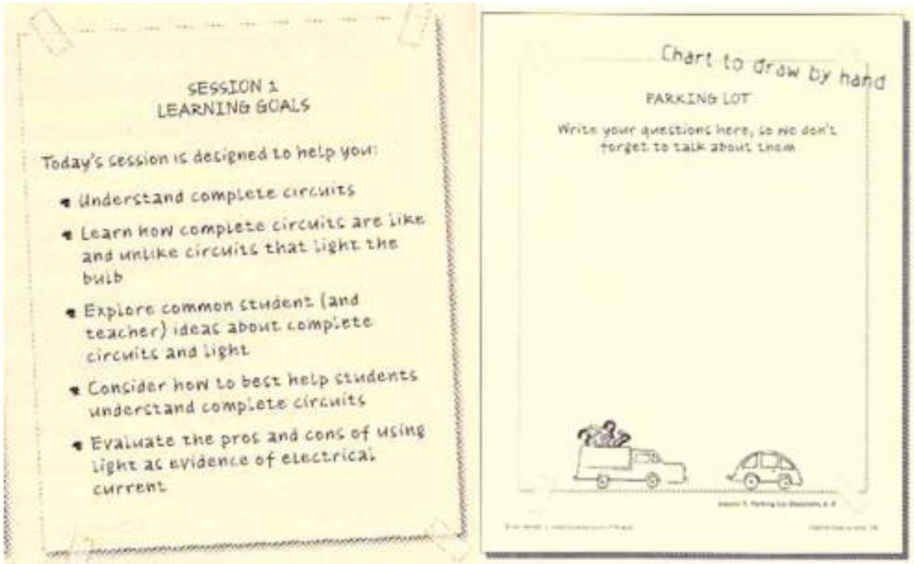

Figure 4.2. Session 1 "Learning Goals" and "Parking Lot" wall charts. These figures are samples of lists or prompts for lists included in the curriculum.

Lists that become populated with learner-generated ideas support learning by promoting sustained discussions about particular concepts. Generally speaking, the task of populating a list is to generate comprehensive, non-redundant collection of relevant information that fits a particular topic or category (Collins & Ferguson, 1993). Within this curriculum, lists are offered as tools for capturing the new understandings and the questions that arise as a result of particular science investigations. The prompt for the content of the list comes from the heading on the inscription itself, but the burden is placed on the facilitator to determine the level of coverage, in terms of breadth, level of detail, and how to handle incorrect statements.

Diagrams. In this analysis, diagrams are graphical depictions that represent the relationship between parts of a whole or show how something is constructed or how something works. Diagrams are the primary form for 13% (17 out of 134) of the wall charts in the facilitator guide. Figure 4.3 shows two examples of diagram wall charts from the curriculum. The figure on the left is the "circuitry inside a light bulb" chart, and the figure on the right shows a series of circuit configurations that might or might not light the bulb.

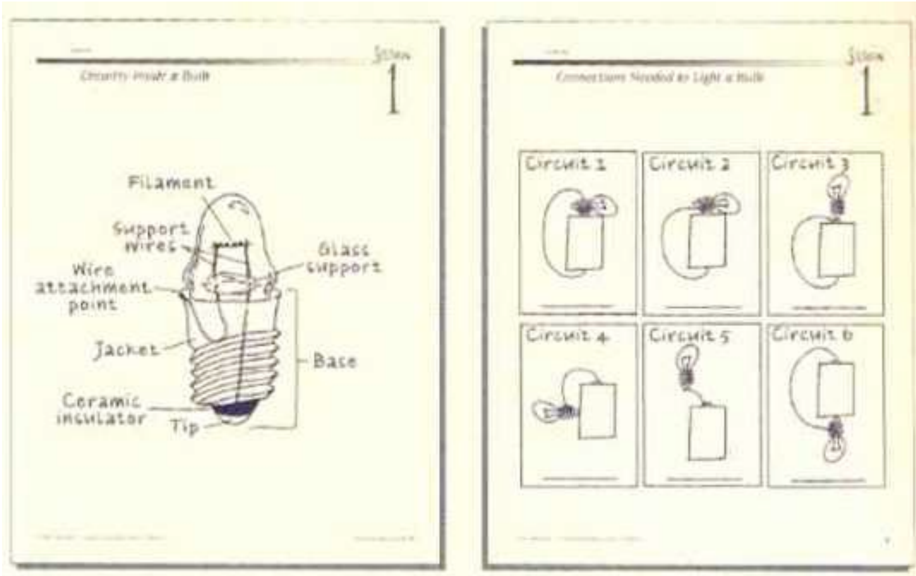

Figure 4.3. Two diagrammatic wall charts included in the facilitator guide.

Most of the diagrams in the facilitator guide, including those shown in Figure 4.3, are iconic in the sense they bear some visual similarity to the objects they depict. Most of the diagrams in the guide are fairly iconic: They have a moderate degree of visual similarity to the things that they represent. Though the drawings are somewhat comic in appearance, the objects and relationships they are intended to represent are easily recognizable by laypeople. For example, the right-hand side of Figure 4.3 shows several diagrams that depict various configurations of a bulb, battery, and light bulb.

Learners are typically invited to come up to a wall chart, which is intended to be posted in a visible location in the room, to modify the diagrams in various ways as they explain some phenomenon. The facilitator guide calls for participants to use markers to write and draw on the diagrams as they trace the path of current flow through various circuits, show the direction and amount of current in a circuit, and identify the similarities and differences between various circuits.

Because these moderately iconic diagrams are not an exact match with reality, these diagrams have the potential to facilitate discussions about phenomena that are not directly visible under ordinary circumstances. For example, when learners mark up inscriptions to indicate the path, direction, or amount of current flowing through a circuit, they use the diagrams as a bridge between the observable and the underlying (unobservable) phenomena. Because these diagrams are an abstraction, they have the potential to support learner' construction of explanations that employ unobservable concepts, such as current and resistance. The challenge for the facilitator becomes one of helping learners relate these hypotheses back to observable phenomena such as presence of light.

A handful of schematic diagrams, diagrams that are not visually similar to the objects they depict, are presented at the end of the course in session 7 and 8. Figure 4.4 shows one example of a wall chart that uses schematic circuit diagrams from session 8. These "circuit diagrams" use conventional symbols to depict circuit components and how they are connected. The schematic circuit diagrams used in this professional development course are intended to introduce the learners to a system of notation used by electrical engineers. These diagrams help bridge learners' activities to those of practicing scientists.

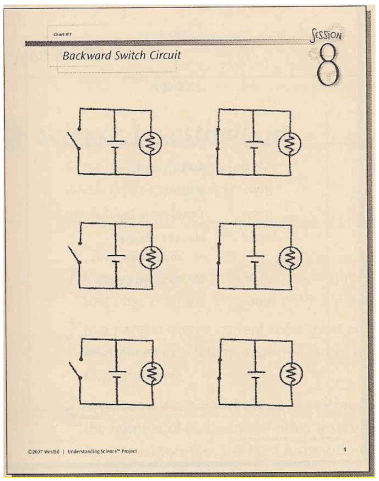

Figure 4.4. Images of schematic diagrams included in the facilitator guide.

Graphic organizers. In this analysis, graphic organizers are inscriptional forms that invite the organization of information through the strategic use of spatial orientation. These forms do not contain specific conceptual content of their own. There were 5 main types of graphic organizers in the facilitator guide: 9 T-charts, 6 matrices, 4 continuum arrows, 1 concept map, and 1 Venn diagram.

The elements that the graphic organizers were intended to organized either appear in text form or as diagrams. These graphic organizers were typically used in conjunction with learner-generated diagrams to support whole-group analysis of observations from the learners' small group work.

T-charts help organize information into dichotomous categories. Figure 4.5 shows a T-chart from session 1, which prompts learners to categorize diagrams of circuits they observed as either "lit" or "unlit." Other T-charts are set up to be populated with text, such as the sample "pros and cons" lists shown in Figure 4.6. T-charts are useful for facilitating comparisons across groups.

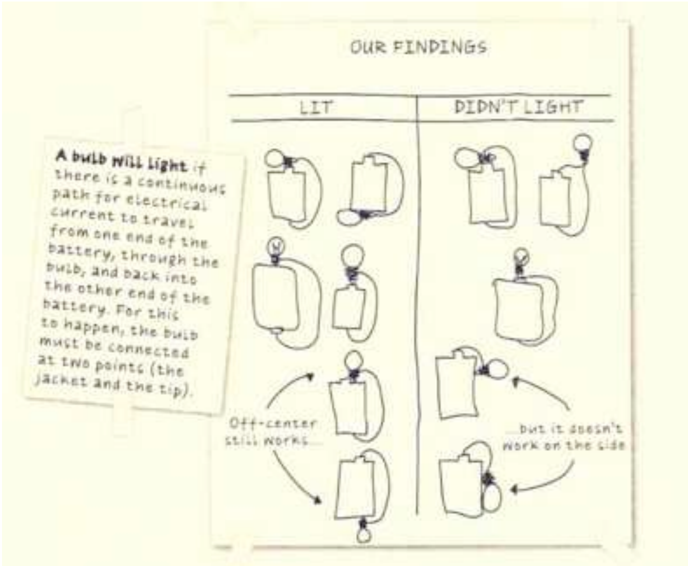

Figure 4.5. Sample T-chart from the facilitator guide. This lit/unlit T-chart has sample responses filled in as a guide for the facilitator.

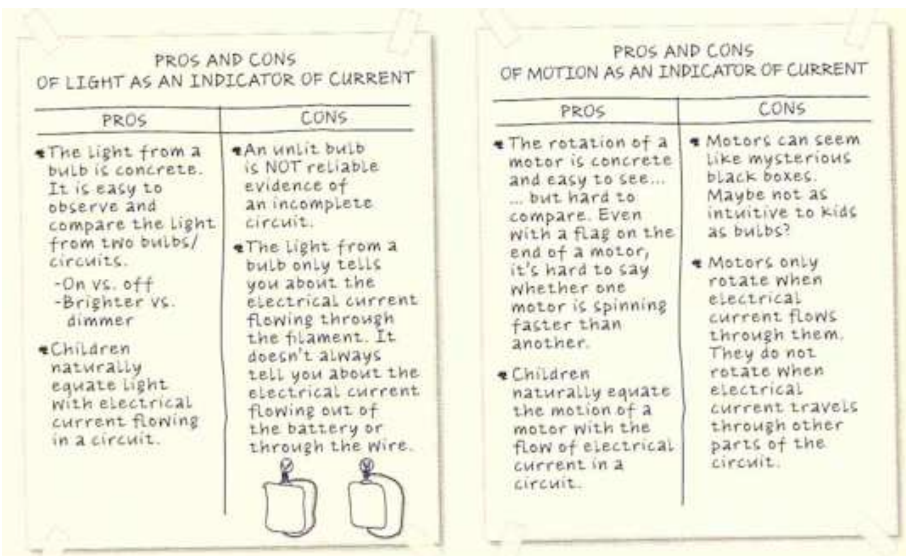

Figure 4.6. Sample T-chart from the facilitator guide. These pros/cons T-charts have sample responses filled in as guides for the facilitator.

Matrices organize elements along two dimensions with discrete categories. Figure 4.7 shows a matrix from session 1 where circuit drawings were categorized along two dimensions: lit vs. unlit and is a circuit (complete) vs. is not a circuit (incomplete). Matrices facilitate pattern identification where multiple variable are involved. For example, in Figure 4.7, one can easily see that there are no incomplete circuits that produce light.

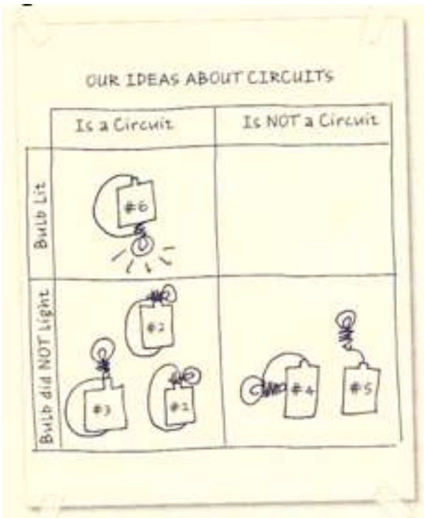

Figure 4.7. Sample matrix from the facilitator guide. This “our ideas about circuits” matrix has sample responses filled in as guides for the facilitator.

Continuum arrows help organize circuit diagrams along a single, continuous variable. In the facilitator guide, they were employed on four different occasions in discussions about the amount of current, resistance, and voltage in various circuits. Figure 4.8 shows a continuum arrow from session 2 that is intended to organize circuit diagrams from least current to the most current.

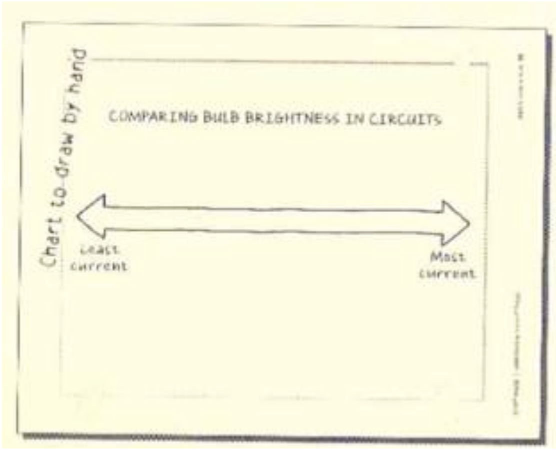

Figure 4.8. Sample continuum arrow from the facilitator guide.

The curriculum calls for learner construction of concept maps near the end of the whole group discussion for the science investigation in session 1. The facilitator guide suggests that these maps are tools for helping the learners summarize the relationship between presence of light and complete and incomplete circuits. (See Figure 4.9 for two sample maps shown in the facilitator guide.) By asking for a concept map and accompanying explanation, this activity engages learners in the task of explicitly naming and creating a visual depiction the relationships between various concepts.

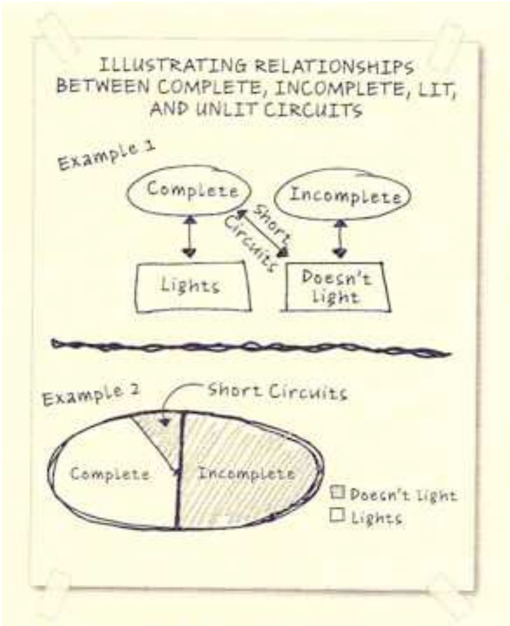

Figure 4.9. Sample concept maps from the facilitator guide. These sample concept maps illustrating the relationships between complete, incomplete, lit, and unlit circuits are provided as sample responses filled in as guides for the facilitator.

Venn diagrams organize information into categories in cases where simultaneous membership in multiple categories is a possibility. The curriculum uses one Venn diagram to help the learners develop a fuller understanding of the ways series and parallel circuits behave. Learners are asked to write down statements about how some circuits behave, and to categories those statements as describing “series,” “parallel,” or “both.” The form of the Venn diagram helps the learners sort out which behaviors are unique to different types of circuits and which behaviors are shared.

Student work. The LSFT curriculum provided fictitious samples of student writing and/or drawing. Based on work generated by actual students, these selected and edited by the curriculum developers to include common student ideas. These samples were intended to provide fodder for rich discussions during the professional development sessions. Each piece of “student work” provided by the curriculum is either prose-only or a combination of prose and one or more diagrams. “Student work” is a specific type of wall chart that has been categorized separately because it is a form that is unique to this curriculum, and it is used in a consistent manner throughout the 8 sessions. Figure 4.10 shows two examples of student work wall charts from session 1.

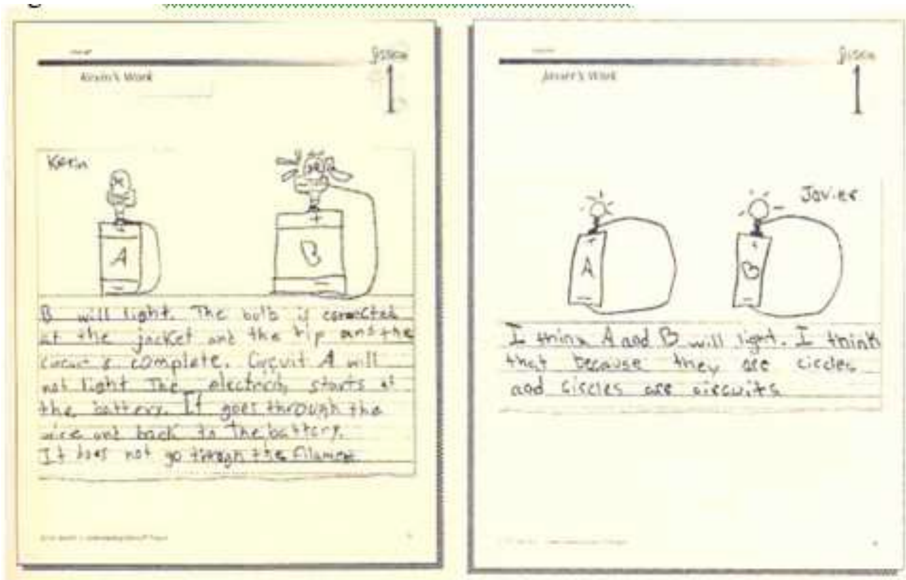

Figure 4.10. Student work wall charts included in the facilitator guide. The samples of student work are fictitious pieces of writing and drawing that are provided by the facilitator guide.

During the portion of the professional development course where learners are asked to discuss cases of classroom teaching and learning, the learners analyze pieces of student work for evidence of student understanding. The facilitator guide asks that learners use different colored markers to annotate the wall charts to show evidence of students' correct thinking and their incorrect thinking. These large displays of student work support help the learners orient to the scientific concepts in the work and to ground their discussion in evidence.

In other words, these wall charts invite the learners to treat student work as data. Their large size supports learners' collaborative analysis.

Summary and Conclusions: Pedagogy Reflected by the Inscriptions and the Inscriptional Activities

What does this survey of the inscriptions in the facilitator guide tell us about the pedagogy in the curriculum? First, inscriptions are a central component of this curriculum. This can be seen readily by the sheer number of inscriptions employed by the curriculum. A close analysis of these inscriptions shows that the curriculum capitalizes on the affordances of particular inscriptional forms for specific pedagogical purposes.

The nature of the inscriptions suggests several things about the roles of the participants and the nature of the discussion that is valued by the curriculum. The inscriptions are not intended to function merely as visual aids that statically and redundantly display spoken or written information. Instead, the inscriptions were intended and designed to actively shape discussions where a) the learners are the primary contributors, b) the public sharing of ideas using inscriptions is valued, c) the discussions are conceptual in nature, and d) questions and tentative understandings surface and explored.

The activities and inscriptional support are consistent with the following pedagogical message that is explicitly stated in the facilitator guide:

> "Explain that the whole-group discussion builds on what happened in the groups of three. During the discussion, you will ask individuals to share how they are thinking about the science, draw on chart paper to explain their ideas, listen carefully to each others' interpretations, demonstrate with circuits, and ask questions of one another to collaboratively make sense of the science. Let participants know it is okay to be wrong at this point in their learning. One purpose of learning this way is to identify the pockets of one's own naïve thinking and refine one's own understanding of the science. The facilitator's role is to help the group explore the science deeply, consider alternative ways of thinking, and use evidence to sort out and ultimately achieve an accurate understanding of the science. The facilitator's role is NOT to be the science expert." (Session 1, pg. 15)

This chapter has exploring the ways the professional development curriculum employs inscriptions and inscriptional practices as resources for supporting learning. This curricular context serves as a backdrop for the analysis of Mayumi's *use* of these resources in chapters 5 and 6. Chapter 5 focuses on the facilitator's use of inscriptions in session 1, and the nature of the resulting opportunities to learn. Chapter 6 investigates the whole group's uptake of these inscriptions, focusing on the interactive nature of the creation, discussion, and modification of the inscriptions during the enacted lesson.

Chapter 5: Mayumi's Structuring of Opportunity to Learn with Inscriptions

This chapter focuses an expert facilitator's use of inscriptions to support learning in the context of a whole-group discussion. The primary data source is the video record and transcripts of the whole-group discussion in session 1 of Mayumi's enactment. This analysis investigates the ways Mayumi used inscriptions to structure opportunities to learn.

This chapter puts forward three key assertions: (a) Mayumi encouraged discussion that was heavily grounded in the use of inscriptions, (b) Mayumi used inscriptions as tools for engaging learners in conceptual discussions, and (c) Mayumi used inscriptions as tools for engaging learners in scientific reasoning practices. Although the conceptual work and the scientific practices are discussed in separate sections of this chapter for the purposes of clarity, it is important to note that the scientific practices the learners were engaged in *supported learners' understanding of the key concepts*. The learners did not engage in process skills that were separated from content.

The Facilitator Encouraged Discussion that was Heavily Grounded in the use of Inscriptions

Figures 5.1[4] and 5.2 shows three poster-sized inscriptions that created and modified by Mayumi and the learners during the whole-group discussion. These inscriptions were known in the professional development course as *wall charts*. Figure 5.1 shows the wall charts in their blank state, before the group used them for their discussion. Almost all of the conversation revolved around the construction, elaboration, and modification of these three charts. Notice the large amount of text, drawing, and highlighting that had been added to each of these charts by the end of the session.

[4] These images are mock-ups of the state of the wall charts at the time that Mayumi put them up on the wall. They were created from digital photographs that were taken at the end of the lesson, and edited using Adobe Photoshop CS. These images were created to reflect the state of the wall charts as they appear in the video record of the lesson. Screen shots from the video were not of high enough quality to be used in this document.

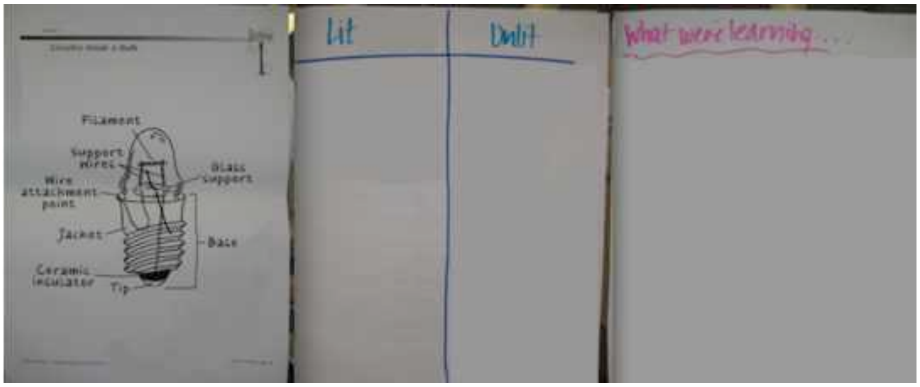

Figure 5.1. Blank wall charts prior to their use in Mayumi's enactment of session 1. From left to right, they are: the "architecture of the light bulb" chart, the "lit/unlit" T-chart, and the "what we're learning" chart.

Figure 5.2. The wall charts at the end of session 1. This figure shows all of the writing and drawing that was added to the wall charts throughout the session.

As reflected in the analysis below, Mayumi invited and encouraged discussion that was heavily tied to inscriptions by (a) explicitly anchoring the activities to key visual representations, (b) setting up the physical environment to allow all participants visual access to those key inscriptions, and (c) encouraging the participants to create representations in such a way that it allowed the learners to operate on their ideas as objects of thought.

The facilitator used wall charts as anchors for discussion in each activity. The whole-group discussion involved three major subtasks. Each task was anchored by at least one 20" x 30.5" (easel paper sized) inscription. Within the professional development course, these large inscriptions were known as wall charts. In the first task, the learners were asked to populate a blank T-chart that had the headings *lit* and *unlit* with the diagrams of circuits they had created during their small group work. Using this wall chart, Mayumi invited the group to categorize and discuss representations of various circuit configurations they had encountered during their science investigations. When the group members spontaneously developed summary statements during the discussion, Mayumi recorded them on a second chart, entitled "what we're learning." Images of the two wall charts are shown in Figure 5.3.

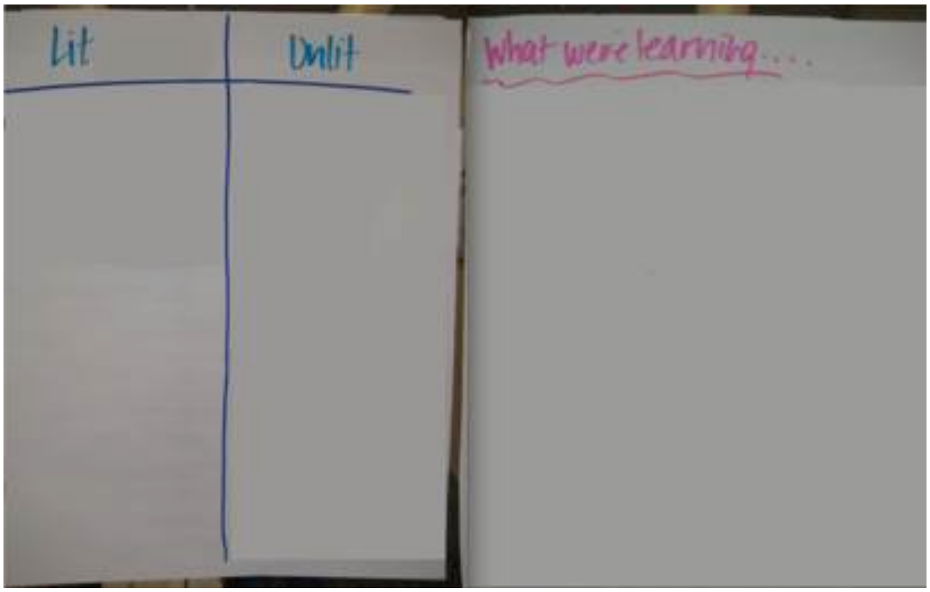

Figure 5.3. Close-up images of the blank "lit/unlit" T-chart and "what we're learning" wall charts.

The second major subtask was an in-depth discussion about the path of current flow in a circuit. As the learners described their drawings from the first subtask, the notion of *path* came up. To further explore this idea, Mayumi introduced a new wall chart: the architecture of the light bulb (Figure 5.4). The architecture of the light bulb is an image that is provided as a printable image in the facilitator guide. It is a standard part of the LSFT curriculum. It is a large image of a light bulb that shows how the filament wire is attached to two places on the bulb: the jacket and the tip. Mayumi introduced this image after the group began talking about the path of the current flow. She added a drawing of a battery and a wire, and encouraged the group to use the image to support their descriptions of the relationship between path of current flow and whether or not the bulb lights.

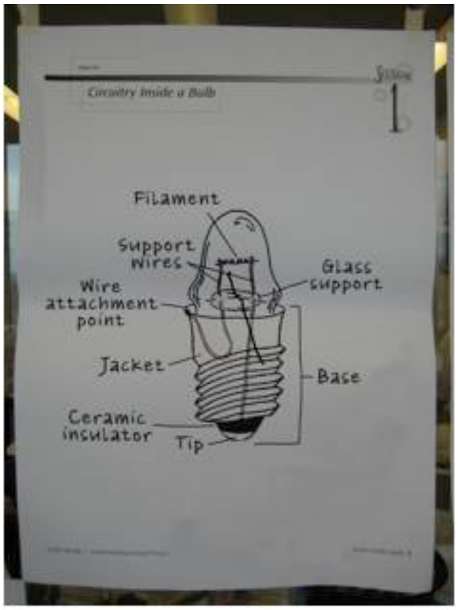

Figure 5.4. Close-up image of the “architecture of the light bulb” wall chart.

The third subtask summed up the discussion by inviting the learners to create concept maps that illustrated their new understanding about the relationship between lit, unlit, complete, incomplete, and short circuits. Figure 5.5 shows photos of two of the three concept maps created and discussed by the learners. These concept maps were created *after* the learners had done extensive work with the wall charts, as a way of summarizing their new understanding.

Figure 5.5. Two concept maps created by the learners at the end of Mayumi’s enactment of session 1.

The facilitator engaged learners in the active creation and manipulation of inscriptions. A line-by-line analysis of the transcript of the whole-group discussion shows that, after her initial invitations for learners to use the inscriptions, Mayumi made an *additional* 13 requests for learners to demonstrate their thinking in some visual form such as creating a new drawing, manipulating or modifying an existing inscription, or gesturing over specific areas on the wall chart. These follow-up requests for learners to engage in the active creation and manipulation of inscriptions made up 6% of Mayumi's verbal contributions during the discussion. This figure indicates that Mayumi placed a sustained emphasis on the learner's use of inscriptions to support the discussion.

The facilitator structured the tasks such that the form of the inscriptions allowed the learners to act upon them as objects of thought. While Mayumi instructed each small group to create drawings to share with the whole group (lines 1-11), she gave them blue half-sheets of paper and dark markers to create these drawings. By providing these specific instructions and these particular materials, Mayumi not only influenced the *content* of the learners' contributions, she influenced the *form*. Mayumi's prompts resulted in a set of inscriptions that had specific characteristics that allowed the learners to act upon them as objects of thought. In the paragraphs below, I describe five of these features and their affordances for supporting the group's conceptual work.

Mayumi: So, we're going to switch over to whole-group in a minute and I'm going to ask people to start off by sharing either a circuit that surprised you, *just like a drawing of it*, or a pair of circuits that helped you to learn something. So either the one or the two. Your choice. (Emphasis added)

….

Mayumi: Oh, and folks, when you draw your circuits, if you could do them with a dark marker, so it shows up really—it's fine to do it with a pencil or pen first, um, but make sure you get dark marker *so we can all see it*. (Emphasis added)

First, the ideas were put on paper. The small groups were asked to come to a consensus about one or two drawings to share with the whole group. Compared to verbal sharing, which only lasts for a few moments, inscriptions remain temporally available for inspection, discussion, editing, and moving around. The physical presence of these drawings allowed the ideas to remain available and salient throughout the course of the discussion. The visual representation lowers the demand on individuals' working memory, and in that way, supports their ability to use the group contributions as a set of ideas that could be discussed and manipulated in relation to one another.

Second, each group was asked to draw only one diagram on each sheet of paper. This setup allowed the papers to be moved independently from the other. The independence of circuit drawings as discrete units and the transportability of the papers allowed for flexible organization and reorganization of the drawings. Each unit was an individual circuit configuration.

Third, the size of the blue sheets imposed a constraint on the size of the learners' circuit drawings: The images were small enough to be organized on the T-chart, but large enough to be seen by all of the participants. The size of the inscriptions was ideal for supporting the collaborative categorization of the circuit drawings.

Fourth, the inscriptions were created using dark markers, which gave all of the learners visual access to the drawings. Mayumi foreshadowed and emphasized the social role that these representations would play in the whole-group discussion by announcing that they should use dark markers "so we can all see it" (lines 10-11). The ideas from the small group were made public. These ideas could then become a part of a shared data set, which the group could then collaboratively analyze.

The importance of visual access to the inscriptions was further reinforced when the whole-group conversation started. Mayumi specifically requested that the learners rearrange their chairs so everyone could see the front board. When her first request was not heeded, she repeated the request and waited until the seats were arranged in a way that allowed everyone to see.

Fifth, the inscriptions were moderately-iconic line drawings that had the benefit of showing conceptually-important details that would prove vital to the participants' learning. Mayumi specifically asked the group to do "just, like, a drawing" (lines 3-4) of the circuits. These moderately-iconic inscriptions stand in contrast to more formal circuit diagrams that scientists might use, which are more schematic. Diagrams can vary in their degree of iconicity or visual similarity to the objects they represent. Figure 5.6 shows an example of the more iconic representations that the learners were asked to draw (on the left) and a more schematic representation (on the right). As shorthand, I will refer to the image on the left as *iconic* and the image on the right as *schematic*. Both images depict complete circuits where the bulb would be expected to light, but they include different pieces of information. In the schematic diagram, the light bulb is drawn as a circle with a squiggle inside. On the left-hand side of the image, the positive and negative ends of the battery are indicated by the long and short lines, respectively.

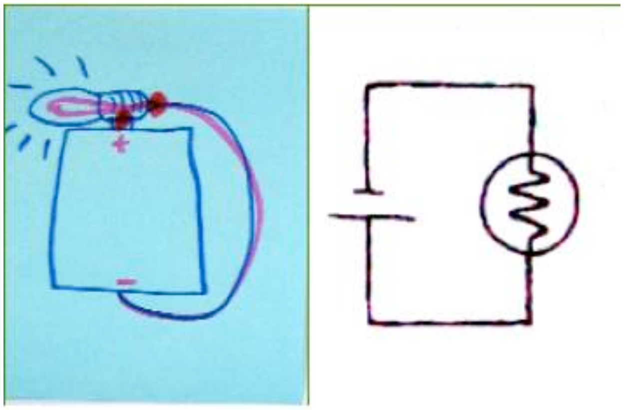

Figure 5.6. Iconic (left) and schematic (right) drawings of complete circuits with lit bulbs.

The iconic representation on the left-hand side of Figure 5.6 depicts features of the circuit that are pedagogically desirable for supporting the understanding of some key concepts, such as *contact points* necessary for the bulb to light during this early stage of learning. This picture shows the physical points of contact between the battery, bulb, and wire. The contact points on the battery have been made more salient through the highlighting with red dots. This information is not explicitly included in the schematic diagram on the right.

Mayumi engineered the task of creating circuit drawings to support the collaborative analysis of a shared dataset by capitalizing on the temporal availability, independence, transportability, size, visibility, and iconicity of the circuit diagrams. She invited the creation of diagrams with these features to support learners in viewing observations in relation to each other, categorizing those observations, and interpreting the data.

The first part of this chapter has characterized the general pedagogy underlying Mayumi's lesson: Her lesson was heavily conceptual, it engaged learners in scientific reasoning, and the instruction was heavily anchored to the learners' creation and engagement with inscriptions. This enactment reflects a strong, inscription-heavy pedagogical approach that has the potential to meet the National Research Council's ambitious new goals for scientific literacy (NRC, 2007). In the two sections that follow, I move beyond the general pedagogical approach in Mayumi's lesson to specify *how* she used inscriptions to support the learners' conceptual understanding and scientific reasoning.

Inscriptions as Tools for Engaging Learners in Conceptual Discussions

The enacted lesson targeted key scientific concepts. Mayumi's lesson focused key concepts that are central to understanding electric circuits. While this statement might appear to be obvious on its surface, research has shown that key science ideas often get shortchanged in science lessons. In a study of nine widely used middle school science curricula conducted by Project 2016, researchers found that key science ideas were obscured by the overwhelming presence of peripheral ideas and facts (Kesidou & Roseman, 2002). In many classrooms, key science concepts become lost in a sea of ideas that have varying degrees of importance.

It is also common for curricula to intentionally set aside key concepts in favor of science process skills. Many of the curricula that were produced as part of the educational reform movement in the 1960s focused on process skills such as observing, measuring, and designing experiments (NRC, 2007). These process skills were divorced from particular conceptual goals. In fact, these processes skills are still outlined separately from the development of conceptual understanding in the current national standards for science education (NRC, 1996).

Mayumi's enactment of session 1 had a specific focus on key concepts, including complete circuits, incomplete circuits, and short circuits. (See Chapter 3 for a brief overview of these concepts.)

This conceptual focus is highlighted by the way the science investigation was structured. In many elementary school classrooms, learners present students with the task of getting the bulb to light. However, these lessons do not always have a conceptual focus: it is common to see learners trying various methods of lighting the bulb, and once they achieve that goal, no further explanations are sought. In Mayumi's lesson, however, the learners used observations from the activity (getting the bulb to light) to support their developing understanding of the underlying science concepts (complete circuits, incomplete circuits, and short circuits). The bulb-lighting activity served as the basis for a 44-minute whole-group discussion about these key concepts.

Mayumi's facilitation of session 1 supported in-depth discussions by focusing on a small number of interrelated concepts. Complete circuits, incomplete circuits, and short circuits (and their relationship to lit and unlit bulbs) were prioritized over other ideas. Discussions about ideas that help explain the relationship between these key ideas were encouraged (e.g., connection points and path of current flow), but other concepts that were less central were not given explicit attention. For example, discussions about the direction and amount of current flow in circuits were purposely held off until later sessions.

The following sections investigate *how* Mayumi recruited inscriptions as tools for engaging learners in discussions that focused on key concepts. In the following paragraphs, I detail the ways Mayumi used inscriptions to (a) invite discussion about new and difficult concepts, (b) prioritize and highlight key concepts, (c) separate and distinguish ideas from one another, (e) document key conceptual questions, and (f) redirect off-topic conversations.

The facilitator invited discussions about new and difficult concepts. The whole-group discussion centered on concepts that the participants were still working to understand: the ideas under consideration were key scientific concepts at the front edge of the learners' understanding. In formal learning settings, it is common for instructors to wrap up small group activities by asking the entire class to re-convene as whole group to share what they learned. Often, a representative from each group is asked to make a summarizing statement. Learners commonly respond to a general prompt, such as "What did you learn?" or a more specific one, like, "What did you need to light the bulb?" This activity results in a list of summary statements, which are treated as known facts and could be considered as takeaways from the day's activities.

There are two problems with this common version of whole-group wrap-up where the content of these takeaway statements is largely determined by the unedited contributions of the learners: First, this activity supports the development of statements about facts where the content is fairly straightforward or easy-to-learn. Participants are likely to give statements that are already within their conceptual comfort zones. Areas of difficulty and uncertainty are less likely to show up on these lists. Second, this type of activity masks areas of incomplete understanding. When the individuals' contributions to a summary list are treated as correct, unproblematic, and understood by all, there is limited opportunity for the facilitator to assess the entire group's understanding of more difficult concepts.

The discussion in Mayumi's sessions went beyond this common version of whole-group wrap-up. By encouraging the discussion of new and difficult concepts, Mayumi supported the learners' consideration of concepts where their understanding was tentative or fragile. The discussion introduced the group members to ideas, ways of thinking, and understandings of concepts not yet achieved during the small-group work.

The prompt that Mayumi used to transition the learners from small groups to whole-group discussion is the key to understanding how she expertly shaped the conversation to focus on the front edge of the learners' understanding. First, Mayumi's prompt encouraged learners to create diagrams that focused on new or difficult concepts. These diagrams served as anchors for the whole-group discussion. Second, because each small group was asked to come to consensus on one or two diagrams, the learners were more likely to present only the most difficult or surprising concepts, the most central concepts. We now turn to a close examination of how Mayumi structured the whole-group discussion to explicate these ideas.

In their small groups, the learners were asked to use a battery, bulb and wire to find as many ways as possible to light the bulb. As the small groups were finishing up, Mayumi walked around to each of the small groups and said:

Mayumi: So, we're going to switch over to whole-group
in a minute and I'm going to ask people to start
off by sharing either a circuit that *surprised* you,
just like a drawing of it, or a pair of circuits that
helped you to learn something. So either the
one or the two. Your choice. (Emphasis added)

As she gave these instructions, Mayumi presented each small group with two half-sheets (5 ½" by 8 ½") of blue paper to create their drawings. The learners' task was to select among all of the observations they had made to report back to the whole group. These diagrams would eventually be posted on the front wall and discussed by the entire group.

Mayumi's verbal instructions requested that the learners to focus on two things: surprise and learning. The word *surprise* in line 14 invited learners to tap into events or observations that went against their expectations. This prompt encouraged learners to report on instances where they experienced dissonance. These cases signal areas of conceptual difficulty and are ripe areas for supporting new learning.

Mayumi's suggestion that the participants focus on two circuits that helped them to *learn something* in line 16 had the potential to direct learners to report something similar to *surprise* or tap into ideas that the learner had never thought about prior to this investigation. By asking the participants to provide *two* drawings, Mayumi encouraged the groups to focus on fruitful comparisons and develop a set of inscriptions that had the potential to support discussions about general rules.

Both of Mayumi's prompts directed the participants to share concepts that they had not understood prior to their small group work. Additionally, each small group was asked to work together to generate only one or two inscriptions to share with the whole group. This strategy had the potential to elicit the most important or most surprising findings in the group. This setup increased the likelihood that the most difficult ideas would surface, thus creating greater opportunities for learning. The whole-group discussion could then serve as an opportunity to solidify shaky understanding.

This setup did, in fact, generate diagrams that highlighted the most difficult aspects of the lesson. At the end of the session, Mayumi pointed out that no one had shared diagrams of circuits that were both incomplete and unlit (see Figure 3.2, Circuit C for an example). When asked why they did not draw any of these diagrams, Debby responded, "It didn't surprise us," indicating that the content of the drawings the groups *had presented* to the whole group *were*, in fact, surprising.

The facilitator prioritized key concepts with headings and highlighting. In her unique role as the facilitator, Mayumi drew upon her understanding of the central concepts in the lesson to ensure that they were prioritized in the discussion. After the small groups of learners created their circuit drawings, Mayumi asked each group, one-by-one, to post their drawings on the front wall and to discuss them. Mayumi had posted a T-chart on the wall, which served as an implicit invitation for the small groups to categorize their circuit drawing as either lit or unlit. These categories are shown as blue column headings in Figure 5.7.

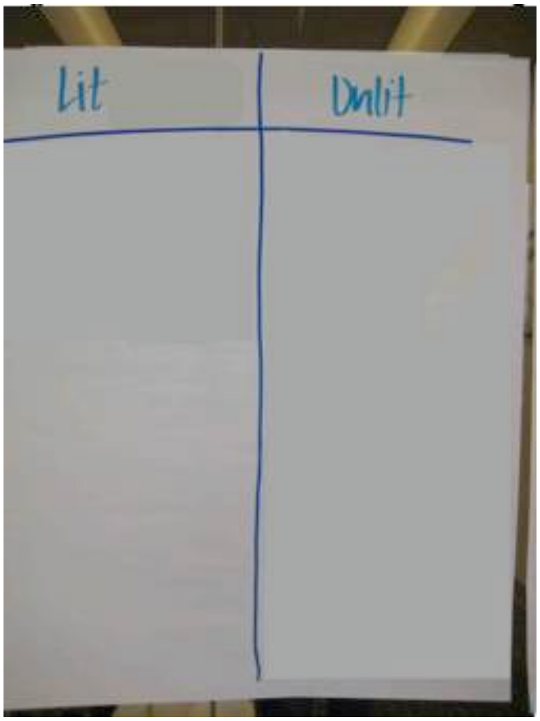

Figure 5.7. Blank T-chart with the category headings "lit" and "unlit."

The T-chart is an example of a tool that was suggested by the curriculum and created prior to the lesson to structure the conversation. As specified by the curriculum, one of the primary purposes of this lesson was to help learners understand that lit circuits always indicate that there is a complete circuit, but unlit circuits can indicate either an incomplete circuit or a complete circuit where current does not travel through the bulb (i.e., a short circuit). By creating the T-chart template for organizing the group's observations, Mayumi structured a comparison between the circuit configurations that led to a lit bulb and those that led to an unlit bulb.

Then, Mayumi pushed the conversation a bit further. After the learners had categorized their circuits as lit or unlit, Mayumi added the sub-categories of "complete" and "incomplete" to the T-chart. These sub-categories are shown in red in Figure 5.8. The addition of these sub-categories pressed the conversation toward a consideration of the relationship between lit/unlit and complete/incomplete.

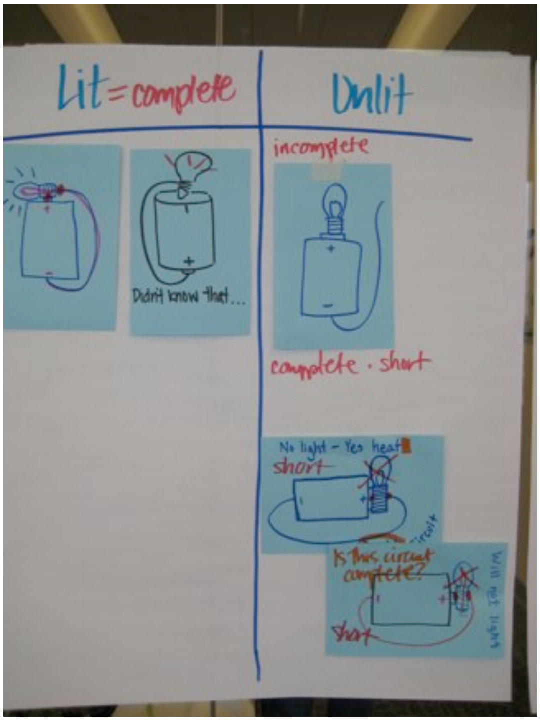

Figure 5.8. The completed T-chart with sub-categories "complete," "incomplete," and "complete-short" added by the facilitator in red.

In addition to appropriating charts from the curriculum, Mayumi also responded to the unfolding conversation by creating in-the-moment inscriptions that highlighted key ideas that came up during the discussion. Mayumi physically highlighted key concepts on the participants' diagrams as they came up in the conversation (e.g., heat, complete, connection points, and short circuits).

Over the course of the lesson, 5% of Mayumi's talk (20 lines) was associated with a highlighting move. She highlighted the following key concepts: heat, jacket, tip, connections, conducting path, positive and negative ends of the battery, complete circuits, incomplete circuits, and short circuits. In the sections that follow, I explore two examples of how Mayumi used highlighting to guide the learners' conceptual focus.

Highlighting example 1: Betty's diagram. To illustrate how Mayumi used inscriptions to physically highlight key ideas in the discussion, we turn to Betty's contribution. As Betty posted her diagram on the T-chart (Figure 5.9), she said:

Betty: Okay, so this one did not light, but was warm. So,
it touched the jacket on the positive end, the wire on

the negative and positive end. . . so, there's no
light, but there was heat. So, it's a complete circuit.

In response to Betty's statements and the audible murmur from the other participants, Mayumi went up to Betty's diagram and marked the key terms "heat" and "complete" with a red marker as she said:

Mayumi: Mm. . . so the "oohing" and "aahing" I heard is
around this notion of *heat* and *complete*. So I just
want to mark those.

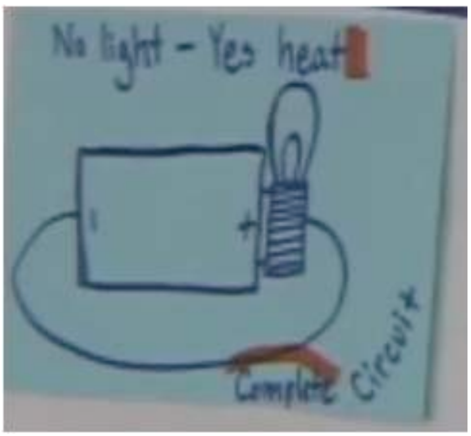

Figure 5.9. Betty's circuit drawing with Mayumi's highlighting in red.

Figure 5.9 shows Betty's original drawing in blue. Mayumi's highlighting of the words *heat* and *complete* are the red lines next to those words.

In this example, Mayumi also re-voiced the key concepts expressed in Betty's contribution. Mayumi named individual terms that Betty used (line 23). It is important to note that Mayumi did not repeat a completely formed statement or add her own information to flesh out the meaning or significance of these concepts. Instead, she merely repeated short segments of what Betty stated. Mayumi's short statements served as requests for further attention and elaboration by the participants. When Mayumi marked the corresponding words in Betty's diagram in red, the highlighting served as a visual reminder about the importance of those ideas.

Highlighting example 2: Reina's diagram of a lit bulb. In another instance, Mayumi listened to a lengthy exchange between the learners and said:

Mayumi: So, it sounds like, um, there's something about
jacket and tip that we're, that we're talking about.
Can somebody summarize what that is?

Here, Mayumi verbally highlighted key concepts (line 26) that came up in the discussion and asked the learners to explicate those ideas (line 27). As the learners elaborated the significance of the jacket and tip, Mayumi created a visual record of those ideas by writing them down on a chart that started out as a blank sheet of paper with the heading "what we're learning" to prompt the formation of a list (Figure 5.10)[5].

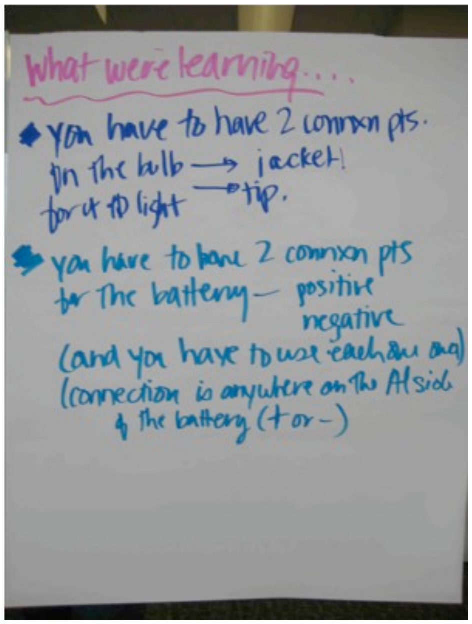

Figure 5.10. The state of the "what we're learning" chart, immediately after the learners made statements about the jacket and tip of the light bulb.

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[5] This image was edited to reflect the state of the wall charts at this point during the conversation. The image is shown in this state in the video record, but the quality of the video was not high enough to be included in this document.

The group developed a list of generalized statements that emphasized the necessity of specific “connection points” or points of contact between the battery and the bulb (Figure 5.10). Mayumi then asked the group to “relate that back to our evidence” by highlighting the corresponding features on Reina’s diagram (Figure 5.11).

As a prompt, Mayumi read aloud one of the statements that had just recorded on the “what we’re learning chart”:

Mayumi: So when we say you have two connection points for the bulb to light—jacket and tip. . .

As her voice trailed off, Mayumi moved her body toward the diagrams on the T-chart as if to indicate that the group should look at the diagrams to find the evidence for that statement.

Sue began explaining and pointing to Reina’s diagram, “The bulb is connected to the cell and the tip is connected to the wire.” Mayumi handed Sue a pink marker and invited her to come up to the board by saying, “Can you show us that?” Figure 5.11 shows three stages of Reina’s diagram of a lit circuit as it underwent highlighting during this exchange.

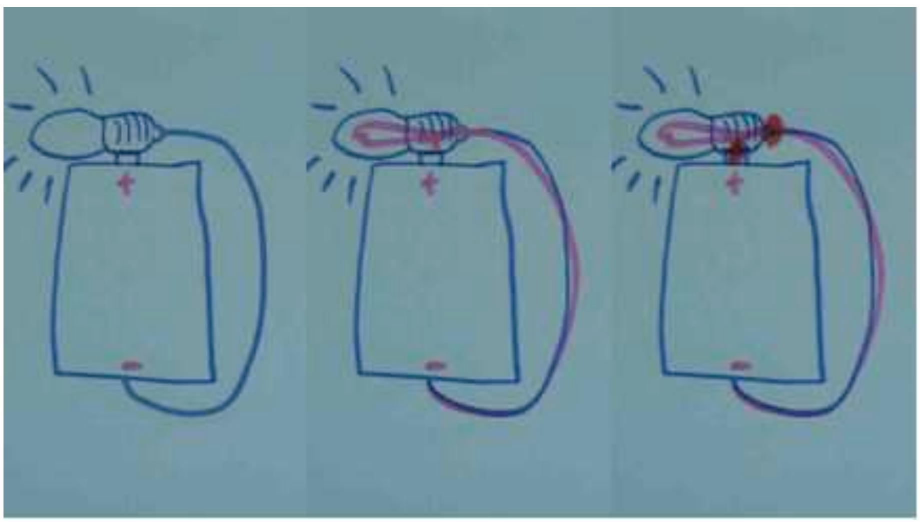

Figure 5.11. Three phases of Reina’s diagram of a lit circuit as it underwent modification by the group. On the left, Reina’s diagram appears the way she originally posted it. The version in the middle shows Sue’s highlighting (pink line). The diagram on the right shows Mayumi’s highlighting (red dots).

The first image in 5.11 shows Reina's original drawing. The second image shows the pink line that Sue added, as she explained where the jacket and tip come into contact with the other parts of the circuit. Sue's highlighting shows the path of current flow.

30 Sue: It's making a complete circuit and going through it.

Mayumi did not seem completely satisfied with Sue's drawing. Instead of a path of current flow, Mayumi was looking for someone to identify and mark the connection points on the bulb jacket and bulb tip. Mayumi pointed to the "what we're learning chart" and posed the question to the group again:

31 Mayumi: So, when we say we have two connection points for
32 the bulb to light, its jacket and tip, where are those
33 connection points then?

Reina gave Mayumi verbal prompts indicating the importance of the jacket and the tip, and Mayumi marked the diagram with two red dots, as shown in the third image in Figure 5.11.

In this episode, Mayumi worked backward from the generalized statement and highlighted the features of the diagrams that linked the observations to the general claims about the conditions necessary for lighting a bulb.

Mayumi's physical act of highlighting corresponds with Goodwin's (1994) notion of highlighting, which he defines as "making specific phenomena in a complex perceptual field salient by marking them in some fashion." Goodwin observes that professionals use highlighting to guide the perception of others and to help them focus on features that are of concern to their profession. Mayumi used her expert knowledge of the subject area to guide the perception of the learners, drawing attention to the most important concepts that arose in the group discussion.

The facilitator used inscriptions to distinguish concepts from one another. As the facilitator, Mayumi helped the learners make sense of what they observed during their science investigations. Two ways of understanding whether a bulb would light came up in the discussion: *connection points* and *path*. The bulb will light if it is connected to the circuit at two connection points, the jacket and tip. The bulb will light if there is one continuous path for the current to flow through the bulb filament. These two ways of thinking are related because the bulb filament is attached at the bulb's jacket and at the tip. If the bulb is connected to the circuit at both the jacket and tip, there will be one continuous path for current to flow from one end of the battery, through the filament, and to the other end of the battery.

The connection points are directly observable from the learners' hands-on work, while the flow of current is not. As the learners worked through their understanding of what is necessary to make a bulb light, Mayumi helped them relate the observable (the connection points) to the unobservable (discussions about current flow).

Mayumi attempted to help the learners separate these two key concepts by identifying them as separate ideas and encouraging the learners to focus on one concept at a time. Mayumi used separate inscriptions and different annotations to address each idea separately before bringing the two ideas together. For *connection points,* Mayumi asked the learners to mark the T-chart diagrams with red dots. For *path of current flow*, she asked the learners to trace over the architecture of the light bulb with a solid line.

The following segment of transcript is taken from a discussion about the connection points necessary for the bulb to light. In the middle of this discussion, Reina introduced the notion of path of current flow. Mayumi encouraged the group to systematically identify the connection points in each circuit diagram before moving to a discussion about the path. The diagram under consideration is shown in Figure 5.12.

Mayumi: So, it sounds like we're talking about two things at once. One is…um, the connections, these connection points that we're now marking in red.
(Points to statements about connection points on the "What we're learning" chart.)

Mayumi: And two, is also the complete…the, the, uh, the complete conducting path.
(Gestures in the air. Her hand draws a curved line that suggests the path of current flow in the circuits.)

Reina: Mmhmm.

Mayumi: So let's, let's just finish up this notion of the two connection points, and then let's get into the notion of 'path.' So, Reina, I thought you were gonna mark off, uh, connections points for us…

Reina: I did…here…
(Points to wire touching negative end of battery on Diagram #3. Show in Figure 5.12.)

Mayumi: Can you mark 'em in red like the way, like we've done here?
(Points to Diagram #1, which has already been marked with red dots indicating connection points.)

Figure 5.12. Reina points to her drawing of an unlit circuit.

In this segment of transcript, Mayumi encouraged Reina to help the group wrap up the discussion of connection points before talking about the path. Mayumi encouraged Reina to mark the connection points on her blue diagram before continuing to talk about path. Mayumi's request that Reina to use the convention of using red dots to mark the connection points had the potential to facilitate comparisons across various circuits.

The facilitator used inscriptions to document key conceptual questions. Mayumi used inscriptions to document key conceptual questions in the discussion. Roughly twelve minutes into the conversation, the learners debated whether the circuit that Reina put up was complete. Figure 5.13 shows the image that Reina put on the board, and Mayumi's annotation "Is this circuit complete?"

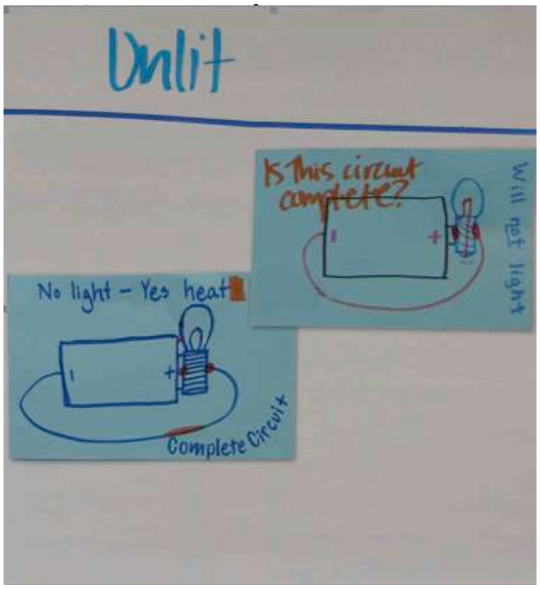

Figure 5.13. Reina's drawing of an unlit circuit (on the right) annotated by Mayumi with the words, "Is this circuit complete?"

When Reina spoke about this unlit circuit, she called it *open* and said that the circuit was *not complete* to indicate that the filament was not a part of the circuit. However, this caused commotion among the learners. Some of the participants took Reina's statements at face value, but others disagreed, arguing that the circuit was, in fact, a complete circuit.

Rather than telling the group whether the circuit was complete or incomplete, Mayumi recorded the question on Reina's diagram, and redirected the discussion to a line of thinking that could potentially help the group figure it out on their own. Mayumi moved the conversation away from contact points to the notion of path. This new conversation had the potential to support learners' understanding that a circuit can have a complete path for current flow that does not pass through the bulb filament. Reina's diagram is one such example

The facilitator used inscriptions to redirect off-topic conversations. The discussion in Mayumi's lesson primarily stayed focused on the scientific concepts identified by the facilitator guide. On a few occasions, the conversation drifted off-topic and focused on instruction. The teacher-learners began talking about what they would teach in their classrooms instead of maintaining a focus on their *own* learning. Although discussions about instruction were an important part of the professional development course design, the course allocates time for these classroom teachers' own learning of science concepts by asking them to hold off on those conversations until the second half of each session. The first portion of each session in the course is intentionally dedicated to supporting their conceptual understanding as adult learners. During the handful of moments when the teachers began to delve into discussions of teaching rather than their own conceptual understanding, Mayumi used inscriptions to acknowledge and document their concerns about teaching while encouraging them to move back to the conceptual discussion at hand.

In some cases, Mayumi used inscriptions as holding place for questions that would be discussed later in the session. Midway through the whole-group discussion, Gaby began talking about planning learning goals for children. Mayumi asked her to write down those questions for examination later in the day. Mayumi then redirected the discussion back to the teachers' *own* content learning.

In other cases, Mayumi used the inscriptions on the front board to reorient learners' attention when the discussion went off track. Below is an analysis of *how* a conversation went off track, and *how* Mayumi used inscriptions to redirect it.

The group ran into a roadblock during one conversation about a particularly difficult concept: whether a circuit is complete if there is no light, but there is heat. The learners seemed to be in agreement that something was flowing in a complete circuit, and they used terms such as *energy, heat, light*, and *electricity*. When the learners stumbled over these terms, the conversation switched from a conceptual discussion into a conversation about instruction.

At first, the learners were having a conceptual discussion. Many members of the group joined the conversation as they unsuccessfully attempted to figure out the defining characteristics of complete circuit:

Gaby: AH, so IS it a complete circuit?
Sue: Yeah, what's, how do…
Gaby: What's the definition of a complete circuit?
Reina: It's producing heat…
Dana: Cause you've got heat
Elly: And it goes in a circle (gestures)
Gaby: It has HEAT…if it has heat, what it's doing…it is providing energy, but the complete circuit where your, your ultimate goal is to light the bulb, that's not being completed.
Reina: Right, that's what we have here…
Michael: That's what we said.
Reina: That's what we're saying…
Elly: But it's still energy…whether it's heat or light.

After several turns, the conversation turned into a discussion about classroom instruction. In the lines below, Reina, Betty and Eduardo talk about various conceptual goals they might have for their 4th-grade and 5th-grade students.

Reina: Well, it goes back to our goal…is what is our goal?
To teach how a light bulb lights, or to teach what
electricity is…?
Betty: Or to teach energy…
Eduardo: <or what a circuit is…>
Reina: Or what a…I'm sorry…what a circuit is…word for
word…I mean, you don't have to use them…you
can use a little <motor>

Once the discussion turned to instruction, Mayumi stepped in to redirect the conversation. Mayumi pointed to the circuits drawings posted on the T-chart as a tactic for reorienting the group to the conceptual work that was going on prior to the off-topic conversation, and then proposed they move to a new, larger representation as a tool for supporting the conceptual discussion. The lines below reflect Mayumi's verbal and inscriptional response to Reina, Betty, Eduardo's inscriptional discussion.

Mayumi: So, it sounds like our question, then, is this circuit
complete? Because we're trying to figure out, what
are we trying to teach? And, therefore, let's get an
idea of the terrain and then, sort of, back track and
figure out what…what makes sense to teach?

So, I heard…I, I see these drawings, including,
now, this notion of path…um, so, Sue had drawn
this path here
(points to diagram #2)

and we're trying to do, sort of, an analogous thing
here
(points to diagram #3)

But, it sounds like we're getting a little bit tripped
up, so, let's, let's back track, and use a bigger
picture.
(walks to the architecture of the light bulb image)

Mayumi began by restating the conceptual question about whether the circuit is complete (lines 78-79). Then, she acknowledged the instructional conversation in which the learners were engaged by framing the purpose of the conceptual work as meeting an instructional end (lines 79-82). Once she established the purpose of figuring out the answer to the question, Mayumi helped the group focus on the conceptual task by orienting them to a series of supporting inscriptions (lines 83-93).

The analysis in this section shows that Mayumi recruited inscriptions to keep the discussion focused on specific scientific concepts by prioritizing key concepts through headings and highlighting, separating ideas from one another, documenting key conceptual questions, and re-directing off-topic conversation. Maintaining the focus on key ideas is vital to facilitating a discussion that supports the learners' conceptual understanding.

In the section that follows, I examine the ways Mayumi employed inscriptions to engage learners in scientific practices such as documenting and reporting observations, analyzing data, making generalized claims, and supporting claims with evidence.

Inscriptions as Tools for Engaging learners in Scientific Practices

The lesson under investigation engaged learners in scientific practices such as making observations, collecting and organizing data, analyzing data, and making generalized claims that were based on evidence.

The scientific reasoning that the learners were asked to engage in supported their understanding of complete circuits, incomplete circuits, short circuits, and the notions of connection points and path of current flow. The learners were asked to develop public inscriptions of the various circuit configurations they had constructed and to share their observations about those configurations with the whole group. Mayumi asked the learners to analyze the pool of inscriptions to identify patterns and make summary statements about the necessary conditions for having a complete circuit, and how the concept of short circuits was related to those ideas. The learners were asked to describe their observations about connection points and the path of current flow as they worked toward a fuller understanding of complete, incomplete, and short circuits.

This section analyzes the inscriptional strategies Mayumi used to structure and support the learners' engagement in each of the following scientific practices: (a) documenting and reporting observations, (b) identifying patterns in a shared data set (analyzing data), (c) making generalized claims, (d) supporting claims with evidence, and (e) describing the relationships between concepts.

Although this document presents Mayumi's invitations for learners to participate in scientific practices in a separate section from the conceptual work, the distinction is merely for clarity of writing. The examples in this section will show that, in practice, they were not separate: the learners were encouraged to engage in scientific practices as a vehicle for supporting their conceptual understanding.

The facilitator used inscriptions to support learner documentation and reporting of observations. As you may recall, Mayumi prompted the learners to transition from their small-group work to the whole-group discussion by asking them to share drawings of circuits: either a circuit that surprised them or a pair of circuits that helped them to learn something. She then asked the groups to come up individually to post their drawings on the T-chart that was labeled with the categories *lit* and *unlit*.

By labeling the T-chart in this manner, Mayumi set up the task so that participants could rely on something that is *observable* in order to make their categorization. Participants only needed to see that the bulb lit or did not light to make this decision. The task was fairly low-risk in the sense that the participants were likely to make the correct categorization. No inferences were required.

In contrast, had the categories been *complete* and *incomplete*, the learners would have had to make the following inference: a circuit is complete because it produced heat, light, or both heat *and* light. Or, they would have had to look at all the connections, and based on their understanding of a complete path or contact points, they would diagnose the circuit as being complete or incomplete.

In this first whole-group task, the learners were asked to first document (through drawing) and report observations. By asking the group to share these observations about whether certain circuit configurations lit or did not light, Mayumi helped the group develop a pool of observations from which they could reason about the conditions under which bulbs light or do not light. In effect, she was asking them to create a shared data set. By de-emphasizing the inferences at this stage, Mayumi shifted the burden of data analysis to the whole group rather than placing it on individual contributors. Additionally, their analysis was based on the pooled observations of several groups rather than simply the lone observations of any one small group.

The facilitator used inscriptions to invite and document generalized claims. Mayumi used inscriptions to invite and document generalized claims, or rules about the conditions under which the bulb would light. These generalized claims are statements that would apply to all cases of 1 bulb, 1 wire, and 1 battery setups, assuming that all of the materials are working correctly. These statements would be expected to have predictive power. That is, on the basis of these generalized claims, the learners would be able to look at various circuit configurations and predict whether the bulb would light.

The "what we're learning" chart (Figure 5.14) is the repository for this type of information. The first two bullet points on the "what we're learning" chart are examples of such generalized rules. The statements are that (a) you have to have two connection points on the bulb for it to light: at the jacket and at the tip, and (b) you have to have 2 connection points on the battery for the bulb to light: on the positive side and on the negative side.

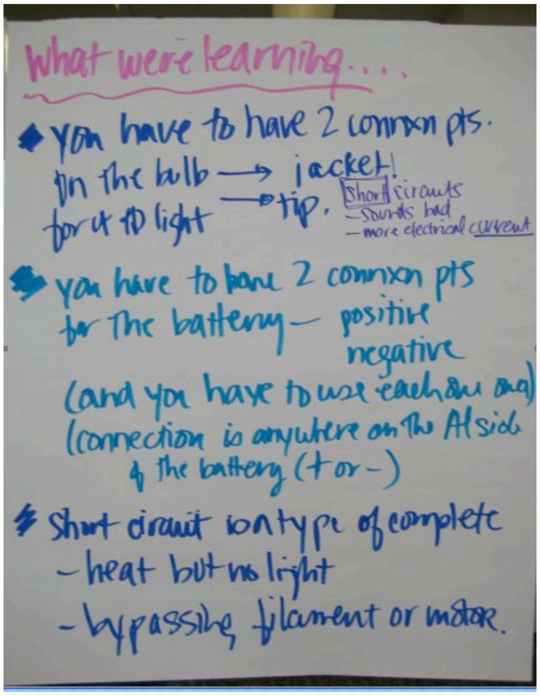

Figure 5.14. The completed "what we're learning" chart contains a series of generalized claims.

Mayumi did not explicitly prompt the group to make generalized claims or summary statements about what the group was learning. However, a few different factors may have contributed to the learners' *spontaneous* sharing of general rules. First, the title of the chart, "what we're learning" suggests that the group should produce a set of statements (a list) of things they learned during the session. Since the science investigation task was to find various ways of lighting a bulb, it stands to reason that the learners would generate a list of conditions under which a bulb would or would not light.

As the facilitator, Mayumi controlled the information that was recorded on this chart. She controlled the level of specificity by pressing the group for detail, which resulted in a set of statements that had a level of specificity that would be useful for making predictions. At first, the learners stated that there need to be two connection points on the bulb (the jacket and the tip), but by prompting the learners to give more information, Mayumi also got the learners to specify the points on the battery that the jacket and tip of the bulb needed to touch.

The facilitator used inscriptions to support the development of evidence-based claims. One of the challenges of facilitating a course where learners are asked to collaboratively analyze data is ensuring that all of the participants have access to the evidence and reasoning that goes behind the generalized claims that group members make. Take Reina's contribution to the group discussion as an example. As Reina posted her drawing of a lit circuit (Figure 5.11), she said:

94	Reina:	We had a statement saying that the wire had to be
95		connected at both positive and negative, and it had
96		to go into one of the points, which we call the jacket
97		and the tip.

Reina entered the whole-group discussion by listing general claims or rules, and Mayumi created a space for surfacing the evidence for those claims. Mayumi did two things here: First, she physically separated claims from evidence by documenting Rosa's claims on the chart on the right. Then, she asked the group to support the claims with evidence by directing their attention to the T-chart.

Mayumi turned toward the T-chart while asking the group for evidence in three instances during this episode. In each of the three examples that follow, notice how Mayumi encouraged the group to relate the claims to evidence by physically moving her body back and forth between the two representations.

Figures 5.15, 5.16, and 5.17 are screenshots from three segments of videotape from the discussion. Each figure is followed by a segment of transcript that corresponds with the still images. Mayumi is shown standing at the front board wearing a black dress. The chart on the right is the "what we're learning" chart. The chart on the left is the lit/unlit T-chart. In each of the three instances, notice Mayumi's movement away from the "what we're learning" chart and toward the T-chart as she requested evidence for the claims (lines 98-104, 105-108, and 109-114).

Figure 5.15. Mayumi's movement between charts, Part 1.

98	Mayumi:	So, can we relate that back to our evidence, then,
99		*(looking up at front wall)*

100 just to make sure that that's…so when we say 'you
101 have to have two connection points for the, for the
102 bulb, to light, jacket, and tip…'
103 *(points to "what we're learning chart," then moves*
104 *to T-chart)*

Figure 5.16. Mayumi's movement between charts, Part 2.

105 Mayumi: So, when we say we have two connection points for
106 the, for the bulb to light: it's jacket and tip, where
107 are those connection points, then?
108 *(Moves in front of Diagram #2 on the T-chart)*

Figure 5.17. Mayumi's movement between charts, Part 3.

109 Mayumi: So, when we say we have two connection points for
110 the bulb to light, jacket and tip,
111 *(pointing to the "What we're learning" chart)*

112 Mayumi: here, we only have…
113 *(pointing to diagram #3 on the T-chart)*
114 (Many): …the jacket.

In each of these examples, Mayumi positioned her body in front of the T-chart and pointed to it as she encouraged the participants to specify the connection points. With these moves, she invited the learners to use the diagrams of the small groups' observations as sources of evidence for the claim that two connection points are necessary for the bulb to light.

The facilitator used inscriptions to support the recognition of patterns in the data. By physically turning toward the T-chart, Mayumi encouraged the learners use the blue diagrams on the T-chart as a source of evidence for their claims. However, her support did not stop there. Mayumi helped the group figure out *how to use the data as evidence* by structuring opportunities for them to arrange and annotate the inscriptions in ways that promoted pattern recognition.

As the mediator between the curriculum and the learners, Mayumi helped the group to see what was important about these diagrams, in terms of drawing conclusions about the various circuit configurations. In this case, the key ideas were: whether the bulb lights or does not, and the connection points at the jacket and tip of the bulb.

Mayumi employed two major strategies to visually support learners' pattern recognition in the data. First, she used the T-chart to invite learners to conduct an initial sort of the data. The visual separation of the data into these groups supports comparisons within and between the lit and unlit groups.

Once the conversation turned to the importance of the jacket and tip for lighting the bulb, Mayumi set up a convention for systematically highlighting those contact points with red dots. Figure 5.18 shows how the highlighting, combined with the T-chart organization, drew attention to the fact that the bulbs with jacket/tip connection produce light, while the bulbs with jacket/jacket connections do not.[6]

[6] The image on the right is an enhanced version of the image on the left. It has been included to help the viewer see where the red dots were placed. Although the highlighting was readily visible in person, this reproduced image is too small to adequately portray the highlighting.

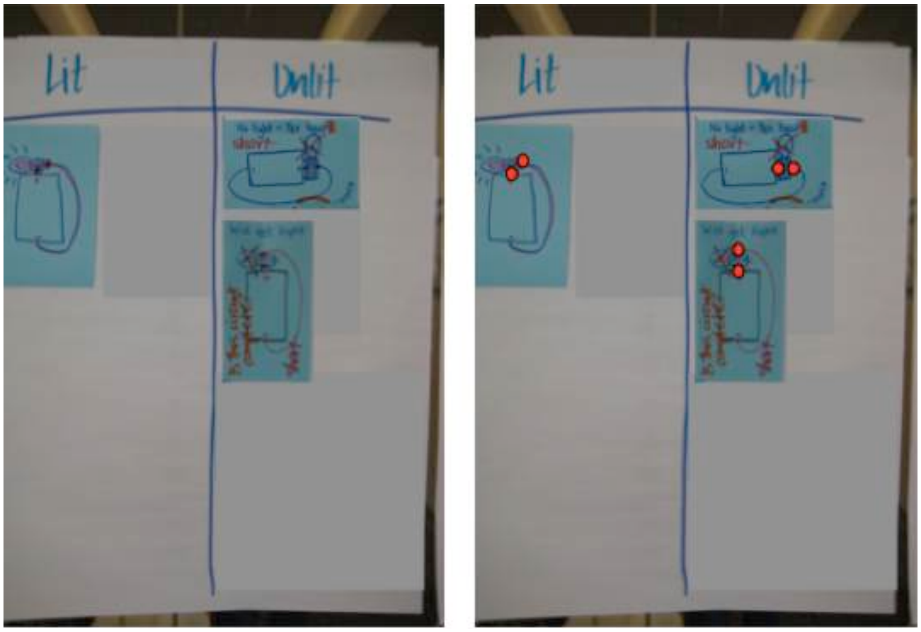

Figure 5.18. Two images of the T-chart with diagrams marked with red dots to highlight the contact points on the bulb. The image on the left appears as it did during the professional development session. The image on the right has been enhanced to provide the reader with a better view of the placement of the red dots.

The facilitator used inscriptions to represent the relationship between key concepts. Mayumi used inscriptions to organize key concepts in relation to each other. The prime example of this can be seen in the organization and reorganization of the T-Chart. Figure 5.19 shows two images representing the state of the T-chart at two different points in time: midway through the discussion and at the end of session 1.

The learners were first encouraged to classify their circuit diagrams as either *lit* or *unlit*. As the discussion went on, the learners introduced the terms *complete*, *incomplete*, and *short*. After these terms came up, Mayumi initiated a re-organization and labeling of the blue sheets on the T-chart, which incorporated those terms. Notice that, at the end of the discussion, the label for the left-hand column is annotated in red so that it read “lit = complete.” In the right hand column, there is a new circuit drawing (on the top), and the blue sheets have been re-organized and divided into two categories. This new categorization indicated that there are two subcategories of unlit circuits: incomplete and complete. It also signaled that unlit, complete circuits are also called short circuits. This T-chart was a public representation of the relationship between lit, unlit, complete, incomplete, and short circuits.

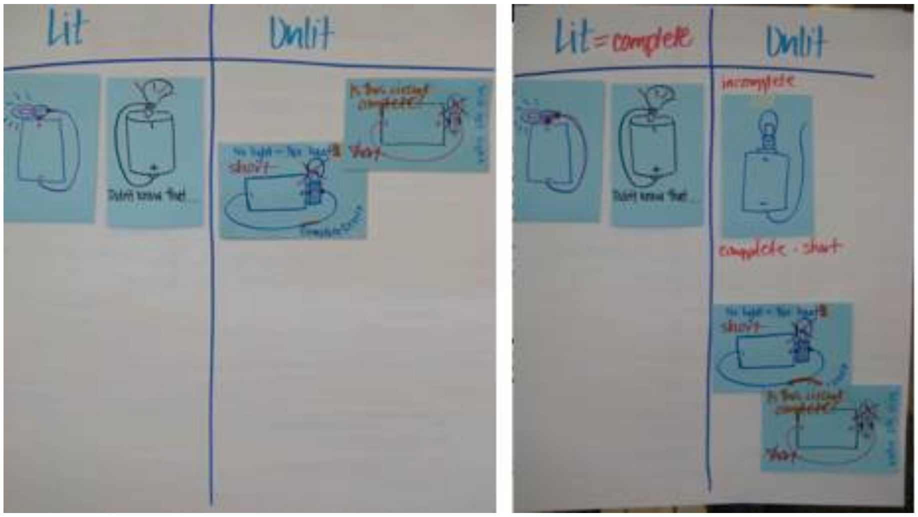

Figure 5.19. The state of the lit/unlit T-chart in the middle of the discussion (left) and at the end of the discussion (right).

This example demonstrates how the independence and transportability of the blue sheets dynamically supported the group's changing ideas about the relationship between concepts. The T-chart provided the first slice of categorization (between lit and unlit). After the group established that all lit circuits are complete, they were left to consider the meaning of unlit circuits. Once they figured out that some unlit circuits are complete, they were able to re-arrange the individual diagrams within the frame of the T-chart because the diagrams were drawn on individual pieces of paper and taped onto the chart. In other words, the inscription was flexible enough to allow the group to change the way the relationships between concepts were represented as their ideas about those relationships became more sophisticated.

It is important to note that this T-chart did not merely document a known relationship between these concepts. Mayumi used the task of categorization in order to promote learner discussion about the relationship between the concepts. In order to complete this task, learners were compelled to articulate and discuss their ideas with one another.

Summary and Conclusions

The pedagogy underlying Mayumi's enactment was closely aligned with the intent of the written curriculum: the group's work was structured and supported by the use of inscriptions, it was heavily conceptual in nature, and it engaged learners in scientific reasoning practices as a means of supporting their conceptual understanding.

Both the designed curriculum and Mayumi's enactment emphasized the elicitation and collaborative analysis of the learners' ideas. These types of discussions pose a significant facilitation challenge: The first challenge is to support learners in expressing their ideas and putting them in a form that allows them to treat their ideas as object of thought. The facilitator must then decide how to handle the abundance of relevant and irrelevant contributions, correct and incorrect ideas, and information that is more or less conceptually fruitful. With an eye toward the conceptual goals of the curriculum, the facilitator must strike a balance between honoring the learners' contributions and moving their discussion toward the most fruitful paths.

Mayumi's invitations for learners to create and modify inscription enabled the group of learners to treat their ideas as objects of thought. Mayumi asked individual learners to make their observations and ideas public through inscriptions and verbal statements. She then invited the group to work together to scrutinize, question, and figure out the relationships between those ideas. The practice of inscription anchored ideas to publicly available words and images in physical space. The physical availability of these inscriptions served as visual reminders, and supported the group's consideration of the ideas in relation to one another.

As a mediator between the curriculum and the learners, Mayumi used multiple inscriptional strategies to *manage the conceptual content* of the discussions and to *engage the learners in scientific reasoning* practices. Each of the following strategies reflects the interactive nature of her facilitation: every move used inscriptions an invitation for or a response to the learners' ideas and actions. Regarding the conceptual content of the discussion, Mayumi used inscriptions to (a) invite discussion about new and difficult concepts, (b) prioritize and highlight key concepts, (c) separate and distinguish ideas from one another, (e) document key conceptual questions, and (f) redirect off-topic conversations. Regarding the scientific reasoning practices, Mayumi used inscriptions to invite and support learners' in (a) documenting and reporting observations, (b) identifying patterns in a shared data set (analyzing data), (c) making generalized claims, (d) supporting claims with evidence, and (e) describing the relationships between key concepts.

Although the analysis in this chapter emphasized Mayumi's facilitation moves, the results indicate that a central feature of her facilitation is the *dynamic and responsive* way in which she employed inscriptions. Mayumi served as a moderator while the learners shared their thinking and their questions with one another, and inscriptions were the primary tool for structuring and supporting that analytic work. The next chapter provides a more in-depth exploration of the *interaction* between the facilitator, the learners, and the inscriptions.

Chapter 6: Interaction between the Learners, Facilitator, and Inscriptions

Although inscriptions are commonly recommended as tools for teaching and learning, the processes by which these tools support scientific reasoning and conceptual development are often ill-defined. This chapter provides insight into the process by which inscriptions are created and interpreted, and how those inscriptions, in turn, affect the learners' talk (and thinking) about key electric circuits concepts.

In contrast to the thematic categorization of strategies presented in chapter 5, this chapter is an activity-centric account and analysis of how the dynamic relationship between the participants, the facilitator, and the inscriptions support conceptual understanding and scientific reasoning. I examine how the interplay between learners' ideas, facilitator guidance, and inscriptional resources (a) led to a shift in the learners' understanding of complete circuits and (b) supported the participants' development of generalized claims that were based on the interpretation of data collected during their hands-on investigations.

Focusing in on the first 20 minutes of the whole-group conversation, I demonstrate how the interaction between these various components in the setting supported learner discussion about a specific set of concepts.

Episode Overview

This analysis is organized into four episodes that chronicle the development of a T-chart, which was a graphic organizer used to categorize the circuit drawings from each of the small groups. Each episode represents either an addition of one diagram to the T-chart or the re-organization of those diagrams. Together, these episodes elucidate the interplay between the facilitator, learners, and inscriptions, and how that interplay supports the group's engagement in data analysis and their understanding of key science concepts. For each episode, a description of the activity is given, followed by an analysis and discussion of the events.

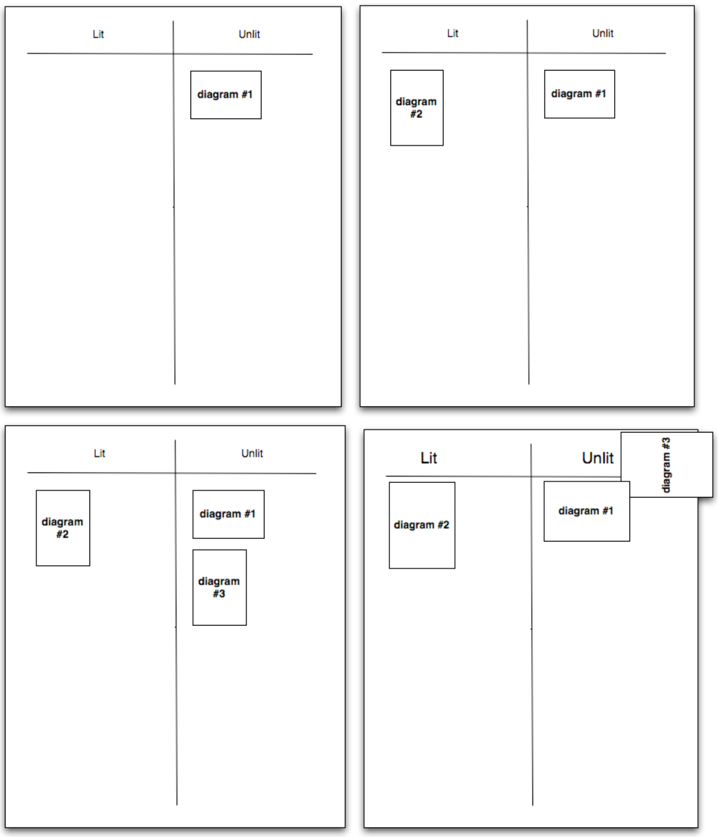

Figure 6.1. Depiction of the development of the T-chart over the course of the four episodes presented in this analysis. To be read from right to left, top to bottom.

Analysis

Episode 1: Diagram #1 and T-chart. The T-chart and Diagram #1 were the first inscriptions introduced in the whole-group discussion (see Figure 6.2). The T-chart was a template suggested by the facilitator guide, which was intended to organize learner-generated circuit drawings into two categories: lit and unlit. Mayumi invited the learners to populate the T-chart with images that they created during their small-group work. The analysis of this episode examines the ways Mayumi's T-chart supported the development of an organized set of observations that was shared among the entire group of participants.

Betty was the first presenter. As her small group's representative, Betty kicked off the whole-group sharing by putting up a picture of a short circuit containing a bulb that was connected jacket-to-jacket (Figure 6.2). She placed her diagram on the T-chart, which Mayumi had posted on the front wall. The column headings on the T-chart read "lit" and "unlit."

In this discussion, I will refer to Betty's circuit as "Diagram #1." Each circuit diagram presented during the whole-group discussion will be assigned a number in the order that it was presented during the lesson. The participants in the professional development did not use this numbering system, but I use this system for the purposes of clarity.

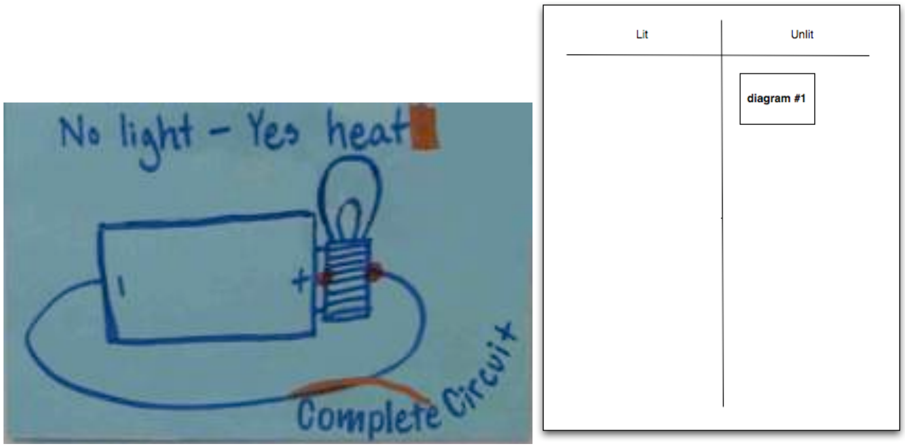

Figure 6.2. Betty's diagram (diagram #1) and a sketch of its placement on the T-chart.

Collaboratively categorizing observations. When Betty posted diagram #1 on the T-chart, she announced that the circuit did not light. She began placing her diagram in the "lit" column, but a member of her small group, Dana, quickly pointed out the mistake. Betty then correctly categorized the diagram as "unlit" by placing it in the right-hand column of the T-chart. As a team, they successfully engaged in the categorization task that Mayumi had implicitly set up with the "lit/unlit" T-chart (i.e., together, Dana and Betty correctly posted diagram #1 on the "unlit" side of the T-chart). This categorization was based on an observation of whether the bulb did or did not light. No inferences were necessary for making the categorization.

Betty: Okay, so this one did NOT light *(diagram #1)*…
Dana: Other side…
Betty: *(moves paper to the right-hand side of chart)*
. . . but was warm. So, it touched the jacket on the
positive end, the wire on the negative and positive
end… so, there was no light, but there was heat.
So, it's a complete circuit.

Documenting participants' ideas. Betty's diagram supported her communication of her group's observation: as she described the connections in her circuit's configuration, she pointed to the corresponding pieces of her diagram. When she left it on the board, she left a visual record of her group's observations, which could then be compared to other group's observations at a later time.

Making observations public. Betty's small group introduced several new concepts into the discussion: the connection points in the circuit, the presence (and significance) of heat, and the notion of a complete circuit. After Betty described the configuration of her circuit, she added that "there was no light, but there was heat" (line 6) The group's observation about the presence of heat went beyond what the T-chart required. By pre-labeling the T-chart columns as "lit" and "unlit," Mayumi framed the task in terms of observations about light. Building from the observation about light and heat, Betty concluded, "So, it's a complete circuit" (line 7). The observations about light and heat, and the conclusion that this was a complete circuit were all written on Betty's diagram before she placed it on the board.

The facilitator identifies and highlights the key concepts that came up in the learners' contributions. After Betty's statements, there was a slight buzz in the room from the other learners. In response to these newly introduced concepts, Mayumi verbally and physically highlighted the ideas. Mayumi said:

8	Mayumi:	Mmm. . . so, the oohing and aaahing I heard is
9		around this notion of "heat" and also "complete."
10		So I just want to mark those.

As she said this, Mayumi marked Betty's diagram with a marker, putting thick, red lines by the words "heat" and "complete." Notice that Mayumi did not add information, rather, she affirmed and brought additional attention to concepts that Betty's group contributed. By using a red marker to physically highlight "heat" and "complete," Mayumi left a visual reminder about the importance of these concepts. At this moment, the group did not go into great detail about their significance: the group would return to these ideas later in the discussion. At this point, the main task was to draw out a variety of observations in the building of a shared data set.

This episode reveals the ways the use of inscriptions (a) framed the whole group task in terms of categorization according to an observable phenomenon, (b) provided publicly-available documentation of one small group's observations and ideas, and (c) allowed Mayumi to highlight, or place verbal and permanent visual emphasis on key concepts (e.g., heat and complete).

Betty presented a normative understanding of this conceptually challenging circuit. A common misconception is that lit bulbs indicate complete circuits while unlit bulbs necessarily indicate incomplete circuits. Betty correctly stated that her group's circuit had heat but no light, and that it was a complete circuit. While Betty's understanding seems unproblematic at this point, the continued conversation in the next episode reveals other learners' incomplete understanding and confusion.

Episode 2: Diagram #2. Reina's diagram, Diagram #2, was the second diagram posted on the T-chart (Figure 6.3). It is a complete circuit where the bulb's jacket touches the positive end of the battery, and wire connects the bulb's tip to the negative end of the battery. There is a complete conducting path through the filament wire. On this diagram, Reina's group had drawn a series of marks radiating from the light bulb to indicate that the bulb was lit.

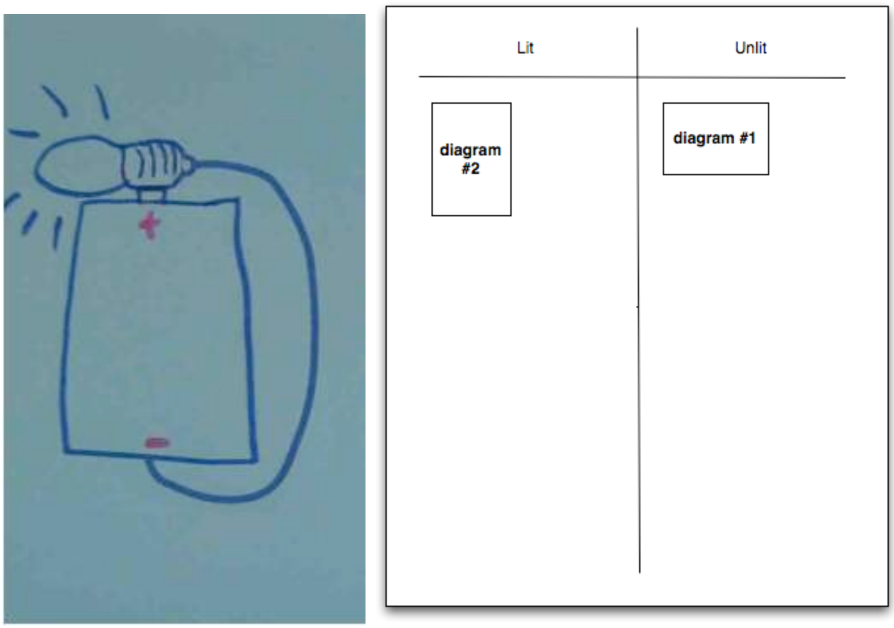

Figure 6.3. Reina's first diagram (diagram #2) and a sketch of its placement on the T-chart.

Reina subtly introduced two new concepts into the discussion with her lit circuit (diagram #2): the concepts of *current* and *path of current flow*. Although Reina used some of the same words that Betty did in her description (positive, negative, and jacket), Reina talked about them in a qualitatively different way. Betty talked about connection points, but notice Reina's use of the phrase "it had to go" in lines 12 and 13. While she didn't specify the entity involved, Reina suggested that something moves through the circuit.

Reina: Um, we had, a, a statement saying that the wire had
to be connected at both positive and negative and *it*
had to go into one of the points which we call the
jacket, the tip, with the wire. (Emphasis added.)

This is a very important conceptual step in the conversation because understanding the path of current flow is the key to explaining *why* some circuits are complete, but do not produce light. Connection points describe *where* parts of the circuit must be connected for the bulb to light, but understanding the path helps explain *why* those connection points are necessary.

Notice also that this subtle introduction was not further elaborated or questioned at this point in the conversation. It merely existed as a new set of ideas put up for consideration. For the time being, Reina's vague use of the pronoun "it" remained unexplored, and the thing to which "it" refers is left to a later discussion.

Reina placed diagram #2 on the "lit" side of the chart with confidence, and treated the diagram as straightforward. Again, as with Betty's presentation, Reina's presentation of diagram #2 seems to indicate unproblematic, normative understanding. The discussion around the next circuit drawing, however, paints a different picture.

Episode 3: Diagram #3. Reina very quickly moved on to her presentation of diagram #3 (Figure 6.4). Diagram #3 shows a complete circuit where the bulb does not light. Reina's presentation led to two key events in the group discussion: First, the discussion revealed varying levels of understanding among the learners. It uncovered the first signs of individuals' uncertainty about complete circuits, but there was also evidence that other learners had more solid understanding. Reina's diagram invited and supported deep discussion about the meaning of "complete circuit." Second, this case reveals the conceptual difficulty that can arise when the group prematurely moves away from discussions about evidence and into the realm of stating generalized statements that are intended to apply across multiple cases rather than simply to single observations.

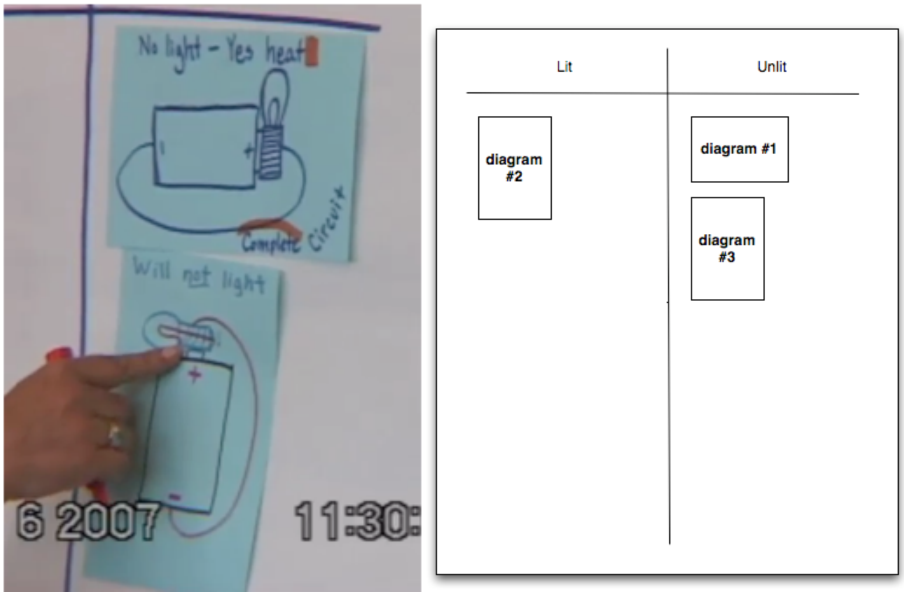

Figure 6.4. Comparison between diagram #1 (top) and diagram #3 (bottom). Betty's and Reina's complete, but unlit circuits.

In diagram #3, there is a complete path for the current to flow from the positive end of the battery, through the bulb's jacket, and through the hookup wire to the negative end of the battery. However, there is no path for the current to travel through the filament wire. Diagram #3 is very similar to Betty's diagram #1: In both cases, the current has a path through the bulb's jacket, but not through the filament wire. However, diagram #1 is presented with the battery on its side, and diagram #3 is presented with the battery standing up.

Categorizing circuits. By placing her circuit diagrams on the T-chart, Reina added to the shared dataset, where the circuits were categorized along the observable dimension of "lit" or "unlit." After Reina's contributions, the T-chart contained one "lit" and two "unlit" circuits. The spatial organization of these diagrams now supported visual comparisons between the two categories of circuits. The grouping of diagram #1 and #3 on the same side of the T-chart facilitated the perception of the similarity between the two circuits.

Surfacing new concepts and revealing confusion. Reina's description of diagram #3 introduced the new and potentially confusing term *open* (see line 20). Reina's group wrote "open" near the tip of the light bulb on diagram #3. In normative usage, *open* describes a circuit that does not have a complete path for current flow from one end of the battery to the other. In contrast to a closed circuit, which is a complete circuit that has a continuous path for the flow of current, an open circuit has an opening or a break in the path. The term *open circuit* is another way of describing an incomplete circuit.

Reina used the term "open" to describe the end of a filament wire that does not connect to anything else at the tip of the bulb. This usage might be confusing in the context of her diagram, because diagram #3 actually depicted a closed circuit. Albeit, a closed circuit that does not include the filament wire.

Reina: . . . what was the eye-opening. . . was that, uh, was that, uh, the reason that this didn't light as opposed to creating heat was because, you see the red…you know how the wire connects to the jacket?
Dana: Ohhh…
Reina: And then it went to the tip and that's *open* so that's why this didn't light. But *it'd probably heat up,* but the heat just goes from the jacket to the positive. Does that make sense? *(Squints, shrugs her shoulders up, and looks in the direction of her small group as she says "does that make sense?" as if to confirm with her group.)* [Emphasis added]

Dana and Michael immediately picked up on Reina's use of this term, whispering to each other in their small group (comprised of Dana, Michael, and Betty). Dana and Michael were surprised by Reina's use of the word "open."

Dana: *(to Betty)* So, she called it 'open.
Michael: *(to Betty and Dana)* I wanna clarify that *(repeatedly tapping his finger against the table)*

Reina's contribution is an instance of the introduction of a non-normative use of a term to the visual record. The visual record allowed the group to table a disagreement for the time being, while making it publicly available for later discussion. It appeared that Michael and Dana disagreed with Reina's use of the term "open," but they did not discuss it with the entire group when Reina first introduced it. Later in the session, the whole group revisited the term. The group's reentry into this discussion was supported by the fact that Reina's group had written term "open" on diagram #3.

Further discussion about diagram #3 revealed that Reina was not the only learner who was confused about the concepts of open and complete circuits. In lines 31-50, below, Betty's and Sue's confusion about complete circuits becomes apparent as Reina attempted to explain her diagram for the second time.

Reina: I put it so it'd illustrate that it went in the jacket and then it was left open here at the tip. And I wrote the

word 'open.' I don't know the word to use. It was incomplete.
[Gloss: I put (drew the diagram) so that it'd illustrate that it (the current[7]*) went in the jacket and then it was left open here at the tip.]*
Betty: not complete.
Reina: Yeah.
Dana: So, you're saying that it's an incomplete circuit.
Elly: But that's confusing, because it is a complete circuit.
Reina: Yeah. Well, the filament's not closed. It's, it's flapping.
Eduardo: it's a complete circuit that will not light the bulb.
Reina: Eh, the. . . (laughs) a complete circuit. . . RIGHT. But it does produce. . .
Betty: AH, so IS it a complete circuit?
Sue: Yeah, what's, how do. . .
Betty: What's the definition of a complete circuit?

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[7] I use the word "current" in the gloss of Rosa's sentence, but I do not intend to convey that she a normative understanding of the term. At this point in the professional development course, the concept of "current" had not yet been addressed. During this session, learners almost exclusively use the term "it" when referring to the entity that moves through the circuit. It is clear that the learners believe something moves through the circuit because they describe the motion of that thing. However, it is unclear what their understanding of what that entity or force is. The learners used the terms "it," "electricity," "power," "current," "output" in reference to the thing that they believe moves through the circuit.

This exchange revealed Betty's and Sue's specific confusion about whether diagram #3 is complete, and their more general confusion about the definition of a complete circuit. It is the continued conversation about Reina's circuit diagram that allowed Betty's and Sue's questions to come to the surface.

This conversation also revealed solid understanding on the part of other members of the group. Elly and Eduardo correctly told the group that the circuit is complete, which prompted other learners to ask for clarification. At this point in the discussion, the learners were working to figure out the relationship between the many concepts that had been introduced into the discussion. Mayumi responded by writing "Is this circuit complete?" on diagram #3. Rather than providing the answer, Mayumi documented the key question that the learners were working to resolve.

The advantage of asking learners to report observations rather than stating generalized claims when trying to support reasoning from evidence. One key to understanding that the circuit in diagram #3 is a complete circuit is to know that it produces heat. It is clear that Reina understood that the light bulb in diagram #3 would not light, but her understanding that it would produce heat is less clear. In line 21, she said, "But it'd probably heat up. . ." Her use of the term "probably" seems to indicate uncertainty about the presence of heat. Betty, on the other hand, stated with conviction that their circuit produced heat but no light when she presented diagram #1. To better understand the factors that contributed to this difference in confidence, I will now do a side-by-side comparison of the statements that Reina and Betty made as they initially presented their respective diagrams:

Betty's presentation of diagram #1:

51 Betty: This one did NOT light. . . it touched the jacket. . .
52 there was heat but no light

Reina's presentation of diagram #3:

53 Reina: Um, we had, a, a statement saying that the wire had
54 to be connected at both positive and negative and *it*
55 *had to go* into one of the points which we call the
56 jacket, the tip, with the wire. [Emphasis added]

Betty presented the circuit in diagram #1 as an *observation of one instance*. She used the past tense and the terms "this one" and "it," indicating that she was describing the observations that her group made about a specific circuit. Reina, on the other hand, presented a *set of general rules*. Her use of the terms "had to be connected" and "had to go" indicated that her group had articulated a set of rules or necessary conditions for the bulb to light.

This episode highlights the distinct advantage of reporting observations rather than articulating generalized claims for supporting collaborative data analysis and group learning. The purpose of the activity was to create a data set that supported reasoning from evidence. When individuals report generalized claims without providing the supporting evidence, the members of the group do not have access to the reasoning that goes behind the claim. Had Reina been discussing particular observations that she and her group made, it would have been clear to her that the circuit portrayed in diagram #3 did, in fact, produce heat. However, since she shifted the nature of the discourse away from the reporting of observations and into the realm of general principles, she was unable to speak with confidence about the presence of heat.

This is not a criticism of Reina: It is very common for whole-group activities to be structured around the statement of general principles, claims, or lessons learned from the day. It is usually left to the small groups to figure out the general claims and report them back to the group. This professional development lesson represents a departure from the common practice of reporting findings during whole-group discussion. In this lesson, the learners were encouraged to report observations and make sense of them as a group. When Reina moved (perhaps prematurely) into the statement of general claims, she got stuck, and the group was unable to help her because they had no access to the observational basis of her small group's claim.

Episode 4: The "what we're learning" chart and the reorientation of diagram #3. In response to Reina's generalized claims and the confusion that emerged following those statements, Mayumi introduced a new inscription, which served as a holding place for generalized claims: the "what we are learning" chart. By recording these rules on a separate chart, Mayumi organized the learners' statements according to their differing epistemic statuses. The T-chart served as an organizing space for reporting and analyzing the observations, while the "what we're learning" chart acted as a space for documenting claims.

Serving as the recorder, Mayumi prompted the group members to repeat and elaborate Reina's statements about the necessary conditions for getting the bulb to light. Mayumi specifically asked for a summary, saying, "So, it sound like, um, there's something about jacket and tip that we're talking about. Can somebody summarize what that is?" As various members of the group called out information, Mayumi recorded it on the "what we're learning" chart. After a minute and a half, the board appeared as it does in Figure 6.5.

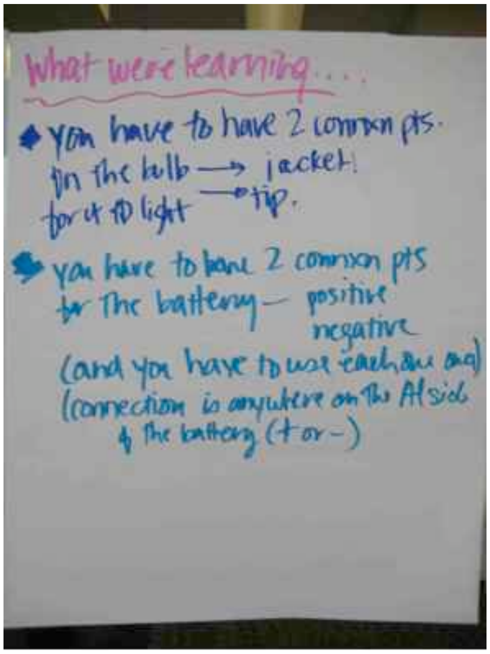

Figure 6.5. The "what we're learning" chart.

The group determined that the following conditions were necessary for the bulb to light: (a) there must be two connection points on the bulb (the jacket and the tip), (b) there must be two connection points on the battery (at the positive end and at the negative end), (c) each connection point must only be used once, and (d) the connection to the battery can be made anywhere on the exposed aluminum. After recording this information, Mayumi stepped back from the board and asked the group to use the diagrams from the T-chart as evidence to support their claims. Mayumi first pointed at the "what we're learning" chart and then to the T-chart as she said:

Mayumi: So, can we relate that back to our evidence, then,
just to make sure that that's. . . so when we say
"you have to have two connection points for the, for
the bulb to light, jacket, and tip. . ."

In this sequence of events, Mayumi picked up on Reina's shift toward discussing generalized claims rather than stating observations. She followed Reina's lead by recording the generalized statements, but then encouraged the entire group to use the diagrams on the T-chart as data to support those claims. Ultimately, the combination of the T-chart and the "what we're learning" chart helped learners use patterned observations to support larger claims about the necessary conditions for lighting a bulb.

The learners used scientific reasoning (in the form of data analysis and the development of evidence-based claims) to support their conceptual understanding.

Reina's shift in conceptual understanding is supported by the equivalence of two inscriptions. When Reina first presented her diagrams, she expressed uncertainty about the presence of heat in the circuit pictured in diagram #3. After a few turns, there was a shift: Reina told the group that the circuit was complete, and that there would be heat. However, there was still a fair amount of confusion expressed in her statements, and she cites Mayumi as the source of this information (line 61).

Reina: But, and this is what I asked you about earlier (to
Mayumi), it's still gonna be a complete circuit
because this jacket is a conductor. . .
Male: It's metal
Reina: so there's. . . I'm guessing it's being diffused
'cause it's fat, and you know, and that's why you
get heat.

By the middle of the lesson, however, Reina had become certain that diagram #3 was a complete circuit. Additionally, she came to this correct conclusion based on observations from Betty's group. No longer did she rely on information from Mayumi. The inscriptions and the group discussion supported Reina's conceptual shift.

Recall that Reina's diagram #3 was very similar to Betty's diagram #1. In the Figure 6.6, Betty's diagram is shown at the top and Reina's diagram is directly below it. Although the two diagrams were oriented differently and Betty had written "No light—Yes heat" and "complete circuit" on her diagram, the configuration of Betty's circuit components was the same as Reina's. Initially, no one in the group commented about the similarity. Figure 6.6 shows the placement of the diagrams immediately after Reina's presentation.

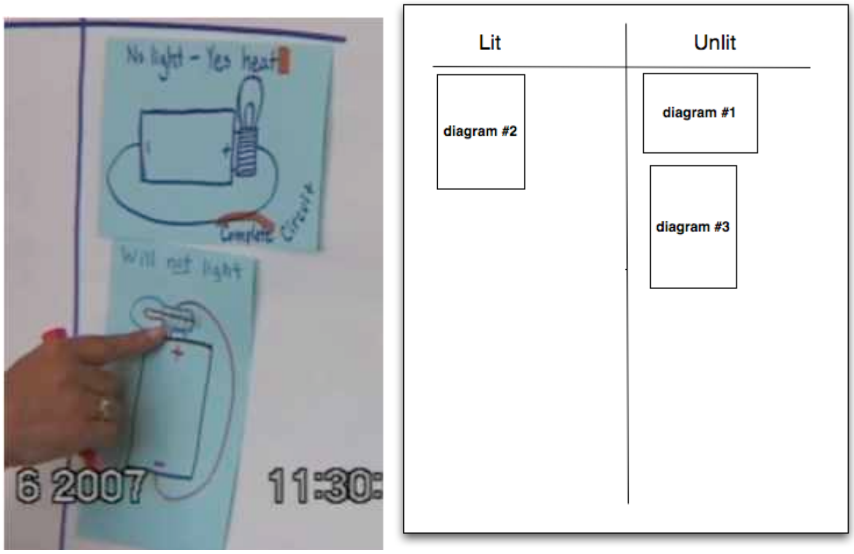

Figure 6.6. The original arrangement of Reina's diagram #3 and Betty's diagram #1.

Five minutes after Reina's initial presentation, Mayumi pointed out that the two diagrams represented the same thing, turned diagram #3 it on its side, and moved it next to diagram #1 to emphasize the equivalence of the two representations. As she moved the diagram, she said, "Oh, these are the same. . . these two." Figure 6.7 shows the new configuration of diagrams. In this configuration, the batteries and the bulbs in these diagrams face exactly the same way.

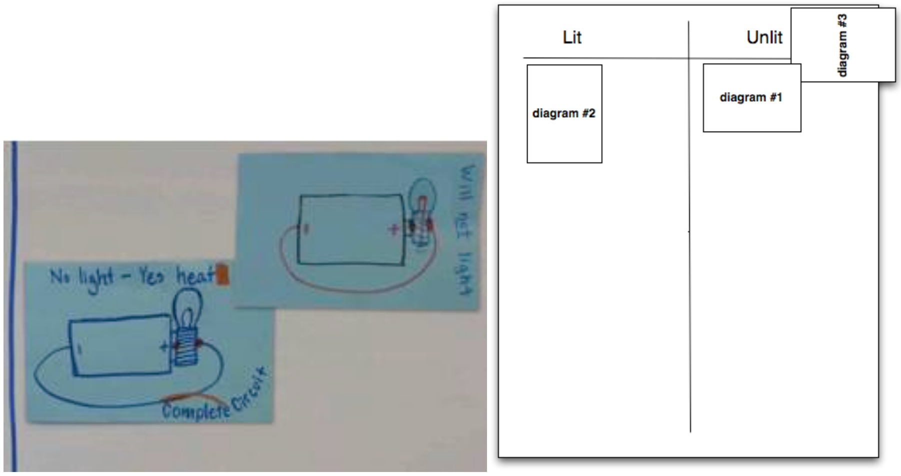

Figure 6.7. The relative positions of diagram #1 and diagram #3 after Mayumi's reorientation. This arrangement makes the similarity between the circuit configurations more obvious that the arrangement shown in Figure 6.6.

At this point in the lesson, Reina now seemed certain that circuit in diagram #3 was complete. She volunteered the following response:

Reina: We decided that it WAS, because that first drawing says it had heat, so it produced. . . THAT was our light bulb."

[Interpretation: "We decided that it (the circuit in diagram #3) was (complete), because that first drawing (diagram #1) says it had heat, so it (diagram #3) produced. . . that was our light bulb (the heat was our indication of a complete circuit, rather than a lit bulb)."]

Armed with the understanding that heat is an indicator of a complete circuit (from the discussion in lines 61-67), Reina pointed to the diagrams on the T-chart and used the equivalence of diagram #1 and diagram #3 to support her argument that diagram #3 is complete. Using the newly established equivalence between the two diagrams, Reina capitalized on Betty's observation that the circuit in diagram #1 produced heat. Because the circuits in diagram #1 and #3 were deemed to be the same circuit, it logically followed that the circuit in diagram #3 also produced heat and was, therefore, a complete circuit.

After Reina's breakthrough, there was evidence that the other learners in the group also understood that diagram #3 was complete. While pointing to diagram #3 (which she had previously annotated with the words "is this circuit complete?") Mayumi asked, "So, we have this question about, is this circuit, here, complete, then?" Six out of the 8 learners verbally responded that, yes, the circuit was complete. Eduardo and Michael did not give a verbal response, but there were strong indications earlier in the episode that they had already understood that diagram #3 was complete. Eduardo told the group, "it's a complete circuit that will not light the bulb" (line 45). Michael understood and described the path that current would travel through the bulb jacket in diagram #3.

The whole-group discussion revealed several indicators of learner confusion about the key concepts of the lesson: several individuals made non-normative statements and asked for definitions. By the end of session 1, there was some evidence that, on the whole, the learners' understanding had become more normative. The group successfully categorized a series of group-generated diagrams into three categories: incomplete, complete and lit, and complete and unlit. There was clear evidence that several learners had moved from tenuous and incomplete understanding to strong understanding.

Summary and Conclusions

The interaction between the facilitator's work, the learner talk, and the physical representations supported learners' conceptual development. The key activity that supported group's learning was scientific in nature: the learners worked collaboratively to make sense of the data they collected during their hands-on investigations. They created a shared data set, organized and interpreted the data, and they developed a set of generalized claims that were supported by the data. This case documents the ways the inscriptions and the facilitation supported these scientific reasoning practices.

The concepts in this session were complex. The facilitator supported the learners' use of inscriptions in a way that helped maintain focus on these concepts. These extended, conceptual discussions revealed varying levels of understanding among group members. As the learners reported and discussed their ideas, both the facilitator and the learners adjusted the inscriptions to reflect their solid, tentative, and shifting ideas. The process of inscribing was dynamic. The shifting inscriptions promoted extended discussion that was evidence based, tuned toward conceptual difficulties, and prioritized central concepts.

Chapter 7: Conclusions

This dissertation explored the ways inscriptions can support science learning by examining the ways an expert facilitator employed inscriptions in her enactment of a teacher professional development course. Informed by the perspective that instruction takes place as an interaction between content, teachers, and learners (Cohen and Ball, 1999), this work examined the inscriptional resources provided by the curriculum; the facilitator's use of inscriptions during her enactment; and the interaction between the facilitator, the learners, and the inscriptions.

Mayumi successfully used inscriptions to engage learners in scientific reasoning practices that supported their conceptual understanding. Mayumi used inscriptions to structure and support discussions that were based on learner-generated ideas, yet led to curriculum-directed conceptual and pedagogical goals. This case of strong inscriptional use took place in the context of a teacher professional development course that employed a challenging curriculum whose pedagogy is in line with recent calls for improved, ambitious instruction for elementary school science. The NRC (2007) defines scientific proficiency in terms of one's ability to participate productively in scientific practices in discourse and to know, use, understand, generate, and evaluate scientific explanations and scientific evidence. It is very difficult to engage and support learners in activities that aim toward this ambitious definition of scientific literacy, but the teacher professional development classroom under investigation did exactly that.

By considering the curricular tools and the interaction with the learners, this study of Mayumi's expert use of inscriptions has allowed us to examine the role of the facilitator as mediator between the curriculum and the learners. The power of this enactment comes from the facilitator's responsive use and modification of inscriptions to match the needs of this particular group of learners.

The Facilitator Capitalized on the Inscriptional Plan in the Curriculum

As intended by the *Learning Science for Teaching* (LSFT) curriculum, Mayumi used inscriptions to structure and support whole-group discussions that were based on learner-generated ideas, yet led to curriculum-directed conceptual and pedagogical goals. True to the written curriculum, Mayumi engaged learners in the use of inscriptions to collaboratively report data from their small-group work, analyze the data, and develop general claims that were based on this evidence. It is through these scientific reasoning processes that the learners strengthened their understanding of the key science concepts in the lesson (i.e., complete circuits, incomplete circuits, and short circuits). Mayumi facilitated the discussion, but the primary sources of ideas and analysis were the learners themselves.

This type of discussion poses a significant facilitation challenge: How does a facilitator make use of learner ideas to meet the conceptual goals of the lesson? When the discussion invites the learners to be the primary contributors of ideas and information, the conversation may become flooded with an abundance of relevant and irrelevant contributions, correct and incorrect ideas, and information that is more or less conceptually fruitful. With an eye toward the conceptual goals, the facilitator must strike a balance between honoring the learners' contributions and moving the conversation toward the most fruitful paths. The analyses in the preceding chapters examined how Mayumi's expert use of inscriptions played a key role in mediating between the curriculum and the learners.

As discussed in Chapter 4, the curriculum provided a series of inscriptional resources that were well suited for the conceptual and scientific reasoning activities that they proposed to support. All of the wall charts Mayumi used for her enactment of the lesson under investigation were reproduced from the curriculum guide, and the activities that she facilitated were consistent with the plans outlined in the curriculum. By using the planned curriculum activities and inscriptions, Mayumi capitalized on the affordances of the designed inscriptions to support learning.

However, this observation is not meant to suggest that her successful facilitation was a simple matter of following the curriculum. In fact, Mayumi's true expertise with regard to inscriptional use is revealed in the examination of her *interactive* use of inscriptions in response to learner ideas and actions. Mayumi strategically employed the resources provided by the curriculum guide to create opportunities to learn which were 1) contingent on learner contributions and understanding, and 2) congruent with the goals of the curriculum. The learners' experience of the curriculum was mediated by Mayumi's responsive use of these inscriptional resources.

The Value of Inscriptions for the Learners and the for the Facilitator

Together, the learner-generated inscriptions and the inscriptions from the curriculum provided the learners with cognitive and social support for treating their ideas as objects of thought. Individual learners made their observations and ideas public through inscriptions and verbal statements. Inscriptions such as the T-chart and the "what we're learning" chart that Mayumi appropriated from the curriculum supported the analysis of the learner-generated inscriptions by framing the tasks in terms of categorization, comparison, and differentiating epistemic status (e.g., evidence versus claims). After layering their own inscriptions on top of the curriculum-generated ones, the learners worked together to scrutinize, question, and figure out the relationships between their inscribed ideas. As a result, the learners collaboratively classified various circuit configurations and developed a set of evidence-based claims about complete and incomplete circuits. Mayumi served as a mediator while the learners shared their thinking and their questions with one another, and inscriptions were the primary tool for structuring and supporting that analytic work. The practice of inscription anchored ideas to words and images in physical space. The physical availability of these inscriptions served as visual reminders and supported the group's consideration of the ideas in relation to one another.

For the facilitator, the inscriptions served as a set of tools for managing the conceptual focus of the discussion, supporting the learners' engagement in scientific practices, and assessing learner understanding. Each moment of interaction with the inscriptions provided Mayumi with an opportunity to assess the ideas that learners brought to the table, decide which ideas should be taken up for further consideration, and direct the learners' attention toward aspects of the conversation that has the most promise for helping them engage in the scientific practices and meet the conceptual goals specified by the curriculum.

The Facilitator Shaped the Form and Content of the Discussion with Inscriptions

In line with the intent of the curriculum, learner-generated ideas served as the raw materials for the group discussion in Mayumi's lesson. While the curriculum provided wall charts for use in the discussion, the intent was that the learners modify these charts by adding their own ideas: they were supposed to populate the charts with their observations, layer over the diagrams with arrows and highlighting to show their thinking about current flow, write down lists of claims, etc. Mayumi's first step in supporting the discussion was to shape the incoming ideas: she needed to help the group in creating inscriptions that had the potential to support collaborative data analysis that would lead them to fruitful conceptual discussions.

Mayumi helped shape the content and form of the group discussion by setting the initial parameters of inscriptional contributions and then tuning the discussion through her manipulation of the inscriptions. Some of the parameters she set included: the form of the contribution (e.g., "draw a picture"), the features of the form (e.g., using dark markers to make the diagrams visible), and the content of the contribution (e.g., "a circuit that surprised you.")

Once the learners' ideas were made publicly available through their inscriptions, Mayumi tuned the group's attention by highlighting and prioritizing certain ideas or sets of ideas for consideration at particular moments. Mayumi supported this tuning by physically highlighting the inscriptions. Similar to the cases of professional vision examined by Goodwin (1994) and disciplined perception studied by Stephens and Hall (1998), Mayumi used her knowledge of the key concepts in the domain and valued scientific practices to guide the learners' perception of and interaction with the inscriptions at hand.

Implications for Pedagogical Content Knowledge Demands

Mayumi's interactive use of inscriptions attests to the many knowledge demands placed on her during her interactions with the learners. Her moves were largely contingent upon the learners' contributions. In each moment of the enactment, Mayumi was faced with the challenge of recognizing and capitalizing on the key ideas and questions that emerged from the discussion. Based on the state of learner understanding and interest, she had to decide what instructional path to take and which inscriptions could support that activity. She also had to find ways of handling off-topic or less-fruitful lines of thinking. While the LSFT curriculum documents did provide some support for helping the facilitators anticipate learner ideas (e.g., sample charts such as the one shown in Figure 4.7), most of the burden for in-the-moment, learner-contingent facilitation decisions was placed on the facilitator.

Beyond knowledge of the conceptual terrain, the teaching knowledge and skills demanded by this work include, but are not limited to:

- Understanding the match between particular inscriptions (or types of inscriptions) and the conceptual or scientific reasoning work they can support
- Understanding the conceptual and pedagogical goals of the curriculum
- Understanding the central concepts in the domain and their relationships to one another
- Ability to elicit learner ideas
- Ability to understand and interpret learner ideas in relation to the curricular goals
- Ability to act upon ideas (e.g., highlight, frame, set aside) in service of curricular goals

This analysis elaborates understanding of the pedagogical content knowledge (Shulman, 1986), or specialized knowledge of the subject matter for the purposes of teaching that is required by an instructor in order to dynamically and responsively employ inscriptions and inscriptional activities to support science learning.

Suggestions for Future Research

One limitation of this study is that there are no strong claims for large, causal relationships. As a case study, this investigation was not designed to test the extent to which particular representations, facilitator moves, or types facilitator knowledge resulted in changes in specific learner outcomes. What this work does offer, however, are explanations of *how* the facilitator employed inscriptions to support learners' engagement in scientific practices and conceptual understanding in a local context. Case studies help us understand complex social phenomena as they unfold in real-life contexts (Yin, 1994). This analysis contributes to a larger understanding about the construction of representational contexts to support learning by providing a powerful domain-specific, context-specific case. It points to specific inscriptions and strategies for supporting learning about electric circuits *and* about supporting discussions that engage learners in scientific reasoning practices.

A second limitation is that this study only focuses on adult learning. If the ultimate goal is to support student learning, we must study the use of various inscriptions and inscriptional activities with children. There is some evidence to suggest that students' abilities to understand and work with representations may play a role in their usefulness as learning tools and that this competence can be learned (diSessa, 2004). Younger learners might need additional support to learn *how* to use inscriptions as tools for supporting their own learning.

A next step in the larger *Learning Science for Teaching* research program is to compare cases of expert facilitation with novice facilitation of this curriculum. One might expect to see variation across enactments where pedagogical content knowledge varies because the learner-centered nature of the LSFT curriculum leaves a great deal of room for variability in facilitator decision-making. This comparison will help us understand the extent to which the enactment is supported by the curriculum materials themselves (e.g., the inscriptions and the activities) and the degree to which variations in pedagogical content knowledge influence opportunities to learn.

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