Middle School Students ' Development of Inscriptional Practices in Inquiry-Based Science Classrooms

by

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ABSTRACT

MIDDLE SCHOOL STUDENTS ' DEVELOPMENT OF
INSCRIPTIONAL PRACTICES IN INQUIRY-BASED SCIENCE CLASSROOMS

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The purpose of this study is to characterize the learning practices demonstrated by seventh graders when they used various scientific inscriptions in an inquiry-based learning environment. Inscriptions are types of transformations, such as graphs, diagrams, data tables, symbols, maps, and models, that materialize or visualize an entity into another format or mode. As suggested by science studies, scientific knowledge and the reality of science are constructed through manipulating a variety of inscriptions. However, little is known about how middle school students make use of inscriptions over time and what resources or features of the learning environment support students in doing so. Drawing on a naturalistic approach, this classroom-based study aims to characterize students' inscriptional practices, trace their learning trajectories, examine potential use of various scientific inscriptions, and analyze the learning supports and resources provided by the teachers and the learning environment.

This eight-month study is conducted in two inquiry-based science classes with participation of two teachers and 27 seventh graders. Two student dyads from each class were observed intensively. Multiple sources of data were collected, including fieldnotes, classroom video recordings, process video recordings, computer-based models,

webpages, science reports, notebooks, and transcripts from interviews with students and teachers. Several analytical steps were taken to analyze and synthesize these data.

Expanding upon early research on students' learning of inscriptions, this study shows that seventh graders could demonstrate competent, purposeful inscriptional practices when they were scaffolded by the teachers and the curriculum in a learning environment where the inscriptional activities were sequenced, iterated, and embedded in scientific inquiry. Additionally, using inscriptions in science classrooms provided students with opportunities to engage in thoughtful discussions about concepts and scientific inquiry. The historical development of students' inscriptional practices documented in this study suggests a progression in scientific thinking. The findings of this study inform theories about social practices, learning communities, scientific reasoning, and science inquiry. This study also provides insights into the design of a learning environment in which students can develop competent and authentic scientific practices.

CHAPTER 1

INTRODUCTION

> The ‘concepts’ of science are not solely verbal concepts, though they have verbal components. They are semiotic *hybrids*, simultaneously and essentially verbal, mathematical, visual-graphical, and actional-operational (original emphasis, Lemke, 1998, p.87).

Visual representations constitute an integral part of science practices. Graphs, diagrams, data tables, symbols, maps, and models are widely seen in science textbooks and professional articles. These representations convey information, organize data, demonstrate patterns and relationships, and communicate scientific knowledge. Science studies argue that scientific knowledge and the reality of science are constructed through manipulating a variety of representations (Knorr-Cetina, 1983; Lynch & Woolgar, 1990). Scientific representations not only simply display the information in a different mode, but also multiply and recreate meanings of the given information that otherwise cannot be realized (Lemke, 1998). Given that educational researchers wish to engage students in authentic scientific tasks (e.g., Brown, Collins, & Duguid, 1989; Resnick, 1987), a focus on the use of scientific representations could provide students with opportunities to develop competent scientific practices (Kozma, Chin, Russell, & Marx, 2000; McGinn & Roth, 1999; Roth & McGinn, 1998; Toth, 2000). The purpose of this study is to characterize the scientific practices demonstrated by seventh graders when they used various scientific representations in an inquiry-based learning environment.

Psychologists use “representation” for describing internal or mental structures (e.g., Chi & Feltovich, 1981) as well as external displays (e.g., Kozma, 1991). To avoid the ambiguity of the term “representation” and emphasize the mobile, sharable and transformable nature of external representations in social practices, this study uses “inscription” to refer to various types of transformations that materialize or visualize an entity into another format or mode. The term “inscription” has been used in science studies (Latour, 1987; Latour, 1990; Latour & Woolgar, 1979) to refer to a sign, a graph, a model, or a spectrum. By using the term “inscription,” this study emphasizes the socially constructed nature of scientific representations in shared practices.

Inscriptions are used by scientists to demonstrate what they already know as well as to predict or discover what they do not know (Nye, 1993). The periodic table, for example, has been a powerful tool that guided chemists to explore many of the unknown elements. Additionally, scientific inscriptions are involved in scientists’ daily practices (Kozma, Chin, Russell, & Marx, 2000). Scientists construct inscriptions to express ideas for a given task, interpret meanings of inscriptions across contexts, use inscriptions to explain phenomena and make predictions, and use various inscriptions for communication (Kozma et al., 2000; Kozma & Russell, 1997; Roth & McGinn, 1998). These practices related to the use of inscriptions are regarded as “inscriptional practices” in this study.

Given the important role of inscriptions in scientific practices, it is unfortunate that many middle school and high school students have difficulties in using, interpreting, and understanding them (Ben-Zvi, Eylon, & Silberstein, 1987; Krajcik, 1991; Leinhardt, Zaslavsky, & Stein, 1990). Empirical studies indicate that students do not demonstrate inscriptional competencies as scientists do (Bowen, Roth, & McGinn, 1999; Kozma, 2000a; Kozma & Russell, 1997). However, little is known about how students develop their understandings of inscriptions over time and what resources or features of the learning environment support students to do so.

Drawing on a naturalistic approach (Guba & Lincoln, 1994; Moschkovich & Brenner, 2000), this study focuses on students' historical development of inscriptional practices in two seventh grade classes during an instructional unit that emphasized water quality and relevant concepts (the water quality unit). The notion of learning as a historical development has been used as an analytical viewpoint in some empirical studies (e.g., Barab, Hay, Barnett, & Squire, 2001a; Roth, 1996a) to portray the diffusion, emergence and evolution of knowledge and practices within a learning community. Lave and Wenger (1991) suggested that "the historicizing of the production of persons should lead to a focus on processes of learning" (p. 51). In this study, by "historical development," I mean that during an instructional unit, inscriptional activities in which students participate constitute a learning history and that the emergence and development of students' inscriptional practices take place in the context of a learning environment overtime. Students' enactment of inscriptional practices at a moment might interact with the knowledge, practices, and experiences that they have learned from previous inscriptional activities. To understand students' learning with inscriptions, therefore, it is important to trace the history of students' practices by documenting and analyzing their discussions, actions, and artifacts over time. That is, instead of viewing students' enactment of inscriptional practices as isolated activities, this study assumes that students' learning with inscriptions is related to past classroom events. Observing and following the use of certain inscriptions and associated practices throughout the eight-month unit could reveal students' learning process and the ongoing nature of practices (Barab et al., 2001a; Barab, Hay, & Yamagata-Lynch, 2001b).

Therefore, this eight-month, classroom-based study aims to characterize students' inscriptional practices, trace their learning trajectories, examine potential use of various scientific inscriptions, and analyze learning supports and resources provided by teachers and the learning environment. The research questions that guide the study are:

(1) What are the characteristics of inscriptional practices demonstrated by seventh graders?

(2) How do students' inscriptional practices change over time?

(3) What are the characteristics of the inscriptions created and used by students?

(4) What aspects of the learning environment help students create various inscriptions and develop inscriptional practices?

It is important to study the development of inscriptional practices at the middle school level because many scientific inscriptions, such as graphs, data tables, and chemical equations, are formally introduced to students at the middle school level. However, empirical studies have documented that many students in the sixth to eighth grade have difficulties reading these inscriptions (Krajcik, 1991; Leinhardt et al., 1990). To find out possible sources of the difficulties, researchers need to study how middle school students learn scientific inscriptions in classrooms.

Middle school is also the stage when students begin to experience the complexity of the scientific inquiry process (Krajcik et al., 1998) that provides a meaningful context for students to engage in scientific practices. It is important for researchers to understand the interactions between the design of a learning environment and the development of inscriptional practices.

Furthermore, most of the studies that investigated students' inscriptional practices have focused on college students (e.g., Bowen et al., 1999; Kozma, 2000b, 2000c). One exception is the study conducted by Roth and Bowen (1994). Yet, Roth and Bowen's study was relatively short-term (three-month) compared with this study which lasted eight months. It did not include students' use of tool-based inscriptions. Nor did it study how students' inscriptional practices are supported by features of a learning environment.

Findings of this study are valuable for theory and practice. This study aims to inform theories about learning and teaching inscriptions that could be practically applied in educational settings. Through exploring seventh graders' use of inscriptions, this study expands the theories that have been established with the participation of college students and scientists by showing the inscriptional practices that could be demonstrated by seventh graders and supported by an inquiry-based learning environment. It also provides insights into theoretical claims regarding the value of using scientific inscriptions at the middle school level (Roth & McGinn, 1998) and the impact it has on science learning. Additionally, this study seeks to provide educational implications for developing a learning environment in which students engage in authentic inscriptional practices. The findings will help educators design instruction and learning environments so that all students benefit.

Overview of the Dissertation

In this chapter, I have provided a rationale to study middle school students' inscriptional practices in an inquiry-based learning environment. I have presented the research questions and indicated the significance of the study. In Chapter two, I situate the study in the ongoing discourse about the topic of how students learn inscriptions and develop a theoretical framework that guides the data collection and analyses. I then detail the overall research design, the trustworthiness features of the study, the settings, the methods for gathering data, and the strategies for analyzing the data in Chapter three. In Chapter four, I present the results of the study. An overview of students' enactment of inscriptional practices and a series of themes document learning trajectories of the students from peripheral participation to full participation in some inscriptional practices, demonstrate interrelations among different types of inscriptions, present the use of inscriptions in the seventh grade classrooms, and indicate the scaffolds and resources provided by the learning environment that might support students' development of inscriptional practices. In the last chapter, I indicate how the findings would inform theories, provide suggestions for designing a learning environment, and indicate a possible direction for future research.

CHAPTER 2

THEORETICAL FRAMEWORK

In this chapter, I explore the role of inscriptions in science, discuss the research on students' learning of inscriptions, and develop a framework for studying inscriptional practices. I begin by defining "representation" and "inscription" and discuss theoretical perspectives proposed by the research on the topic of scientific representations. I then review the research on graphs, chemical representations, and models and analyze the relationship between an inscription and the inscribed, the role of inscriptions in science, and students' learning of inscriptions. In the summary of my review, I indicate possible directions to investigate students' development of inscriptional practices. Expanding upon my review, finally, I discuss components of inscriptional practices and provide definitions of practice and other related constructs.

Representations/Inscriptions in Science

Psychologists use "representation" for describing internal or mental structures (e.g., Hegarty, Carpenter, & Just, 1991; Shah, 1997) as well as external displays (e.g., Kozma, 1991). In this study the term "representation" is restricted to the latter definition. Representations refer to various types of transformations that materialize or visualize an entity into another format or mode, which could be a sign, a graph, a model, or a spectrum. In a broad sense representations could be in a textual form; yet, this study is particularly interested in those that illustrate phenomena, concepts or scientific entities visually, such as graphs, diagrams, data tables, maps, and models. By using the term "representation," however, this study does not imply a similarity that exists between mental content and physical external representations as some studies in cognitive psychology do (e.g., Larkin & Simon, 1987).

To avoid the ambiguity of this term "representation," some science educators (e.g., Anderson, 1999; Barnett, MaKinster, Barab, Squire, & Kelly, 2001; Roth & McGinn, 1998) began to adapt the term "inscription," which has been used in science studies (Latour, 1987; Latour, 1990; Latour & Woolgar, 1979) to refer to all types of representations and transformations used in science. Although in some science education studies, the terms "representation" and "inscription" were used interchangeably (e.g., Bowen, Roth, & McGinn, 1999), "the focus on inscriptions entails a concomitant focus on the establishment and maintenance of shared practices" (Roth & McGinn, 1998, p. 41). Namely, by using the term "inscription" science education researchers take a different theoretical position from cognitive psychologists and emphasize the mobile, immutable, sharable, supercomposable, and transformable nature of external representations in shared practices within a social context (Roth, 1995; Roth & McGinn, 1998). This study shares the theoretical assumption with those studies of inscriptions that the ideal science learning includes engaging students in inquiry activities and shared practices that approximate to the real-world science. Thus, I choose to use "inscription" to indicate the theoretical traditions in which this study is grounded.

Theoretical Perspectives on Learning Inscriptions

Creating and reading scientific inscriptions are valued as important skills for the development of scientific literacy (American Association for the Advancement of

Science [AAAS], 1990). A considerable number of studies in science education investigate whether students are able to interpret and construct inscriptions (Ben-Zvi et al., 1987; Berg & Phillips, 1994; Roth, 1996b), how educational interventions support them in doing so (Gabel, Samuel, & Hunn, 1987; Kozma, 2000; Linn & Nachmias, 1987) and what inscriptional activities scientists and students engage in their daily practices (Bowen, Roth, & McGinn, 1999; Kozma, Chin, Russell, & Marx, 2000; Roth, Bowen, & McGinn, 1999). Among these studies, two theoretical perspectives on learning were proposed.

One theoretical perspective is based upon a view of learning as a process of individual cognitive development. Research done within this theoretical frame emphasizes students' comprehension of canonical inscriptions (Ben-Zvi, Eylon, & Silberstein, 1987), their ability to construct inscriptions (Berg & Phillips, 1994; Brasell & Rowe, 1993), and their alternative conceptions of scientific inscriptions (Clement, 1989). The results indicate that many students have difficulties in understanding scientific inscriptions and hold alternative conceptions while interpreting and constructing inscriptions (Leinhardt, Zaslavsky, & Stein, 1990). The possible explanations of these difficulties and alternative conceptions include that students may not possess mental structures and logical thinking skills (Berg & Phillips, 1994) and that students do not have accurate understanding of relevant concepts to support interpretation and construction processes (Keig & Rubba, 1993; Nakhleh, 1992).

As sociocultural factors that mediate learning become more prominent, alternative explanations of students' conceptions about inscriptions are provided by a second theoretical perspective that considers learning inscriptions and inscribing as social practices (Greeno & Hall, 1997; Kozma et al., 2000; Roth & McGinn, 1997; Roth & McGinn, 1998). Science studies illustrate that the relationship between an inscription and the inscribed entity was established through a considerable amount of social interactions and situated work (Lynch & Woolgar, 1990). When inscriptions are taught as ready-made-science (Latour, 1987) in a science classroom, however, "context and contents merge" (p. 5). The social and contextual factors involved in inscriptional activities are simplified into a straightforward and self-evident relationship between an inscription and its referent (Roth & McGinn, 1997). Thus, it is not surprising that students make errors while interpreting and constructing inscriptions, because without opportunities of experiencing the iterative and social processes in which inscriptions were originally constructed, it is difficult for them to reconstruct the canonical meaning of an inscription. Therefore, instead of emphasizing mental cognitive processes, recent research from this learning-as-practice perspective focuses on creating a context or a learning environment in which students develop competent inscriptional practices such as using inscriptions to make explanations and predictions, and producing inscriptions to convince others (Roth & Bowen, 1995; Roth & McGinn, 1998).

Developing a theoretical framework for the study, I do not intend to argue that either one of the perspectives is better; rather, I mainly focus on how the educational implications provided by the two theoretical perspectives (i.e. the individual cognition perspective and the social practice perspective) complement each other. As will be seen, by emphasizing different aspects of the learning process, research from the two theoretical perspectives reveals how inscriptions could be learned through developing individual cognitive abilities as well as through participation in social practices.

The Relationship between Inscription and Inscribed

Scientific inscriptions are used to represent phenomena or conceptual entities. What does "inscribing" mean? What is the relationship between an inscription and the situation, object, or conceptual entity which is inscribed? How can the relationship be established and become valid and socially accepted? These questions are critical for a study of how people learn inscriptions. In this section, I use graphs, chemical representations and models as examples and explore the relationship between an inscription and its inscribed entity.

Graph

Compared with other types of visual displays, graphs are unique. Instead of depicting spatial information, graphs typically represent the quantitative attribute of concrete objects or abstract concepts (Hegarty et al., 1991; Shah, 1997). For example, when a line graph is created to describe changes of the distance between an object and an origin, it represents a functional relationship that shows changes of the distance with an increase of the time. This graph does not represent the distance or time per se but the quantitative attribute of them. Hence, the referent of a graph, an entity to which a graph refers, is the situation described by some quantitative attributes. Additionally, the quantitative information is systematically related to features of a graph. The relationship between a graph and its represented information is neither arbitrary nor a first-order isomorphism (Winn, 1987). Instead, it is based on "an analogy between quantitative scales and visual dimensions such as length, color, or area in which the visual dimensions are usually analog representations of this quantitative information" (Shah, 1997, p. 94). Thus, a graph, as a conventional symbol system, is based on rational imagery (Bertin,

1983) in which the qualitative attributes of objects or concepts can be mapped onto some quantifiable features of the graph, such as labels of the scales or positions on a coordinate space.

Informed by the recent work in science studies (e.g., Latour, 1987; Lynch, 1992), Roth and McGinn (1998) argued that graphs are semiotic objects and the relationship between a graph and its referent to which the graph refers is arbitrary. Like words that are not a first-order isomorphism of their references, inscriptions are ontologically independent of their referents. When a line graph is created to describe changes of the distance with an increase of time, features of the graph, such as numbers, axes, and fitted line, has no direct correspondence to the situation it constitutes, i.e. a dynamic movement. The relationship between a graph and the movement it represents was constructed in the same way as the relationship between a word "air" and the colorless, odorless gas surrounding us, that was not based on a predetermined ontological connection but convention.

Furthermore, because graphing is not a simple mapping exercise, establishing this relationship and developing competence to present data graphically require a considerable amount of inscriptional practices. In Roth and Bowen (1995), over a period of seven weeks, students gradually adopted more and more graphical inscriptions in their reports. The development from less to more abstract inscriptions was accelerated by the teacher or peer requests to present their data in a more convincing way. Roth and Bowen attributed students' competent inscriptional practices, such as translating or mathematizating their physical experiences into graphical representations and using graphing as a strategy to solve problems, to "cultural accomplishment" (p. 98), because through interactions within and between small groups the learning community created a culture (or social norm) that encouraged students to use graphs in their practices. Thus, Roth and his colleagues (Roth & McGinn, 1997, 1998) argued that an interpretation about the existence of an analogical or conceptual relationship between a graph and its referent oversimplifies the complexity of the representing process and ignores the social and integrative nature of representing practices.

Although the metaphor of classroom-as-a-cultural-community provides an explanation of students' increasing use of inscriptions in Roth and McGinn (1997, 1998), it raises a concern about whether a classroom culture always accelerates the ideal science learning, because the classroom culture could match as well as conflict with the culture in the community of scientists (Kelly & Green, 1998). Given that educational researchers wish to engage students in the practices of scientists (Brown, Collins, & Duguid, 1989), social norms or a classroom culture should be guided or constrained by the disciplinary culture of science. However, in Roth and McGinn (1997, 1998), it is unclear how social norms in a learning community are developed towards those in the community of scientists, even though a comprehensive use of inscriptions is part of the disciplinary culture of science. Additionally, social norms could promote students' increasing use of inscriptions and determine what types of inscriptions are meaningfully to be constructed, but the criteria generated by the learning community and used to determine the accuracy of inscriptions might not be those used by scientists.

Chemical Representation

While graphs transform observable phenomena into two-dimensional visual representations, other inscriptions, such as chemical formulas and symbols, represent invisible scientific entities (e.g., molecules, atoms, and chemical bonds) and concepts (e.g., electron resonance). Kozma et al. (2000) described chemical representations as tools that "mediate between the physical substances that they [chemists] study and the aperceptual chemical entities and processes that underlie and account for the material qualities of these physical substances" (p. 105). This description indicates that chemical representations are used to refer to both physical phenomena and conceptual entities (Fig. 2.1).[1] For instance, a chemical formula, $H_{2(g)}$, represents a colorless, inflammable gas called hydrogen gas (relationship (1) in Fig. 2.1) as well as a hydrogen molecule composed by two hydrogen atoms (relationship (2) in Fig. 2.1). By using chemical representations, chemists' reasoning process could easily move back and forth between phenomena and concepts.

Kozma agreed with Roth's argument of the arbitrary and socially constructed nature of the relationship (1) (personal communication, November 8, 2000). Furthermore, he argued that the establishment of the relationship (2) is even more critical and difficult for science learning, because conceptual entities are inseparable elements of scientific knowledge. Additionally, physical phenomena and inscriptions are visible, whereas conceptual entities are not perceptually available. When a chemistry teacher writes down a chemical equation on the board and uses it to explain a chemical reaction, students may recognize the physical phenomena, such as color change or precipitation, represented by the equation (relationship (1)). Yet, it is relatively more difficult for

[1] Kozma et al. (2000) argued that chemical representations are mediators between concepts and phenomena, but this does not mean that inscriptions are the "only" mediators between the two. In fact, in his other studies (Kozma, 2000a; Kozma, 2000b), Kozma regarded language and technology as mediators as well.

students to visualize the chemical entities, such as molecules or chemical bonds, associated with the equation.

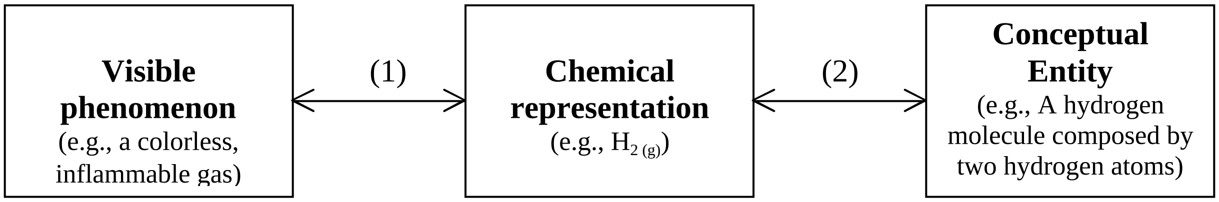

Figure 2.1. Inscriptions as mediational tools between phenomena and conceptual entities

The nature of relationship (2) is also socially constructed and somewhat arbitrary (Kozma, 2000c), for example, using “hydrogen” or “H” to represent an element with only one valence electron. In order to help students assign meanings to inscriptions, the use of inscriptions need to be in conjunction with the referents. One way to do so is through discursive interactions within a social context. The discussions between a doctoral student and his advisor reported by Kozma et al. (2000) illustrated how an apprentice learned to assign meaning to a scientific inscription. When discussing a NMR (Nuclear Magnetic Resonance) spectrum with his student, the advisor, as a professional chemist, demonstrated how to identify the existence of a specific structure from patterns of the spectrum, redirected his student’s attention to the features ignored by the student, and engaged his student in interpreting inscriptions. At the same time, the doctoral student showed his acknowledgment by repairing his responses, adopting some of the advisor’s ideas, applying the knowledge that he just learned about features and compounds into a new situation, and using certain features as evidence for his arguments. Using inscriptions in shared practices is one of the primary activities in the chemist community through which a student comes to establish a linkage between an inscription and it aperceptual referent and adopts a specified pattern of talking about inscriptions within a social context (Lemke, 1990; Wu, 2001). Thus, Kozma et al. (2000) suggested that science instruction should help students to develop abilities to “identify and analyze features of a representation (such as a peak on a graph) and use them to explain, draw inferences, and make predictions about chemical phenomena or concepts” (p. 136).

To further analyze the socially constructed nature of relationship (2) in Fig. 2.1, I use an example from the history of chemistry to present the process of validating the relationship between chemical representations and conceptual entities. The focus on this validation process reveals the establishment and maintenance of shared practices within a knowledge community and provides insights into how inscriptions (or a symbolic language system) make the conceptual entities accessible.

From a modern chemistry point of view, the language of chemistry before Lavoisier (1743-1794) composed by alchemical symbols was full of mystery and ambiguity. Lavoisier and his colleagues began to use pseudo-algebraic symbols occasionally and demonstrated a strong tendency to make chemistry as a quantitative science that could include numerical values for calculating energy and other factors, although he stated that these symbols were not algebraic but shortcuts for convenience (Nye, 1993). Similar to the symbols Lavoisier used, in 1814 Berzelius first used letters of the alphabet, numbers, bars, and signs to represent a chemical reaction. Rather than using Dalton’s (1766-1844) geometrical and pictorial symbols, he included grouped letters within these alphabetical linear formulas. However, including Dalton, chemists objected to this new symbolic system because of their philosophical preferences for pictorial symbols and the confusing use of Berzelius's "rational" formulas that made most compounds have more than one rational formula. Additionally, this symbol system was in conflict with the fundamental rules of algebra. For instance, Berzelius intended to use NH^4Cl as N + 4H + Cl, but in algebra, it means multiplication, $N \cdot H^{4} \cdot Cl$. Compared to the ordinary language with words, however, this system was convenient to represent a chemical process, so in 1833, Edward Turner became the first author who used Berzelius's symbolic system in the chemistry textbook, because it was efficient for educational purposes. This symbolic system was not fully accepted by the community of British chemists until in 1835 a committee constituted by the British Association for the Advancement of Science reported that a majority of its members approved the new notation.

This new symbolic system was not developed to represent colors or properties of chemical compounds (relationship (1) in Fig. 2.1), as the language of alchemistry intended. Instead, it was designed to represent the qualitative and quantitative composition of a compound that reflected chemists' ideas about elements, compounds, and chemical reactions (relationship (2)). To decide whether they should accept a new symbol system, not only did chemists consider whether this system successfully represented what they already knew about chemical compounds (e.g., composition), but they also evaluated whether it conflicted with an existed symbol system and whether it was rooted in their philosophical preferences. Therefore, the process of validating a set of symbols (relationship (2)) as a legitimate inscriptional system involves objections, discussions, and considerable inscriptional works and requires the social recognition and consensus of members within a community.

Model

Like chemical representations, models are mediators between concepts and phenomena. A model represents a phenomenon or a system and concentrates attention on specific aspects or components of a system, such as objects, events or processes (Ingham & Gilbert, 1991). It usually integrates conceptual knowledge to explain the phenomenon and uses components of the model (i.e., objects, variables, factors or relationships) to elaborate on interactions within the system (Gobert & Buckley, 2000; Ingham & Gilbert, 1991). For example, a model of the water quality is enriched when the model contains ideas of related concepts, such as dissolved oxygen, conductivity, and pH value, and builds causal relationships among them. These concepts and relationships add complexity of the model structure and enable the model to be an explanatory one.

In general, models could be defined into two types based upon where a model exists (Gobert & Buckley, 2000; Greca & Moreira, 2000; Norman, 1983). Models that exist in one's mind are mental models. They are mental entities that people have, construct, and reason with (Johnson-Laird, 1983). Mental models allow people to have personal internal representations of a system or phenomenon, to describe the complexity or structure of a phenomenon, and to model how a system operates. A second type of models are expressed models (Gobert & Buckley, 2000). They are "external representations of the target generated from one's mental models and expressed through action, speech, written description, and other material depictions" (Gobert & Buckley, 2000, p. 892). This definition assumes that people have a mental model prior to constructing an expressed (or external) model. From this theoretical point of view, the referent of an expressed model is a mental model instead of the target phenomenon, and modeling refers to the process of constructing (or externalizing) one's mental models of phenomena (Gobert & Buckley, 2000). This definition of model then is compatible with the individual cognition perspective that knowledge must be constructed within the individual mind.

Viewing models as inscriptions used for social practices, on the other hand, foregrounds the relationship between a model and its inscribed phenomenon and emphasizes the social and rhetorical functions of an expressed model (Barnett et al., 2001; Roth & McGinn, 1998). Models visualize a phenomenon and stimulate the creators and viewers to pose questions that take them beyond the original phenomenon to formulate hypotheses that can be examined experimentally (Dunbar, 1998; Penner, Lehrer, & Schauble, 1998). In this case, whose mental models are materialized and what part of a mental model is visualized by an expressed model are not the primary concerns for this theoretical approach. Although the researchers who conducted studies from the social practice perspective (e.g., Barab, Hay, Barnett, & Squire, 2001a; Barnett et al., 2001; Bowen et al., 1999) acknowledged the existence of prior knowledge, understandings and experiences, these experiences and knowledge are not necessarily existed in a form of mental models. Nor do students need a mental model prior to the construction of an expressed model. Consequently, modeling is a process that affords students the opportunities to engages students in inscription-related practices and allows them to transform their understandings of a phenomena into objects, variables and a series of relationships between variables (Lehrer & Romberg, 1996).

Similar to the use of chemical representations, modeling requires students to establish referential relationships among a phenomenon (e.g., causes and effects of water pollution), an inscription (e.g., a water quality model), and concepts (e.g., conductivity and dissolved oxygen). As students try to use the components of a model (i.e., objects, variables, and relationships) to represent their emerging understandings of concepts and phenomena, the representing process might not always be successful. Following the notion of mental model, these unsuccessful attempts could be attributed to students' inaccurate or incomplete mental models (Kozma, Russell, Jones, Marx, & Davis, 1996). If students' modeling process is regarded as social practices, these unsuccessful attempts could be interpreted as a lack of opportunities or a lack of experience to participate in similar inscriptional practices. The two theoretical positions suggest different explanations of students' unsuccessful attempts and learning difficulties in modeling. In the section of Students' Learning of Inscriptions, I will discuss sources of students' learning difficulties in detail.

Science-in-the-making and Ready-made-science

What is the nature of the relationship between an inscription and its inscribed entity? Is it conceptual or arbitrary? To summarize my preceding discussions, I apply Latour's (1987) notion of two sides of science: Science-in-the-making and ready-made-science. According to Latour's first rule of method to investigate science-in-the-making, "we either arrive before the facts and machines are blackboxed or we follow the controversies that reopen them" (p. 258). Describing the relationship as conceptual and analogical is like taking a snapshot after the relationship was established, whereas portraying the relationship as socially constructed is setting the timing of research back to the time when the relationship just began to be recognized and established by a community.

Inspired by Latour's works and other science studies (e.g., Knorr-Cetina, 1995), a learning-as-social-practice perspective addresses the ongoing, evolving nature of knowledge construction and investigates scientific knowledge before it is concretized as taken-for-granted. That is, rather than treating inscriptions as unchangeable knowledge elements for students to learn in a science classroom, the social practice perspective sees inscriptions as sociocultural tools that are co-constructed and changed through interactions among community members and ready-to-hand resources, such as an innovative technological tool and a newly developed theory that members use to carry out a practice (Kozma, 2000b). By opening the black box of how the relationship between an inscription and its inscribed entity has been established, moment-to-moment interactions and shared practices established over time are revealed. As recent research in science education emphasizes the importance of providing students with opportunities to learn, this perspective is helpful to study and characterize social interactions among contexts, members, and resources in educational settings (Kelly, Chen, & Crawford, 1998).

When science-in-the-making addresses the ongoing and dynamic process of knowledge construction, however, it raises concerns about what knowledge is made through this science-in-the-making process inside a classroom. This notion of science-in-the-making was originally used to examine how scientific knowledge is constructed within the disciplines of science that are recognized by society as cultural institutions whose purpose is to create new knowledge about the physical and natural world.

Scientists have developed particular concepts, instruments, beliefs, and value systems to determine the legitimacy or accuracy of knowledge generated by the community members, but students may not have these resources to evaluate new knowledge constructed by the learning community inside a classroom. That is, local understandings about science developed and valued by a learning community might not be consistent with those in the disciplines of science. Thus, although science-in-the-making is a powerful idea to examine the knowledge construction process, in educational settings, teachers and educational researchers need to assure that the knowledge made through science-in-the-making is also recognized by the disciplines of science.

Consequently, as science-in-the-making is garnering much research attention recently, ready-made-science needs to be recognized as an essential part of school science. Established rules or conventions, as examples of ready-made-science, are required to operate a symbolic system within a cultural community. Any related inscriptional activity must follow certain rules of a symbolic system in order to represent the entities that members already know as well as new entities that are discovered or invented. For example, after the professional community of chemists accepted using symbols and numbers to represent chemical compounds, chemists began to use this system to name chemicals for their joint inquiry; otherwise, they could have not known if two groups of chemists were investigating the same compound. Thus, rules or conventions are necessary for any symbolic system, which are like grammars for a language. Without these rules, to create a legitimate inscription to a new compound, chemists would have composed a committee every time when a new compound was synthesized or found.[2] In this sense, the relationship between an inscription and its inscribed entity is rule-based, and students need to construct scientific inscriptions that would be accepted by the scientific community outside the school. On the other hand, appropriately using inscriptions cannot be achieved by simply applying the rules or conventions. Students might not be able to recognize and adapt exceptional and situational uses of representations unless they are engaged in inscriptional practices. Therefore, from a pedagogical point of view, students need to experience the two sides of science.

In summary, the relationship between an inscription and its inscribed could be arbitrary at a level of creating an inscriptional system, but after a system is established, the use of this system is usually rule-driven. In a science classroom, these rules should be introduced and applied in a variety of inscriptional activities. Students need to recognize the dual nature of an inscriptional system, which is arbitrary as well as conceptual. To better understand a given inscriptional system, students must experience the situational use of inscriptions across tasks and contexts. What does the situational use of inscription look like? What are inscriptional practices enacted by scientists daily? In the following, I present how inscriptions are used in science that provides insights into how to engineer an inscription-rich learning environment in educational settings.

2 Although composing a committee for every new compound is not necessary in chemistry now, to avoid the controversy of naming new compounds (or elements), the community of professional chemists relies on International Union of Pure and Applied Chemistry (IUPAC), which is the official body for naming, to name new chemical elements and set naming rules.

The Role of Inscriptions in Science

Studies from the individual cognition and social practice perspectives address different aspects of why and how inscriptions are used in scientific practices. These views about how inscriptions are used in science lead to different ideas of what is meant by "understanding" inscriptions.

Graphs: Data Organizer and Rhetorical Device

Data organizer

In the studies that address the development of mental structures and individual cognition, graphs are described as useful displays for visualizing trends in quantitative data (Preece & Janvier, 1992). They can be used to summarize a functional relationship between variables (Wavering, 1989), and condense and organize quantitative information (Brasell & Rowe, 1993; McKenzie & Padilla, 1984). These descriptions about using graphs as data organizers emphasize the efficiency of using a graph as a visual display to represent quantitative information.

Following this view of how graphs are used, the assessments of graphing skills include items that ask students to make a graph from the given numbers (McKenzie & Padilla, 1986; Wavering, 1989), to identify a pattern in the graphed points (Preece & Janvier, 1992), and to describe a graphed relationship (McKenzie & Padilla, 1984). For example, the Test of Graphing in Science (McKenzie & Padilla, 1986) was designed to assess students' skills of "selecting appropriate axes, locating points on a graph, drawing lines of best fit, interpolating, extrapolating, describing relationships between variables, and interrelating the data displayed on two graphs" (pp. 572-573). Based on this test, graphing skills include two parts: Construction and simple reasoning. One is to correctly identify and use the basic, technical elements of a graph, such as axes, scales, data points, and fit lines. The other is to appropriately use graphs for reasoning, such as making predictions (e.g., interpolating and extrapolating) and generating interpretations of a relationship. Thus, from this individual cognition perspective, understanding graphs is to correctly create and interpret a graph, and use it for scientific reasoning.

Rhetorical device

According to recent research of science studies, some researchers argued that the “correctness” of using scales and presenting data points depends on the context in which the graph is used (Roth & McGinn, 1997; Wainer, 1992). Additionally, making predictions and explanations in descriptive works is only part of scientific reasoning involved in inscriptional practices. From a social practice perspective, graphs are constructed and interpreted based on the arguments scientists intend to make (Roth & McGinn, 1998), and serve as a rhetorical device and a means of communication in scientific practices (Greeno & Hall, 1997; Lemke, 1998; Roth & McGinn, 1997).

Like verbal discourses, graphical inscriptions are an essential part of doing and talking science (Latour, 1990; Lemke, 1998; Smith, Best, Stubbs, Johnston, & Archibald, 2000). Graphs, frequently presented in conjunction with texts, elaborate the statements provided by texts. Graphs highlight certain information as well as eliminate some information that may distract the audience’s attention. This information highlighting function can be achieved by employing some graphing and mathematics techniques, such as changing scales and mathematically differentiating or integrating linear functions. For example, by using an example of a double y-axis graph, Wainer (1992) illustrated how different arguments could be made by manipulating scales. The original double y-axis graph was to support a claim that as education expenditures have increased over the last decade, students' academic performance measured by mean SAT (Scholastic Aptitude Test) scores has almost remained the same. However, as Wainer (1992) changed the scales of the two y axes separately, the graph suggested an opposite interpretation that students' mean SAT score has increased substantially when the expenditures for education remained constant. As a result, there seems more than one appropriate way to determine the scale of a graph and one that largely depends on the situations in which the graph is used.

Furthermore, some mathematical practices such as differentiating or integrating functions allow physicists to "amplify" or even "create" signals (Roth & McGinn, 1997). Without these techniques, some phenomena cannot be seen or even do not exist. When graphs are used as the evidence to support claims or justify arguments, to some extent, scientific reality is constructed through inscriptional practices (Knorr-Cetina, 1981; Knorr-Cetina, 1983). Therefore, graphs not only depict a functional relationship descriptively, as portrayed by researchers from an individual cognition perspective, but also serve as rhetorical devices to elaborate texts, direct readers' attention to certain information, and support arguments that are intended to make (Lynch & Woolgar, 1990). According to the view of using graphs for rhetorical purposes, learning with inscriptions need to go beyond an "operational level" (Greeno & Hall, 1997, p. 366). Not only do students have to learn to create inscriptions accurately by following conventions, but they also need to realize that the meanings of these potential inscriptions depend on their interpretation.

Therefore, students' graphing competence is evaluated "on the extent to which they participate in specific practices as described by their status along a trajectory from legitimate peripheral to core participation" (Roth & McGinn, 1997, p. 101). That is, in addition to assessing students' graph skills of constructing inscriptions of given information, from this social practice perspective, researchers in science education should evaluate the degree of students' participation in graphing practices promoted by a designed learning environment and examine students' learning trajectories as they become competent in enacting scientific practices (Bowen et al., 1999; Roth & McGinn, 1997; Roth & McGinn, 1998). These practices serve social purposes and include constructing graphs as evidence to support arguments, generating meanings from graphs, and schematically choosing appropriate graphs for scientific reasoning.

Chemical representations: Conceptual Construct and Mediational Tool

Conceptual construct

In the research that stressed conceptual understanding from an individual cognition perspective, students' abilities to interpret, construct and translate these inscriptions are used as an indication of understanding concepts (e.g., Ben-Zvi, Eylon, & Silberstein, 1986; Ben-Zvi, Eylon, & Silberstein, 1987; Gabel, Samuel, & Hunn, 1987; Krajcik, 1991; Nakhleh, 1992). For instance, in Ben-Zvi, Eylon, and Silberstein (1988), students were asked to interpret chemical formulas. As a majority of students were unable to use conceptual terms (e.g., atom and molecule) for interpretation and tended to generate some macroscopic descriptions of a compound (e.g., its physical properties) while viewing chemical formulas, (Ben-Zvi et al., 1988) concluded that students did not have an conceptual understanding of the nature of matter. In Ben-Zvi's study, chemical formulas were regarded as conceptual constructs that convey information of atoms, molecules, and the quantitative composition of a compound, so they could be used as an instrument to evaluate students' understanding of chemical concepts.

Additionally, Keig and Rubba (1993) found that students' ability to translate between different kinds of inscriptions in chemistry (i.e. electron configuration, ball-and-stick model, and chemical formula) were correlated with students' prior knowledge of relevant concepts. The analysis of interviews indicated that the most common translation errors made by students were caused by a lack of content knowledge. This study indicated that chemical representations convey conceptual information and that students' understanding of underlying concepts is correlated to their ability of making translations.

This line of studies indicates that constructing, translating, and interpreting chemical representations require certain amount of conceptual knowledge in chemistry, and suggests possible interactions among mental models, conceptual understanding, and external inscriptions. Canonical inscriptions used in chemistry, e.g., chemical formulas, structural formulas, or chemical equation, are portrayed as conceptual constructs used to represent chemical concepts symbolically and visually. However, as the conceptual aspect of chemical representations became the main focus of this line of studies, the question of how chemists use these inscriptions in their daily practices was unanswered.

Mediational and cultural tool

From a social practice perspective, Kozma (2000c) showed that in addition to conveying the conceptual information, chemical representations play a central role in scientific practices. Chemists not only understand concepts and theories underlying inscriptions, but also use a variety of inscriptions to make predictions, explanations and justifications in their daily practices. Kozma and his colleagues defined "representational competence" as a set of observable behaviors that include: generating inscriptions to express ideas; using microscopic and symbolic inscriptions to explain phenomena and make predictions; using appropriate inscription for a given task; and using various inscriptions for communication in a social context (Kozma et al., 2000; Kozma & Russell, 1997).

Furthermore, based on the findings of their observational study, Kozma et al. (2000) argued that inscriptions are mediational tools as well as communicative resources that were constructed to link visible phenomena or substances to unseen chemical entities, such as atoms and molecules. Progress in theory and experimentation could be made by the invention of a new inscriptional system (Hoffmann & Laszlo, 1991). Inscriptions and their associated inscriptional systems allow scientists to think and communicate their ideas of scientific phenomena (Kozma, 2000c). Notation systems (e.g., electron dot structures and chemical formulas) and technological tools (e.g., machines to produce NMR or ultraviolet spectra) are examples of inscriptional systems. With the creation of symbolic expressions provided by a new inscriptional system, such as chemical formulas and molecular structures, chemists have moved the discipline of chemistry beyond a science of substances to the modern science of molecules. Technological tools also provide new symbolic expressions and formats (e.g., various types of spectra) that make many invisible processes and entities accessible. These conventional and tool-based inscriptions create a chemical reality to substances as well as conceptual entities which otherwise do not exist. Thus, Kozma (2000c) stated that "the use and understanding of a range of representations is not only a significant part of what chemists do—in a profound sense it is chemistry" (p. 15).

Chemical representations, which are socially accepted constructions, allow chemists to have a common language for their joint inquiry (Nye, 1993) and serve as tools to conduct science investigations, to communicate with professional community members, and to confirm their membership (Kozma et al., 2000). Nowadays chemical representations, such as formulas, symbols, equations, and structures, are widely seen in professional journals and paradigmatically used to describe and explain chemical reactions and phenomena. Therefore, understandings of chemical representations are observable and tie to the situated use of them across tasks and contexts. This social practice approach suggests that to support understandings of symbolic inscriptions and related phenomena, students should be encouraged to participate in inscriptional practices (e.g., using chemical representations to describe observed phenomena) that are similar to activities in the community of practitioners (Brown et al., 1989; Kozma et al., 2000; Roth & McGinn, 1998).

Types of Inscriptional Practices in Science

According to how scientists use inscriptions for investigations, types of inscriptional practices scientists enact in their daily practices could be identified. First, scientists use tools or instruments to *construct* and generate inscriptions for various purposes, such as organizing data and highlighting information. These instruments (Latour, 1990) could be paper and pencil, computers, or machines that generate, record, and transform signals or readings into a materialized form.

Next, scientists read and *interpret* inscriptions. When constructing inscriptions is to transform a phenomenon or a conceptual entity into another form, interpreting could be viewed as a reverse process of construction (Latour, 1987). It is a process of generating meanings out of an inscription and reconstructing the phenomenon or concept that is represented by the inscription. Yet, the provider (or constructor) and the reader of an inscription are not always the same person. This increases the difficulty interpreting an inscription. Also, as discussed previously, some inscriptions, such as chemical formula, convey substantial conceptual knowledge, so interpreting them requires understandings about concepts. Therefore, students' competence in interpreting chemical representations and their conceptual knowledge mutually influence or co-evolve one another (Kozma, 2000c). As in Barab et al. (2001a), students' emerging understandings about a phenomenon involve close interactions among model-related practices, conceptual knowledge, and prior experiences.

A third type of inscriptional practice is *reasoning*. Scientists demonstrate various ways to reason about and with inscriptions (Bowen et al., 1999; Kozma et al., 2000; Roth & McGinn, 1998). They use inscriptions to generate hypotheses, make predictions, elaborate ideas, construct evidence, justify arguments, and make conclusions. These reasoning processes may involve resources that could be material (e.g., a visualization tool), social (e.g., supports from peers or teachers), or linguistic (e.g., supports given by discourse as shown in Kozma et al. 2000).

As inscriptions are constructed, scientists have particular concepts, instruments, beliefs, and value systems to *critique* and determine the quality or accuracy of inscriptions (Schank, 1994). Similarly, within a learning community, students need to generate (or be introduced by teachers) criteria to evaluate the quality of inscriptions that are consistent with those used in the scientific community (diSessa, Hammer, Sherin, & Kolpakowski, 1991). Thus, the processes of generating criteria and critiquing each other's inscriptions are regarded as critiquing practices in this study.

Students' Learning of Inscriptions

In additional to different views on what counts as understanding inscriptions, the two theoretical perspectives hold different ideas about what factors influence students' understanding of inscriptions. These ideas lead to different interpretations for students' alternative conceptions.

Understanding of Inscriptions and Cognitive Skills

As graphs typically represent the quantitative attribute of concrete objects, they could be regarded as a bridge between concrete (e.g., objects and situations) and formal operations (e.g., numbers, scale and lines) (Berg & Phillips, 1994; Mokros & Tinker, 1987). Hence, it is reasonable to suspect that students' graphing skills are affected by their cognitive development and logical reasoning skills. Wavering (1989) was one of the studies that attempted to correlate students' graphing ability to their logical reasoning skills (Berg & Phillips, 1994; Bohrens, 1988; McKenzie & Padilla, 1984). One hundred and fifty students in grades six through twelve participating in Wavering's study were asked to make a graph from a given set of numbers and to describe the reasons for why they chose to make a graph. Students' responses were characterized into nine categories, which closely followed Piagetian stages of development (i.e., preoperational reasoning, concrete operational reasoning, and formal operational reasoning). The result showed that students in higher grades appeared to score mainly in upper categories. Namely, students in higher grades tended to have mental structures of logical reasoning and better performance on graphing. Wavering concluded that logical reasoning was necessary to make graphs.

This age-related difference in graphing skills was further supported by Berg and Phillips (1994). In their study, 72 students in grades seven, nine, and eleven were administrated individual Piagetian tasks to assess their mental structures related logical reasoning and interviewed to construct and interpret numerous graphs of varying content and difficulties. They found that students who possessed logical thinking structures were more able to interpret or construct graphs correctly. According to their studies about students' graphing skills, Berg and Smith (1994) concluded that logical thinking structures were "mental tools for students to engage in a high level construction or interpretation of graphs"(p. 549).

Two major problems in working with graphs have been documented: 1) a graph-as-picture confusion and 2) a problem with scaling graph axes (Clement, 1986; Leinhardt, Zaslavsky, & Stein, 1990; Mokros & Tinker, 1987). Students usually see a line graph as a pictorial drawing. For example, instead to interpreting the slope as a functional relationship between distance and time, students view it as a representation of an incline or a hill. This graph-as-picture confusion could be attributed to a lack of logical thinking reasoning and is caused by a tendency of interpreting a visual display perceptually. When students develop the logical reasoning structure mentally, "logic overrides perception" (Berg & Phillips, 1994, p. 339) that helps students to interpret beyond perceptual cues. In other words, without the cognitive development of logical reasoning, students depend upon their perceptions and low-level thinking to interpret graphs. Similarly, scaling axes requires proportional reasoning. Berg and Phillips (1994) found a significant correlation between students' development of proportional reasoning and their performance on questions that addressed scaling or comparing scales. They concluded that the origins of graphing difficulties were students' deficient logical thinking abilities.

Understanding about Inscriptions and Inscriptional Practices

As the two graphing conceptions were common from students at the middle school level to college students, Barclay (1986) argued that graphing ability was not simply an issue of developmental cognition. The age-related differences among students might be attributed to the amount of class instruction students received as students in higher grades had more experiences in graphing. Roth (1996b) challenged the view of graphing as a composite of individual cognitive abilities by showing that under the circumstances, eighth graders even demonstrated higher graphing competence than university graduates did. In Roth's studies (Roth, 1996b; Roth, McGinn, & Bowen, 1998b), scientists, preservice teachers who had undergraduate or master degrees in science or mathematics, and eighth graders were displayed a map with 5, 8, or 17 pairs of measurements and asked to indicate whether there was a pattern between two variables and to provide supports for their claims. All scientists, as expected, graphed the data, indicated the outliers, did analysis, and provided mathematically sophisticated solutions. As it was assumed that higher logical thinking skills led better performance on graphing, surprisingly, only 19% of preservice teachers provided answers with graphs and correlational analysis, while 48% of the pairs of eighth graders used graphs and correlational techniques to support their answers. Additionally, a qualitative comparison showed that the solutions provided by the eighth grade pairs were more mathematically sophisticated than the ones given by preservice teachers.

From the view of graphing as cognitive abilities, the findings in Roth's studies could lead to an interpretation that preservice teachers had relatively lower reasoning abilities than eighth graders. However, it seemed unlikely that these preservice teachers who had undergraduate or master degrees in education, science or mathematics did not possess mental structures of logical thinking or proportional reasoning. To obtain an alternative interpretation for these findings, therefore, Roth and his colleagues (Roth, 1996b; Roth & McGinn, 1997; Roth & McGinn, 1998) argued that science education researchers should consider adopting the social practice perspective. This perspective emphasizes the importance of creating a social context where students engage in inscriptional activities (Brown et al., 1989). While these preservice teachers had little or no experiences in conducting scientific research, the eighth graders designed experiments, collected data, and reported findings with convincing inscriptions including graphs and diagrams in a long-term ecology unit (Roth & Bowen, 1994). These students made links between situations and inscriptions by generating their own inscriptions within a group, using inscriptions to demonstrate their thinking process, and presenting inscriptions to convince their peers. Compared with the preservice teachers, these eighth graders were more involved in graphing practices in the way scientist did. Thus, Roth and McGinn (1998) concluded that inscriptional competence was not influenced by the logical thinking skills but opportunities students had in a social context where they engaged in inscriptional activities.

This social practice approach was also suggested by Kozma et al. (2000). They argued that students should be encouraged to participate in inscriptional practices within a knowledge-building community (Scardamalia & Bereiter, 1994). Inscriptional practices could develop students' inscriptional competence as well as achieve a better understanding of scientific concepts. Rather than emphasizing cognitive abilities, Kozma et al. (2000) recommended inscriptional competencies including inscription-related reasoning (e.g., conjecturing, justification, using evidence) and discursive practices (e.g., discussing, questioning, and critiquing) that could be developed through social interactions in classrooms. Several modeling tools or visualization tools are designed to encourage students to engage in inscriptional practices (Barab et al., 2001a; Gordin & Pea, 1995; Zhang, Wu, Krajcik, Fretz, & Soloway, 2001).

According to this social practice perspective, students' scaling errors and graph-as-picture confusion are caused by the inexperience in inscriptional practices rather than by the lack of mental abilities (Roth & McGinn, 1997; Roth & McGinn, 1998). Studies from an individual cognition perspective asked students to make inferences in a domain where they had little prior knowledge and few opportunities to engage in relevant representation practices. It is not surprising that students tend to interpret graphs literally. Even scientists encounter difficulties and generate inaccurate interpretations when they are unfamiliar with the context of the inscribed (Roth, Masciotra, & Bowen, 1998a).

Therefore, inscriptional competence is not simply dealing with technical or visual elements of inscriptions; instead, it is grounded in layers of embodied knowledge developed from conceptual knowledge, personal experiences, epistemological position, and relevant rhetorical practices (Kozma et al., 2000; Roth & McGinn, 1998). Many of students' confusions (or alternative conceptions) are caused by the ways in which the inscriptions are introduced and learned in classrooms. Inscriptions are traditionally taught as canonical scientific constructs that could be created accurately by following a set of rules. However, inscribing is more than creating a visual display. Where, when, why, and in what ways inscriptions are used largely depends on the context, so the design of learning environment should enable students to use inscriptions in open-ended and flexible ways (Greeno & Hall, 1997). Additionally, establishing the relationship between an inscription and its referent requires a considerable amount of situated work and social interactions. When inscriptions are traditionally taught as ready-made-science in a science classroom, the social and contextual factors involved in representing activities are combined into a straightforward and self-evident relationship between an inscription and its referent. Without opportunities of experiencing the iterative and social processes in which inscriptions were originally constructed, it is difficult for students to reconstruct the canonical meanings of inscriptions.

Furthermore, inscription-related activities need to be valued within a knowledge-building community. Within a community, not only do members pursue individual meanings to enhance their individual cognition, but they also construct social meanings to become members of a group (Kelly & Chen, 1999). Roth's notion of "cultural accomplishment" suggests the importance of social interactions within a learning community through which students' inscriptional competence was supported and accelerated. As graphing becomes part of culture or norm in a class, activities associated with graphing constitute membership. As in Kozma et al. (2000), using scientific inscriptions is a way for scientists to confirm their membership in the professional community. A simple survey conducted by Lemke (1998) showed that among 20 articles from two issues of Physical Review Letters, the average number of graphics used per page is 1.2. Among the technical reports published by Science, the average number of graphics per page is even higher (2.5 per report). Therefore, using scientific inscriptions is an integral part of scientific practices that should be promoted in science classrooms.

Students' Development of Competent Inscriptional Practices

The studies from an individual cognition perspective identified students' alternative conceptions and helped practitioners and researchers realize the difficulties students may encounter while learning inscriptions. This research tradition, however, provides relatively less information about the process of how students develop their inscriptional competence (or alternative conceptions). Additionally, when students' learning difficulties are attributed to their developmental stages, it seems that not many instructional methods or strategies can be used to facilitate students' learning, except accelerating their cognitive development. In this sense, a social practice perspective provides more insights into how to reengineer a learning environment in order to improve students' understandings of inscriptions.

Within a learning environment, social interactions are not only a catalyst for cognitive development, but also influence the learning products (Cobb & Yackel, 1996), which are increasingly sophisticated ways of representing scientific knowledge (Roth & Bowen, 1995). In this environment, teachers and students are community members who create particular ways of talking, thinking, and interacting, which shape and are shaped by their inscriptional activities. Their social interactions and class discourse processes become rule-driven (Bloome & Egan-Robertson, 1993) to allow and exclude what and how scientific inscriptions are practiced, constructed, and intertextually connected through class interactions (Kelly & Chen, 1999). From this social practice perspective, therefore, meanings of inscriptions and inscriptional activities are co-constructed by community members including students, teachers and sometimes learning tools (Kelly & Crawford, 1996). Some studies have shown that teachers' discursive strategies would play an important role in establishing a culture of classroom that promotes certain class activities to happen (Tabak & Reiser, 1999).

Nevertheless, as this social practice perspective regards a group of students as a local knowledge-building community, significant differences between a local learning community and a professional community of scientists should be acknowledged. The first difference is between the tasks (and activities) conducted in a science classroom and the ones in a science laboratory. Students at the secondary school are unlikely to conduct the investigations documented by science studies (e.g., Knorr-Cetina, 1983; Lynch & Woolgar, 1990). This difference may qualify the implications that science education researchers derive from these science studies.

Secondly, based on the expert and novice studies (e.g., Chi & Feltovich, 1981; Kozma & Russell, 1997), scientists and students demonstrate different ways of using strategies, solving problems, and applying knowledge due to different levels of understandings in scientific concepts and processes. Students are not able to, for example, transform one inscription into another as fluently as scientists (Kozma & Russell, 1997). Students need more resources and preparations to support their development of inscriptional competencies (Kozma, 2000a). Thus, educational research that investigates what resources students need in order to engage in inscriptional practices will advance the understandings of how to help students learn inscriptions.

Finally, the norms developed by a learning community in educational settings could match as well as clash with those in the community of professional scientists. Inscriptions, for example, generated and recognized by a learning community might be not accepted by the disciplines of science. This, in turn, could be a barrier for students to enter into the community of scientists. Hence, the cultural negotiation process (Bruner, 1990) between a local group and the community of scientists should be seriously considered when a class is regarded as a cultural community. Knowledge and practices generated within the disciplines of science do not directly enter into a middle school science classroom. They are interpreted and brought into a classroom by social mediators, such as teachers, curriculum designers, and science educators, who initiate and socialize students to the norms and expectations of the scientific community and help students develop science literacy (Kelly & Green, 1998). At the classroom level, therefore, a teacher plays a critical role in constructing a learning community that allows students to experience "what scientists do" based on her understandings of the disciplines of science. The question facing teachers and educators then becomes: "how, in what ways, under what conditions, and with what outcomes will *students* and *scientific knowledge* and *practices* come together?" (original emphasis, Kelly & Green, 1998, p. 156). A similar question is asked in this study: How, in what ways, under what conditions, and with what outcomes do students use inscriptions in a science classroom and engage in inscriptional practices that approximate to how scientists do? To answer the question, this study characterizes what inscriptional practice students engage in and how the features of a learning environment (including teachers' instruction and scaffolding) support them to do so.

Summary

By reviewing the related literature of students' learning of inscriptions, in previous sections, I displayed the research perspectives that undergrid this study and described the assumptions, values, and educational implications that come with these perspectives. This review suggests possible directions to investigate students' development of inscriptional practices.

In my discussion of the relationship between an inscription and its inscribed, I indicated that both sides of science—science-in-the-making and ready-made-science—should be practiced in school science in order to help students establish and understand the relationship. That is, in a science classroom the rules and conventions about an inscriptional system should be introduced and applied in a variety of inscriptional activities across different contexts. This notion of two sides of science raises several questions related to this study: Are the rules about an inscriptional system introduced and practiced across different contexts in an-inquiry based classroom? How are the rules presented by teachers and practiced by students? Do the ways that teachers present the rules and frame the inscriptional activities shape students' development of inscriptional practices?

Additionally, I analyzed the roles of inscriptions in scientific practices and based upon the analysis I categorized different types of inscriptional practices. The analysis allows me to indicate the differences between students' use of inscriptions to scientist's use of them (as will be showed in Chapter 5), and the categorization provides an initial scheme to portray and characterize students' inscriptional practices (described in detail in Chapter 3).

Furthermore, according to the research on students' learning of inscriptions, several factors (e.g., cognitive skills, conceptual knowledge, and participation in authentic inscriptional tasks) might interact with students' understandings of and about inscriptions. Without the data of students' cognitive skills, this study focuses on students' participation and their conceptual knowledge involved in inscriptional activities within a learning community. In addition, there are significant differences between a local learning community and a professional community of scientists. These differences suggest that students need preparations and resources in order to engage in inscriptional practices and that teachers play an important role in constructing a learning environment where students could experience "what scientists do." This indicates a need to investigate a question of "what aspects of the learning environment help students create various inscriptions and develop inscriptional practices?"

Expanding upon my review, in the following section, I present a conceptual framework that is used to analyze students' learning of inscriptions.

The Nature of Inscriptional Practices

The focus of this study is on students' inscriptional practice. To conceptualize this construct, I develop a framework that provides definitions of practice and other related constructs. The conceptual framework is the lens that guides interpretations of my observations. The premises underlying this conceptual framework are drawn from science studies and social theories of learning.

Competence, Practice and Participation

Competence is the quality of having sufficient skills, knowledge or experiences. According to Lave and Wenger (1991), "the mastery of knowledge and skill requires newcomers to move toward full participation in the sociocultural practices of a community" (p. 29). Thus, students' inscriptional competence could be determined by the degree of participation in inscriptional practices of a learning community (Bowen et al., 1999). This determination of competence involves three theoretical constructs—practice, participation, and community.

Practice is not just doing of itself and does not exist in isolation; it is doing in a social and historical context that gives the shared resources, structures, meanings, and perspectives to what individuals do (Wenger, 1998). In educational settings, the curriculum design and classroom instructions are aligned with the history of disciplinary knowledge interpreted by curriculum designers and teachers. Therefore, both the classroom history and the history of disciplinary knowledge constitute the historical context in a science classroom. Practice in a context involves explicit instruction, implicit relationships, subtle cues, underlying assumptions, and embodied understandings that are shared with and co-constructed by members in a community (Wenger, 1998). To study the historical development of inscriptional practices in education settings, therefore, I need to analyze relevant events in the history of a class and regular social interactions among class members in order to interpret the meanings and purposes of their practices.

Newcomers of a community cannot realize the explicit and the tacit practices unless they participate in it. There are different degrees of participation defined by a community (Lave & Wenger, 1991). In this study, full (or central) participation is identified when students engage in inscriptional practices purposely and meaningfully. By "purposely," I mean that students recognize when, where, and in what ways scientific inscriptions are used. Students' recognition could be captured by classroom observations and interviews when they make statements about the goal of creating inscriptions. Also, because participation means taking part in an activity, students need to be agents of inscriptional activities and should be providers and/or users of inscriptions. For example, students are identified as becoming more competent in construction practices, as they are able to construct and/or provide more inscriptions for a given task with less support from the teacher.

Additionally, the inscriptions that students choose to use or construct could be either conventional or self-generated. The choices of types of inscriptions may interact with the purpose of using an inscription and influenced by the user or provider's prior experiences. As students are able to state reasons or elaborate ideas about why they choose certain inscriptions for a task, it indicates a development of inscriptional competence. Therefore, purposes, providers or users, and types of inscriptions are all related to each other when students participate in inscriptional practices, and become indicators for investigating inscriptional practices and competence.

Community and Social Norms

Community members create particular ways of talking, thinking, and interacting and share common missions and interests (Bowen, Roth, & McGinn, 1999). These particular ways of acting and common goals become social norms of the community that shape and are shaped by the communicative and interactional processes (Cobb & Yackel, 1996; Tuyay, Jennings, & Dixon, 1995). As a class is viewed as a learning community, examining classroom discourse and related social interactions could be a way to understand a class as a community (Rex, 1999). In this study, discourse is defined as "language-in-use" (Gee, 1999, p. 17) which includes both oral and written texts used in the classroom (Lemke, 1990). Social practices and discourses in a classroom are rule-driven to allow and exclude what and how scientific knowledge is practiced and constructed through class interactions. To become a community member, students participate in activities that are valued by the community, to confirm their membership. When constructing scientific knowledge in a class, members not only pursue individual meanings to enhance their individual cognition, but they also construct social meanings to become members of a group. Thus, to support students in demonstrating desirable actions or behaviors and achieving the mastery of skills or knowledge, a class needs to develop a culture or norms that signal the social meanings of these behaviors and skills.

In this study, to study how the classroom culture interacts with learning, the question of how the use of inscriptions becomes a socially meaningful activity instead of an isolated assignment or task in a historical and social context is addressed. According to a theory of practice, cognition and communication in and with the social world are situated in the historical development of ongoing activity. The qualitative data collected for this study provide rich information about contexts, social interactions, and cultural practices that constitute membership in a classroom learning community (Tuyay, Jennings, & Dixon, 1995).

Regular Instructional/Learning Sequence and Breakdown

To characterize social practices in a classroom, regular instructional and learning sequences involved in these practices are one of the primary concerns. By means of these sequences, the inscriptional practices get enacted. For example, when students begin to learn a new inscription, the regular instructional sequence of constructing practice could begin with teacher demonstration and follow with students' questions. As students are familiar with the construction of an inscription, the sequence of constructing practice may involve more back and forth dialogues among the teacher and students. Analyzing regular instructional or learning sequences could present how students' inscriptional practices change over time and provide insights into a question of why students are able (or not able) to develop some inscriptional competencies. Additionally, different classes might demonstrate different learning and instructional sequences of certain inscriptional practices that might indicate differences in teachers' expectations or scaffolds.

Moreover, by identifying regular sequences, the transient occasions (Rex, 2001) or breakdowns (Bowen, Roth, & McGinn, 1999) become salient. Transient occasions or breakdowns are interruptions of regular instructional and learning sequences, changes of the usual roles taken by community members, and changes of discursive patterns, which usually happen when teachers introduce the new content knowledge and skills or when students do not have sufficient skills or knowledge to engage in standard practices. For example, in Rex (2001), when the teacher recognized students' transformation of becoming a more competent reader, he shifted his actions and allowed students to step into the floor and to take up an authoritative role in interpreting the text. In this case, transient occasions indicate the emergence of a new identity of the students which is a more competent reader. Transient occasions and breakdowns could also indicate insufficient resources or a lack of common knowledge among members that provide possible explanations for students' learning difficulties.

Resources

Students could demonstrate expert-like behaviors when they have material or linguistic resources to support learning processes (Kozma, 2000b). Resources could be a piece of information, object, tool, artifact, or machine that participants use to carry out a practice (Kozma, 2000b; Roth, 1996b). For example, in Wu, Krajcik, and Soloway (2001), a visualization tool as a technological resource sustained students' engagement in interpreting practices of chemical representations. In additional to materials and technological tools, resources include those of a conceptual nature and those of a social nature. Understandings of the context become a resource as they allow students and scientists to interpret graphs (Preece & Janvier, 1992; Roth et al., 1998a). Linguistic distinctions provided by knowledgeable others that allow students to enact inscriptional practices could also be viewed as a type of resource (Bowen, Roth, & McGinn, 1999; Lemke, 1990). Resources afford students to accomplish tasks and to demonstrate inscriptional practices (Gibson, 1977; Roth, 2001). This focus on resources is particularly important for understanding how features in a learning environment promote students to develop competent inscriptional practices.

In the next chapter, I will discuss how I use the ideas and the framework developed in this chapter to analyze data and generate findings to answer the research questions.

CHAPTER 3

METHODS

This eight-month, classroom-based study aims to characterize students' inscriptional practices, trace their learning trajectories, examine the potential use of various scientific inscriptions, and analyze learning supports and resources provided by teachers and the learning environment. In order to accomplish these purposes, multiple sources of data are collected. In this chapter, I first discuss the overall approach and rationale of the research design. I then describe the context of this study and provide a detailed account about data collection and analytical procedures. Finally, I indicate the limitations of the study.

Overall Approach and Rationale

The review in Chapter two provides a conceptual foundation on which the study is built. As indicated in the summary of the review, my discussions about the studies from different perspectives suggest possible directions to investigate students' development of inscriptional practices (e.g., examining whether and how the two sides of science are presented and practiced, comparing students' use of inscriptions to scientists' use of them, documenting different types of students' inscriptional practices, and analyzing resources and supports provided by teachers and the learning environment). Although this study conceptually combines studies from different perspectives and is guided by the directions described above, because of the nature of my research questions and a lack of data about students' cognitive skills this study leans towards a social practice perspective methodologically.

In Chapter two I suggests several components to understand students' inscriptional practices. These components (i.e., participation, community, social norms, standard practices, and resources) constitute a conceptual framework and provide the guiding lenses for my data analysis. Guided by this framework, the study is a long-term, classroom-based investigation and aims to reveal students' performances, interactions, and practices in a social context. The framework regards students as members of a learning community and suggests that within and through the community, the content and meanings of inscriptions are continually renegotiated and coconstructed by the class members (including the teachers and students) as part of the learning process. To understand this dynamic and ongoing process of knowledge construction in a learning community, therefore, the methods I employ draw from a naturalistic approach (Lincoln & Guba, 1985; Moschkovich & Brenner, 2000). This approach have been taken by other studies to examine how students or scientists use inscriptions in real-life settings (e.g., Barab, Hay, Barnett, & Squire, 2001a; Kozma, Chin, Russell, & Marx, 2000; Roth & Bowen, 1994).

Naturalistic Approach

According to Lincoln and Guba (1985) and Moschkovich and Brenner (2000), there are three principles for conducting a naturalistic study. First, it is critical to study cognitive activities in context. In this study, context refers to the relationship between an environment (both social and physical) and participants' interpretations of this environment, including the meanings of actions and shared practices (Lave, 1988). Due to its interpretive nature, “context is experienced differently by different individuals” (Lave, 1988, p. 151). Learning and cognition within a set of practices are situated and happen to occur in particular physical and social settings (Lave & Wenger, 1991). Namely, aspects or structures of the particular physical and social settings allow certain cognitive activities to occur in a classroom. My deep familiarity with the settings, teachers’ teaching styles, and regular interactions among students and teachers becomes a basis for interpreting situated cognition in contexts.

The term “naturalistic” suggests that one way to capture participants’ cognitive activities in context is to analyze their behaviors in “natural” settings without any interventions. As Moschkovich and Brenner (2000) indicated, however, “it is more important to consider and describe in detail the characteristics of the setting and how they might impact cognition and learning” (p. 463). To study a specific aspect of learning and teaching, researchers could integrate a structured situation into a natural setting that maintains the integrity of the natural setting. This technique is consistent with the principles of the design-experiment methodology. For example, in this study, the use of a computer-based modeling tool, Model-It, could be seen as an intervention as well as part of a natural setting. Model-It was designed to promote modeling practices (Zhang, Wu, Krajcik, Fretz, & Soloway, 2001) and the use of it was associated with a large research project. The use of Model-It became a research intervention compared to other regular classroom activities. On the other hand, the science curriculum, which emphasized the importance of using technology for science learning, was developed by the teachers and informed by university researchers. Using Model-It was consistent with the features of the curriculum and promoted the use of technology to become a recurrent theme in the learning process. In this sense, using Model-It was "natural" to the classes and the curriculum. Hence, it would be more meaningful for the study to indicate how and when the use of Model-It was situated in a project, rather than arguing whether the setting with or without Model-It is more "natural."

Secondly, it is important to consider multiple points of view of events. A naturalistic approach assumes that meaning is constructed by both participants and observers so they may generate different interpretations about what is happening inside a classroom (Lincoln & Guba, 1985). These multiple ways to interpret the same classroom event are shaped by both theoretical and value frameworks of the participants and observers. Thus, a research study could never achieve pure objectivity (Howe, 1998). The goal of this study is to identify the variety of theoretical constructions (e.g., practices, participation, and community) and converge them towards as much consensus as possible (Guba & Lincoln, 1994). In doing so, I collect and analyze multiple sources of data to triangulate my interpretation of an event. For example, to investigate students' constructing practices, I trace student-teacher interactions in classroom activities, group discussions, and teachers' feedback on students' science reports.

Additionally, to examine unexpected practices demonstrated by students and to avoid a traditional assumption that there is only one correct way to do science, in this study, I try to understand students' practices inside a learning community as much as possible prior to comparing them to those of scientists. I share my data analyses and findings with the teachers and pursue the meanings of community members before comparing them with an ideal model held by experts. Also, I realize that the theoretical lenses I use to examine classroom activities are standards for data collection and analysis

(Emerson, Fretz, & Shaw, 1995). I make them explicit in my theoretical framework as well as in my descriptions of the data collection process.

Finally, it is necessary to verify existing theoretical frameworks as well as generate new theories to move the field forward (Moschkovich & Brenner, 2000). My observations in the classroom are guided by research questions and learning theories. In my discussions of the theoretical framework, I situate this study in a tradition of related research. I identify types of standard inscriptional practices from the literature (e.g., construction, interpretation, reasoning, and critiquing) and use them to analyze the data. In addition to examining the types of inscriptional practices that have been discussed by the literature, this study explores the unexpected practices of middle school students' understandings about inscriptions and the social and material supports from a learning environment that allow certain inscriptional practices to happen. Through this exploration, this study expands the theories that have been established with the participation of college students and scientists.

Overall Approach of the Study

Drawing on a naturalistic approach, this study uses the following strategies to conduct the qualitative research. First, this study investigates cognitive activities in a classroom context instead of laboratory contexts and views aspects of a learning environment as interdependent components. Next, to have multiple views of an event, I gather different types of data to investigate the research questions and allow a consensus of an event to emerge from a repeated review of data. Thirdly, I realize that a learning environment involves various factors influencing students' learning, so I consider interactions of multiple variables in the classroom (e.g., practices, inscriptions and teacher's teaching experiences) and do not attribute the learning effects to certain variables in the classroom. Furthermore, although this study itself does not involve an iterative process described by the design experiment methodology (Brown, 1992; Collins, 1999), this study could also be used as a baseline study for future design experiments. Finally, one goal of this study is to expand current theories about how students learn inscriptions and provide educational implications for developing a learning environment that promote students to demonstrate competent inscriptional practices.

Trustworthiness Features of the Study

The assumptions underlying the naturalistic approach, such as constructing multiple interpretations of a given event and giving up the notion of controlling variables, raise issues about the objectivity and credibility of the research. To ensure the quality of this study, I use a set of standards and strategies suggested by Moschkovich and Brenner (2000). Using Lincoln and Guba's (1995) four dimensions with other researchers' recommendations (e.g., Jick, 1979), Moschkovich and Brenner (2000) reframed the traditional concepts of internal validity, external validity, reliability, and generalizability into credibility, transferability, dependability, and confirmability (Table 3.1).

Credibility (Internal validity)

Credibility (or in the traditional term, internal validity) is defined by "how well the results capture the constructs used by the participants in a context and the particular dynamics of that context" (Moschkovich & Brenner, 2000, p. 479). There are several strategies that could be used to assure that the data and findings record the primary features of the phenomena under study. The first strategy is prolonged engagement. Researchers need to spend enough time in the settings to avoid distortions that occur due to unusual events, such as the presence of the researchers. Secondly, to achieve adequate depth in the phenomena under study, persistent observation is necessary which involves taking an analytical view of the data, searching for significant patterns, and looking for information to confirm or disconfirm the emerging understandings about the phenomena. A third strategy, triangulation, could be achieved by using multiple sources of data, so the interpretations of a phenomenon could be confirmed by more than one type of data. Finally, member checking is a useful technique to minimize the research bias and pursue participants' meanings of practice.

To achieve the credibility, I observed the two classes for eight months and collected multiple sources of data. When analyzing data, I reviewed the data corpus repeatedly to search for confirming and disconfirming evidence for findings. Each finding is warranted by multiple sources of data. For member checking, I shared my data analyses and findings with the teachers and based upon their feedback, I modified my interpretations about what was happening in the classes. Table 3.1 indicates how I adapt these strategies to enhance the credibility of the study.

Transferability (External validity)

In the traditional framework, research studies are expected to have high applicability (or external validity). It means that the results obtained from a given study, regardless of the specific sampling or context, hold in a larger population. Because a naturalist or a design-experiment study concerns about phenomena that happen in a specific context, Lincoln and Guba (1985) argued that it is not the researcher's task but the reader's to decide whether and how the results may be relevant to his interested topic or context. Yet, as the following two strategies suggest, the researcher is responsible to describe the research process in sufficient detail that allows the reader to make such decision.

Table 3.1

Standards of Quality for Naturalistic Research Studies

Dimension of quality (Lincoln & Guba, 1985)	Truth value	Applicability	Consistency	Neutrality
Traditional term	Internal validity	External validity Generalizability	Reliability	Objectivity
Naturalistic term	Credibility	Transferability	Dependability	Confirmability
Definition	How well the results capture the constructs used by the participants in a context and the particular dynamics of that context.	How well the results obtained from a given study, regardless of the specific sampling or context, hold in a larger population.	How well the same results could be duplicated if a researcher outside the project conducts a study under the same circumstances.	How well the biases of the researcher could be eliminated in the process of research.
Sample strategies for a naturalistic study (Moschkovich & Brenner, 2000)	Prolonged engagement Persistent observation Triangulation Member checking	Thick description Purposeful sampling	Audit trail Multiple researchers Recording devices	Audit trail Research's role defined
Trustworthiness features of this study	Observing the classes for eight month. Taking fieldnotes including theoretical comments on the use of inscriptions in the classes. Collecting multiple sources of data. Generate assertions across multiple sources of data. Asking the teachers to comment on drafts of the findings.	Providing detailed descriptions of the setting. Providing detailed descriptions of data analyses. Selecting the research site and target students purposely.	Providing detailed description of the process of research. Inviting other researchers to selectively examine temporary research assertions. Using recording devices to capture classroom activities.	Providing detailed description of the process of research. Describing the role of the researcher.

To establish the transferability of a naturalist study and help readers to decide its applicability, Mosckovich and Brenner (2000) suggested two strategies: Thick description and purposeful sampling. Thick and detailed descriptions of the settings, data collection, and analytical procedures allow the readers to make judgments about applicability of the presented study. Additionally, a naturalistic study has less intention to represent a larger population randomly. To assure that the sources of data provide necessary information to answer research questions, naturalistic researchers choose a sample purposely, describe procedures of sampling, and provide a rationale behind it. For example, this study relies on students' conversations to understand their reasoning process, so a student's ability to verbalize their thinking process was one of the factors to determine whether she could be a target student of the study. Other factors included students' gender (having equal numbers of boys and girls) and academic achievement (having students from average to high learning achievement). Therefore, instead of assigning target students randomly, the teachers and I nominated them after a two-week observation.

Dependability (Reliability)

The third dimension, dependability, means that if a researcher outside the project conducts a study under the same circumstances, the same results should be found. To establish the dependability of the study, researchers should document the process of research in detail and report the decision-making processes, particularly in data analyses. These detailed and logical descriptions of the research process constitute an "audit trail" that allows other researchers outside the project to scrutinize the study. Another way to eliminate research bias and increase the dependability is having multiple researchers analyze the same set of data. In addition, by using audio or video recording devices, qualitative data could be collected in detail, instead of relying on the researcher's memory or fieldnotes. This in turn would achieve the dependability of certain types of data, such as descriptions of classroom activities.

In this study, I apply these suggested strategies to increase the dependability of the study (see Table 3.1). I provide detailed descriptions of settings, data collection and data analyses. The findings and analyses are reviewed by another researcher and teachers. Also, all qualitative data were collected by using audio or video devices that allow me to re-examine my descriptions of class events.

Confirmability (Objectivity)

The fourth dimension, confirmability (or objectivity), addresses a concern about how the biases of the researcher might be involved in the process of research. To present how a researcher deals with her biases, keeping an audit trail is a useful technique that allows other researchers to examine the assertions generated by data analyses. When research methods, such as interview or participant observation, are used, it is not possible to completely eliminate the effects of the researcher. Thus, it is important to define the role of the researcher and describe his participation in the research context. Because collecting absolutely "clean" or "neutral" data is unrealistic in a naturalistic study, describing the researcher's activities in the research site is more important to achieve the confirmability of the study. In the next section, I will provide a detailed account of the research process and my role in the research site.

Context

School and Science Program

The study is conducted in two seventh grade science classrooms taught by two teachers at an independent school in a Midwest university city. This school is a sixth to twelfth grade school with a student enrollment of approximate 75 students per grade. It is not a school for gifted students but does have an admission process that generally includes accepting students from the upper two-thirds of standardized test norms.

This school was chosen as a research site because there existed a relationship between the teachers and university researchers. Additionally, based on my previous research experience with them, I expected to see a range of inscriptions used in the site. The teachers in the science program have been working with university researchers to develop and implement interdisciplinary, integrated, project-based science curricula (Novak & Gleason, 2001). The goal of the program is to promote students to develop in-depth and integrated understandings of fundamental science concepts and process skills within a context of inquiry. During each school year, several science units are explored that incorporate fundamental science concepts across several science disciplines. Each unit begins with a driving question (Marx, Blumenfeld, Krajcik, & Soloway, 1997) that provides students with a real life context. Students collaboratively work with their group members and conduct a long-term investigation of the driving question and its related sub-questions. Teachers provide substantial supports as students engage in inquiry through activities such as asking questions, collecting data, analyzing data, presenting ideas, and generating conclusions (Krajcik et al., 1998). This instructional approach is consistent with the National Science Education Standards (National Research Council, 1996).

School Year

During the school year of 2000-2001, two science units, Water Quality unit and Decomposition unit were explored. Students experienced three rounds of data collection for the water quality unit in order to investigate the change of water quality over a year, so in this study the water quality unit is labeled as Water Quality I (WQ I in the fall season), Water Quality II (WQ II in the winter season), and Water Quality III (WQ III in the spring season). Figure 3.1 indicates the timing of the three sub-units.

Between these three water quality sub-units, students investigated decomposition and its related concepts. Both water quality and decomposition units were introduced based on the same instructional approach. Students were engaged in a similar inquiry process that involved asking questions, collecting data, analyzing data, presenting ideas, generating conclusions, and writing reports (Novak & Gleason, 2001). In this study, the intensive observations and data collection were made during the three water quality sub-units across the school year.

The Water Quality Unit

During each of the three seasons (i.e., fall, winter, and spring), students investigated the stream behind their school. The teachers used lectures, experiments, group activities, and videos to introduce students to key ideas in science, including fundamental concepts, the process of inquiry, collaboration, and the use of various technological tools (Figure 3.1).

School Year 2000-2001									
Sep. 2000	Oct. 2000	Nov. 2000	Dec. 2000	Jan. 2001	Feb. 2001	March 2001	April 2001	May 2001	June 2001
	WQ I					WQ II		WQ III	

WQ I											
Week	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Date	9/27- 28	10/2-5	10/10-13	10/17-18	10/24-27	10/30-11/3	11/6-10	11/13-17	11/27-12/1	12/7-11	1/8-11
Concept	pH	pH	Neutralization Buffers	Thermal pollution	Conductivity Eutrophication	Conductivity Turbidity D.O.			Topography Watershed		
Inquiry	Design pH experiment	Make predictions Create data table	Share data	Use and calibrate emate probes	Design conductivity experiment	Make observations	Make predications Collect data	Analyze data Share data Make conclusion	Drew maps	Construct model	Revise, present, critique models
Inscription	pH scale	Data table	Data table Chemical equations Chemical symbols		Data table	Stream drawing	Pictures Physical data sheet Table for standards	Data table Graphs	Map 3D watershed model	Computer-based model	Computer-based model
Field experience						Visit the stream	Visit the stream				

WQ II				
Week	Week 1	Week 2	Week 3	Week 4
Date	2/26-3/1	3/5-6	3/14-16	3/19-21
Concept				
Inquiry	Make predictions Collect data	Make graphs Analyze and share data	Construct model	Revise, present, critique models
Inscription	Data table	Graphs	Computer-based model	Computer-based model
Field experience	Visit the stream			

WQ III			
Week	Week 1	Week 2	Week 3
Date	5/21-25	5/29-6/1	6/4-5
Concept			
Inquiry	Make predictions Take pictures Collect data Analyze data	Create webpage	Create webpage
Inscription	Data table Graphs Digital picture	Webpage Digital pictures Graphs	Webpage Digital pictures Graphs
Field experience	Visit the stream		

Figure 3.1. Overview of the year-long water quality unit

Students asked questions about water quality and worked with one or two classmates. Student groups collaboratively designed and carried out a plan to investigate their assigned portion of the stream. They collected qualitative data based on their observations, made predications and then collected quantitative data by using a portable technology, emate. In writing science reports, they combined the data, analyzed them and made conclusions about the health of the stream. Concepts, processes, inscriptions, and field experiences that constituted their scientific practices in the water quality unit are shown in Figure 3.1.

Students and Teachers

Twenty-seven seventh graders participated in this study (N=27, 16 girls, 11 boys) and were taught by two teachers (Class I: 12 students, 8 girls; Class II: 15 students, 7 boys). The water quality unit was the first time that most of the students were exposed to the inquiry-based instructional approach. They were not familiar with the features of this integrated curriculum, including an emphasis on asking questions, long-term investigation, collaboration, and the use of technological tools. Among the participants, twenty-five of the students were Caucasians and two were Asian Americans.

In each class, two dyads (four students) were nominated by the teachers for intensive observation. These target students are nominated by considering their genders, academic achievement levels, and abilities to verbalize their learning process. According the school records, all of the target students were identified as Caucasians, although one of them had Asian Indian heritage. The two target dyads in Class I were the same gender groups (one girl group and one boy group) and formed by student self-selection, while the two dyads in Class II were mixed gender and formed by the teacher. Table 3.2 summarizes the information of the classes and target students.

Table 3.2

The Classes and Target Students

Class	Class composition	Target student	Gender	Academic achievement
Class I taught by Andrea	12 students	Cynthia	F	High
	8 girls, 4 boys	Smita	F	Medium
	12 Caucasians	Charles	M	Medium
		Stefon	M	High
Class II taught by Celia	15 students	Nathan	M	Medium
	8 girls, 7 boys	Olisa	F	High
	13 Caucasians	Ally	F	High
	2 Asian Americans	Denny	M	Medium

Class I was taught by Andrea[1] who had taught for ten years, had a Bachelor of Science (BS) with a major in broad field science, a minor in biology and health, and a Master of Art (MA) in adolescent development. Celia taught Class II and had 28 years of teaching experiences. She had a BS with a major in biology, a minor in chemistry, and an MA in special education. Both teachers had secondary science teaching credentials. The teachers regularly met before the first class period for planning curriculum, creating materials, sharing handouts and discussing students' progress.

As many teachers have experienced, different classes have different "personalities" due to the class composition, the class meeting time, and other reasons that may not be attributed to teachers' teaching styles and the curriculum design. This is true in the two classes I observed. While students are members of their science class, they are also members of other groups (e.g., other classrooms and social network). They

[1] Pseudonyms for teachers and students that maintain their gender are used throughout this paper.

bring their experiences, beliefs, knowledge and practices into the science class that match or conflict with the scientific practices promoted by the teachers and the learning environment (Santa Barbara Classroom Discourse Group, 1992; Kelly & Green, 1998). Because this study aims to reveal students' practices in a learning community, it is necessary to describe the class atmosphere as the background information. When analyzing data I foreground students' inscriptional experiences, knowledge and practices that were encouraged and shaped by the science learning environment.

Class I met during the first class period in the morning. This class was described as a "dream class" by Andrea, because students in the class always paid attention to given instructions, volunteered their ideas to Andrea's questions, and worked diligently when they were in groups. Andrea was called by her first name in the class, which was unusual for the seventh graders. The class atmosphere was relatively casual. Andrea rearranged the class tables every week and students changed their seats very often, although the four boys usually sat in the same table. Andrea allowed students to select their partners for conducting water quality investigation and formed the decomposition groups for them, so they could learn from working with different classmates. Four target students were Cynthia, Smita, Charles, and Stefon. Cynthia and Smita were partners and volunteered to be videotaped, and Charles and Stefon were nominated by the teacher (Table 3.2).

Class II met during the third class period in the morning before which was a longer break (15 minutes) that was either the "advisory" or "class meeting" time.[2]

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[2] At the time I collected data, seventh graders' advisory time was on Monday and Wednesday, and the class meeting time was on Tuesday and Thursday. The advisory time was seen as a social activity for most students during which students met with their advisor and other students advised by the same teacher and discussed some social topics. Students took turns bringing snacks to their advisory group. During the class meeting time, all seventh graders gathered together and the seventh grade advisors announced events or talked about important social and academic issues with them.

Students in Class II were highly motivated and actively participated in classroom activities, but compared with students in Class I they sometimes were involved in more social talks, particularly at the beginning of the class period or when they worked in groups. Two groups of students usually sat together. To encourage students to learn from working with unfamiliar classmates and prevent students from spending too much time on non-academic discussions, Celia formed the student groups and assigned seats once during the time I was collecting data. Two student dyads, Olisa and Nathan, Denny and Ally, were nominated by the teacher. The information of their gender and academic achievement can be seen in Table 3.2.

Role of the Researcher

Through the eight months of data collection, I attended every class period when the students had activities related to the water quality unit. I knew every student's names and chatted with different students during breaks. During the class I was an observer and a researcher conducting the study and did not participate in classroom activities, although I sometimes answered students' questions about the tasks they were supposed to do. When students used the modeling tool, created webpages, and used other computer software, I was a helper and interacted with them for their content questions and tool problems.

Technological Tools

The science curriculum developed by the teachers was integrated with learning technologies. Each science classroom was equipped with eight Apple iMac desktop computers with an AppleTalk network connection to servers and a laser printer, and a network that connected each machine to the Internet. The commercial software available on each machine was Microsoft®Office, Microsoft®Explorer, Netscape® Communicator, and Graphic converter. Each computer was provided for two to three students in class. Students were encouraged to do science investigations by using computers to gather information through telecommunications, analyze data, create scientific models, and write reports during the class, lunch time and work sessions.[3]

Portable technology

Portable technology named “emate” produced by Apple was provided when students investigated the water quality of the stream behind their school. emate looked similar to a small laptop computer with an 8 inch touchable screen, a plastic pen and a keyboard. Students attached different types of probes to the emates to collect water data, such as temperature, conductivity, pH value, and dissolved oxygen (DO). emate also had capabilities to save the data, graph the data, and create a data table. However, because of its short battery life and small memory students used the emates for only data collection. When students obtained a reading from the emate, instead of saving it, they immediately recorded it on their notebooks. Because Apple corporation stopped producing emates, the teachers were not able to purchase supplies to repair or upgrade their machines. Although the science program had more than 10 emates, at the time of collecting data only six emates worked and their working conditions were not stable. Most of seventh grade science classes had more than six student groups, so some groups needed to take turns using the emates.

[3] Every seventh grader had two work sessions weekly. These sessions were scheduled in the last two class periods from Monday to Thursday. During the session, students worked independently on their homework or course projects.

Digital Camera

Additionally, five Olympus® D-360L cameras were used to capture pictures of the stream. With six to seven groups per class, student groups took turns using the cameras. Students took pictures of their stream sections across three seasons. Teachers downloaded these pictures onto the teachers' computers from which students could have access to the files and save them to their group's computer through the school network. Students used these pictures to support their longitudinal analysis and results in their webpages.

Modeling Tool

The computer-based modeling tool used in the study was Model-It developed by the Center for Highly Interactive Computing in Education (http://hi-ce.org) at University of Michigan (Jackson et al., 1999). Model-It was designed to support students, even those with only very basic mathematical skills, as they build dynamic models of scientific phenomena, and run simulations with their models to verify and analyze the results. This learning tool scaffolds students' modeling process with three modes—Plan, Build, and Test.

In the Plan mode (Figure 3.2), students create, define, and describe objects (e.g., stream, plants and people) and qualitative or quantitative variables associated with specific objects (e.g., the water temperature of the stream and the number of people). An object editor allows students to describe what the object is and to select an icon to represent it. A variable editor allows students to describe what the variable is, set the variable as a qualitative or quantitative one, and decide the scales of the variable.

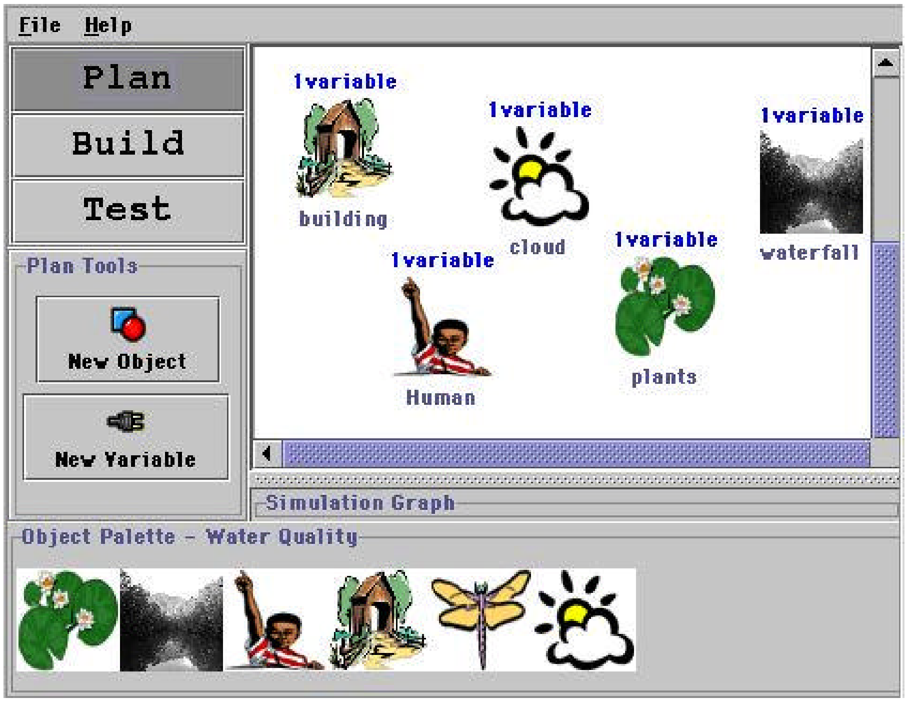

Figure 3.2. The graphic interface of Plan mode

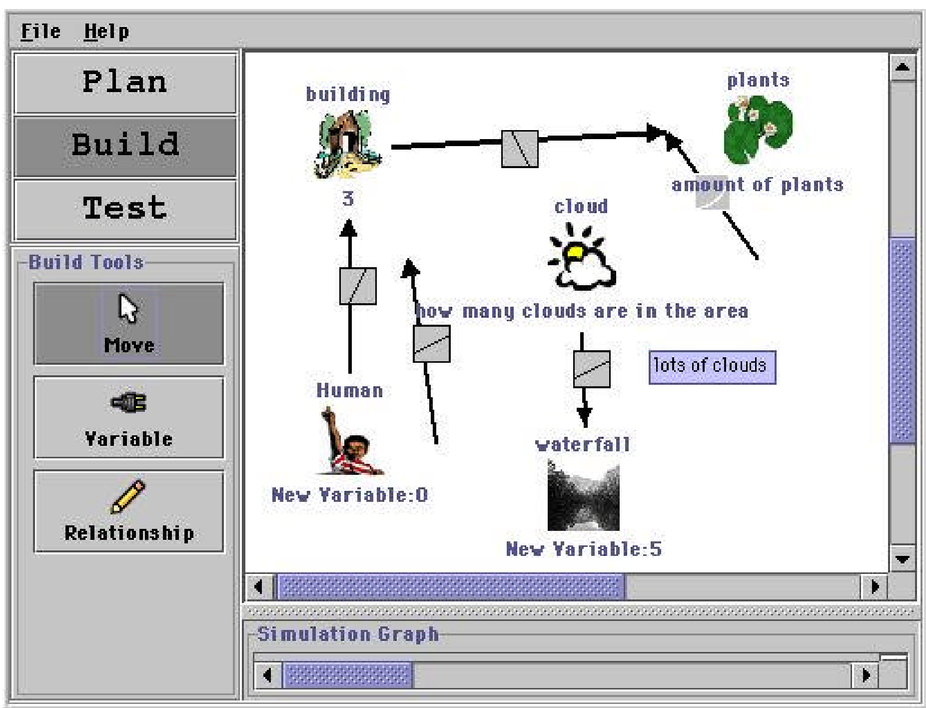

Figure 3.3. The graphic interface of Build mode

Next, in the Build mode (Figure 3.3), students create relationships between two variables by clicking on one variable (independent variable) and drawing a line to another (dependent variable). After the two variables are connected, a relationship editor pops up. In the editor, there are verbal descriptions and a graph to represent the relationship. For example, if students create a relationship between the amount of salt and conductivity, a verbal description on the relationship editor would be "as the amount of salt increases, conductivity [increases] by [almost the same]." The term [increase] and the change of degree [almost the same] could be changed to other options, such as [decrease] and [more and more] respectively. The graphical representation next to the statement would change as students choose different options. The small square icon on the relationship line (Figure 3.3) shows the graphical representation of the relationship.

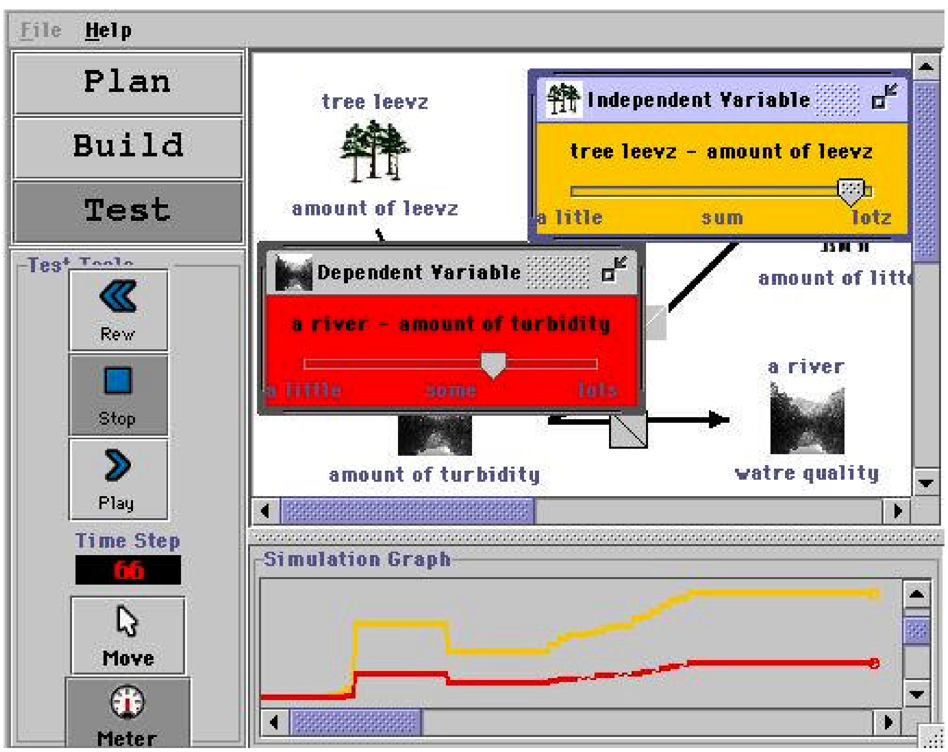

Figure 3.4. The graphic interface of Test mode

For data visualization, in the Test Mode (Figure 3.4), Model-It provides meters and graphs to view variable values. As students test their models they can change the values of variables and immediately see the effects on meters and the simulation graph. If the simulation does not run as the way students expect, Model-It allows them to move back to the Plan or Build mode to revise objects, variables or relationships.

Model-It provides an easy-to-use object-oriented visual format so that students can define their models without having to use traditional programming. To use this computational modeling tool, students do not need to compute quantitatively, which relieves the computational burden. Students do not need to write equations to specify the relationship between two variables, but rather they can specify the relationship between two variables either quantitatively or qualitatively without computation. This allows students to construct models quickly and easily so that they can focus their attention on the tasks of analyzing, causal reasoning, testing and re-examining their models (Stratford, Krajcik, & Soloway, 1998).

Data Collection Methods

Multiple sources of data were collected throughout the water quality unit over eight months (Table 3.3). They included video recordings and fieldnotes of classroom observations, video recordings when target students used Model-It, students' artifacts, and teachers' and students' interviews. Based on the format and content of the data sources, I categorized the sources of data into four types: (1) Classroom activity data, (2) tool-based inscription data, (3) text-based artifacts, and (4) interview data. Table 3.4 summarizes the sources of data, purposes, and group sizes.

Table 3.3

Data Sources and Timing

Data	Sep. 2000	Oct. 2000	Nov. 2000	Dec. 2000	Jan. 2001	Feb. 2001	March 2001	April 2001	May 2001	June 2001
Classroom video recordings	■	WQ I ■	■	Model-It ■	Model-It ■	WQ II ■	Model-It ■		WQ III ■	■
Fieldnotes	■	WQ I ■	■	Model-It ■	Model-It ■	WQ II ■	Model-It ■		WQ III ■	■
Process recordings				■	■		■			
Models				■	■		■			
Webpages										■
Science Report					■		■		■	
Notebook					■					
Teacher Interviews		■								
Student Interviews									■	

Table 3.4

Data Sources, Purposes and Group Size

Data Type	Data Source	Purpose	Group size
Classroom activity data	Classroom videos Fieldnotes Audio recordings	Describe a variety of inscriptional activities students had in the water quality unit; illustrate how the teachers supported students to demonstrate their inscriptional competencies; and provide data of what inscriptional practices students had during the class.	Whole class Class I (n=12) Class II (n=15)
Tool-based inscription data	Process video of Model-It	Allow me to document conversations of students, and analyze their computer activities and inscriptional practices of modeling.	Dyads (target students) (n = 8, 4 girls)
	Computer-based models	Allow me to analyze students' descriptions and examine students' progress in constructing models.	Dyads (target students) (n = 8, 4 girls)
	Webpages	Externalize students' understandings of the water quality and allow me to analyze how students used digital pictures and webpage features to elaborate their ideas about water quality.	Dyads (target students) (n = 8, 4 girls)
Text-based artifacts	Science reports	Present types of inscriptions and illustrate ways of using inscriptions in the artifacts. Teachers' feedback and comments on the reports indicate how certain ways to represent data and reported analyses were valued and emphasized by the teachers.	Dyads (target students) (n = 8, 4 girls)
	Notebooks	Allow me to analyze inscriptions generated by students that may be different from conventional inscriptions or those instructed by the teachers.	Dyads (target students) (n = 8, 4 girls)
Interview data	Teacher Interview Transcripts	Understand the rationale behind the curriculum design and teachers' perceptions about the use of scientific inscriptions in the unit.	Two teachers
	Student Interview Transcripts	Assess students' competencies to construct, interpret, and critique inscriptions.	Dyads (target students) (n = 8, 4 girls)

Classroom Activity Data

Video recordings and fieldnotes of classroom observations

Classroom video recordings and fieldnotes described a variety of inscriptional activities students had in the water quality unit and illustrated how the teachers supported students to demonstrate inscriptional practices. Field notes were taken during each of the class periods I attended to capture the major events of the day and to note particular episodes related to inscriptional activities. These fieldnotes included a summary description of the class period, jottings of events, time stamps for each event, and analytical comments on events relevant to my research questions (Appendix A). A Hi-8 video camera placed on one corner of the classroom recorded all classroom activities. The observations and fieldnotes taking focused on the teachers as they introduced scientific inscriptions and guided students to engage in inscriptional practices. The observations also focused on students' activities. When students had group discussions, the video camera and an audio recorder were used to capture interactions of the two target student dyads in each class. Recordings of group discussions provided data of the inscriptional practices that students engaged in during the class.

Tool-based Inscription Data

Video recordings of target students' use of model-It

Target students' activities while using Model-It were recorded by a technique called Process Video (Krajcik, Simmons, & Lunetta, 1988). This process changed a computer monitor signal to a standard television signal by using a converter module. This television signal was sent to a high quality video recorder (Hi-8 VCR), where the students' screen activity was recorded on tape. In addition, each student wore a microphone and the audio signal was increased with a mixer, and sent to the video recorder where it was saved on the audio track of the videotape. The process videos allowed me to document conversations of students and to analyze their computer activities and inscriptional practices during modeling sessions.

However, some data may be lost with this type of data collection method, because process videos did not record students' gestures or actions. When students used figures pointing to the screen and made references to "this" and "that," it was difficult for me to make interpretations of their actions unless students moved the cursor or had follow-up conversations that elaborated on their previous ideas. In this case, classroom activity data that recorded students' body language and gestures became useful because they could complement the data of process videos.

Models

When students used Model-It during WQ I and WQ II, their model files were collected daily. Due to the limited video resolution the process videos do not clearly show the descriptions and statements that students typed into the description boxes. The daily models allowed me to analyze students' descriptions, examined students' progress in constructing models, and evaluated the quality of the models. By combining these two sources of data (i.e., model files and the process videos), the process of how models were constructed could be characterized.

Webpages

Students used Netscape® Communicator to create webpages. Webpages were the final products of the unit in which they presented their longitudinal study of the stream quality in the three seasons. Their webpages included digital pictures that students took during each season and seven hyperlinked pages: a homepage, five water test pages (i.e., pH, conductivity, dissolved oxygen, turbidity, and temperature difference), and a conclusion page. In their homepage, students described how they conducted their longitudinal study, made links to water test pages, and showed a picture of the student group. In each test page, students wrote a paragraph to summarize their findings in each season, used graphs to represent data, and included pictures of their assigned portion of the stream. In the conclusion page, students presented the overall conclusion about the health of the stream.

When students worked on their webpages in groups, I used the Hi-8 camera, which was mainly used for classroom video recordings, to videotape the target student pairs. Thus, the process of creating webpages was captured in classroom videos.

Both science reports and webpages demonstrated students' understandings of water quality. Compared with a paper report, webpages provided different features and characteristics that allowed students to represent their understandings through creating hyperlinks, making references to digital pictures, and integrating information in a multimedia fashion. Webpages as a type of inscription allowed certain inscriptional activities to take place as they might not be observed in other types of inscriptions like reports and models. Thus, I used these webpages to analyze how students used digital pictures and webpage features to illustrate their ideas about water quality.

Text-based Artifacts

Target students' artifacts, including reports for water quality unit (water quality booklets[4]) and notebooks, were copied and collected.

Science reports

After each round of data collection, students turned in their water quality report. A final completed report included (1) the background information; (2) the WQ I investigation; (3) the WQ II investigation; and (4) a longitudinal analysis across WQ I, II and III. In the background information section, students included the information of how much clean water is available on the earth, gave definitions of the five water tests (i.e., pH, conductivity, dissolved oxygen, turbidity, and temperature difference), and described causes and effects of water pollution. They also attached a hand-drawing map of their assigned stream portion (stream drawing) and labeled the three locations where they collected data on their drawing. In each water quality investigation section, students reported their predictions, data readings, data analysis, graphs, and conclusions. These reports were collected after teachers graded them. The grading criteria were also copied and gathered. Teachers' feedback and comments on the booklets were an important source of data that indicated how certain ways to represent data and reported analyses were valued and emphasized by the teachers. This in turn might shape students' understandings of how to use inscriptions in a written text.

After collecting data in WQ III, students were asked to do a longitudinal analysis for each of the water tests (i.e., dissolved oxygen, temperature differences, conductivity, or turbidity). They analyzed the data individually and constructed webpages in groups.

They synthesized and represented their understandings of the longitudinal analysis on the webpages.

Notebooks

Target students' notebooks were also collected and copied. Notebooks included the notes students took during classes and data tables they created for pH and conductivity experiments. Their notes allowed me to analyze inscriptions generated by students that might be different from conventional inscriptions or those instructed by the teachers.

Interview Data

Teacher interviews

In the third week of WQ I, I had informal interviews with teachers during lunch time. Each teacher was interviewed individually. The purposes of the interviews were to share my initial observations about students' use of inscriptions with teachers, understand the rationale behind the curriculum design, and realize teachers' perceptions about the use of scientific inscriptions in the unit. During the week of interviews, students were creating data tables for their experiments so the interviews began with questions about students' use of data tables and then followed with questions about the use of inscriptions in the unit. The questions included: Did you see any students have problems creating tables or graphs? What kind of difficulties do they usually have? How do you help them? What kind of scientific representations will be used in the unit? Compared your students with scientists, what are the similarities and differences between their use of

[4] "Booklet" is a folk term (Spradley, 1979) used by the teachers and students. The understandings of folk terms (e.g., booklet, com book, graphic notebook, and background information) are important for me to

representations in science inquiry? Each interview was about twenty minutes and conducted in each teacher's classroom. The interviews were later transcribed and analyzed.

Student interviews

The purpose of this interview was to understand when, how, and why students choose to use graphs, data tables or other types of inscriptions in a scientific investigation. The interview was also used to assess students' competence to construct, interpret, and critique inscriptions. Semi-structured interviews with students were conducted and videotaped during WQ III. Target students were interviewed individually. They were first asked to design an investigation that answered a driving question of how the stream quality changed over a year. Then predictions, data, and the standards were given in a text format (Appendix B). Students were required to sketch or write down the data analysis process and to provide reasons for their analysis. Additionally, six graphs of the same data set were provided for students to choose the most appropriate display of the data. Based on the graph they chose, they had to come up with a conclusion about the driving question. Students' explanations of their choices and critiques of different graphs were recorded and later transcribed. Each interview was about twenty minutes and conducted outside of the science classroom.

Several interview strategies were used. First, any information about inscriptions, such as graphs and data tables, were not mentioned unless the topic was raised by students. Second, any unclear responses were questioned further. This strategy was used in students' as well as teachers' interviews. Third, when I interviewed students, I

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interpret classroom discourses and the semantic relationships among the terms.

remained open to emerging meanings and alternative explanations for the interview questions.

Data Management and Reduction

As Erickson (1986) stated, "the corpus of materials collected in the field are not data themselves, but resources for data.… All these [fieldnotes, videotapes, site documents, and interview transcripts] are documentary materials from which data must be constructed through some formal means of analysis" (p. 149). Thus, the goal of data management and reduction was to transform these multiple sources of data into items of data. They could be texts or two-dimensional displays (e.g., tables, pictures, and diagrams) that were ready for data analysis and foregrounded the fields of interests, i.e., inscriptions and related practices. Because the text-based artifacts and interview data were already in a text form, below I describe the steps I took to manage and reduce other two types of data: (1) Classroom activity data (i.e., fieldnotes, classroom videos, and audio tapes) and (2) tool-based inscription data (i.e., process videos of Model-It, models, and webpages).

Classroom Activity Data: Fieldnotes, classroom videos, and audio tapes

Classroom activity data required a series of transformations before used for analysis. The transformations were oriented by the theoretical framework and research questions. As discussed previously, practice is not isolated but exists in a social and historical context (Lave & Wenger, 1991). To demonstrate interactions (or intertextual links; Bloome & Egan-Robertson, 1993; Floriani, 1993) across various classroom activities, I took several steps to create charts and descriptions in different time scales that illustrated the class history and allowed me to flexibly zoom in and out on particular events about the use of inscriptions (Roth, 2001).

First, I reviewed my fieldnotes and created an overview of the whole water quality unit. Figure 3.1 shows an eight-month classroom history and displays a variety of classroom activities, available technological resources, inscriptions used across tasks that constituted scientific practices in the unit.

Next, I reconstructed detailed descriptions of each class period that included concepts covered, the events of the class, the length of events, inscriptional activities in the events, and inscriptions used in the events. An event was defined as a bounded set of activities about a common theme on a given day (Jordan & Henderson, 1995). Each class period could contain more than one event. Each event could contain one activity or a series of socially and academically linked activities that comprised episodes. This level of description made a range of events visible and allowed me to identify the events that were relevant to my research questions.

Thirdly, I identified events that involved the use of inscriptions and broke them down into "episodes." Episodes were "smaller units of coherent interaction within events" (Jordan & Henderson, 1995, p. 57) which were equivalent to "chunks of meanings" in Lincoln and Guba (1985) and "nodes" in Barab et al. (2001a). An episode contained only one main topic and kept similar activity modes (e.g., recitation, group discussion, and class discussion). I further broke down an episode into segments. A segment kept similar interactional patterns among the teacher and students or among students. Figure 3.5 shows an example of how I identified events, episodes, and segments within Day 1, Week 2 in WQ I. This class period contained three events:

Planning experimental procedures, discussing what data analysis is, and discussing how to record data. In Event 3, three episodes were identified based on activity modes and inscriptional practices demonstrated. Five segments were then identified within Episode (EP) 3.

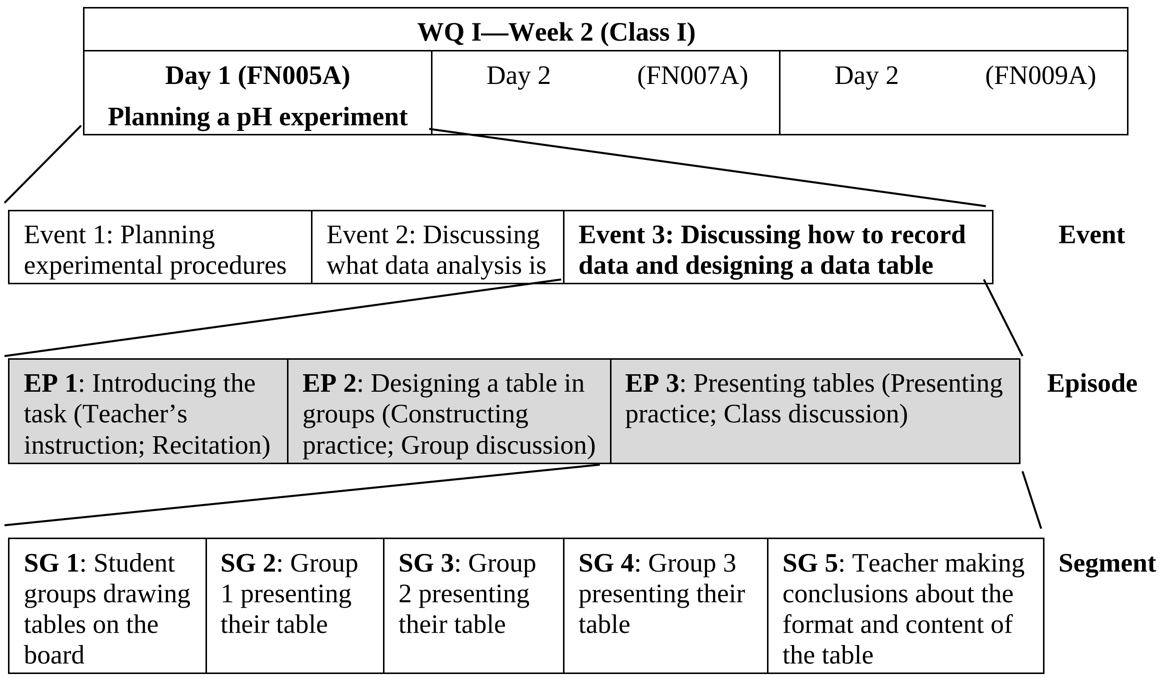

Figure 3.5. Events, episodes, and segments within Day 1, Week 2 in WQ I. The episodes selected for verbatim transcription are highlighted.

Lastly, the episodes that involved the use of inscriptions were transcribed in detail (see examples in Figure 3.5). According to the time stamps recorded in fieldnotes, I retrieved classroom video recordings and audio tapes to generate verbatim transcripts of conversations. Among the 124 classroom videotapes collected from the two classes, 82 tapes involved episodes of inscriptional activities. The transcripts of episodes (see

Appendix C) captured inscriptions used, discourse (oral and written language in use), and actions (gestures) that allowed me to analyze the interactions among students and the teacher (Jordan & Henderson, 1995). To facilitate coding and manipulating these transcripts, a qualitative data analysis tool, NUD*IST®, was used.

Tool-based Inscription Data

Process videos of Model-It

The process videos of students' use of Model-It were transcribed[5] into a text format. Because modeling is a process in which students transform their understandings of a phenomena into a variety of objects and variables and a series of relationships between variables (Lehrer & Romberg, 1996), when creating a model students might bring in their field experiences and conceptual understandings about water quality. Thus, the transcripts of process videos had to capture these interactions among field experiences and conceptual understandings, inscriptions, and the tool. Below I describe the steps I took to transcribe the process videos.

Students' use of Model-It during a class period was identified as an event. Similar to how I did with the classroom activity data, I then identified "episodes" during which students stayed on one specific mode of the tool (i.e., Plan, Build, and Test; see Figures 3.2, 3.3, and 3.4). For each episode, understandings of field experiences, concepts, phenomenon that allowed such conversations to happen were identified and noted. I also described tool activities associated with conversations and identified

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[5] I view the process of summarizing and describing the content of a video tape as transcribing based upon Baker's (1997) notion of transcription as textual representation. The summaries and descriptions of an event are oriented and selected by the theoretical framework. In this sense, each step of data reduction could be viewed as a level of transcription.

features of the tool that allowed these tool activities to happen. Sometimes students' activities were interrupted when they did not know what to do in order to accomplish an intended task or needed content supports. These situations were recorded as breakdowns (Bowen, Roth, & McGinn, 1999) that helped me understand what difficulties students encountered when engaged in model-related practices (see Stefon and Charles's modeling segment shown in Theme 11, Chapter 4).

Webpages

As mentioned in the Data Collection section, the process of creating webpages was partially captured in classroom videos because I used a camera to film one of the target student pairs when they worked in groups. I transcribed these video recordings in a matter that was similar to what I did with the process videos of Model-It. In the transcripts, I recorded students' discourse, tool activities, and related knowledge.

To visualize the structure of webpages, I drew a site map for each target pair's webpages. A site map indicated how webpages were linked to others and the numbers of inscriptions used on each page (Figure 3.6). To describe how students used inscriptions on their webpages, I used a scheme that addressed: (1) the purpose for which the inscription was used; (2) the type of the inscription (e.g., digital pictures, graphs, or tables); (3) the resources or devices that allowed students to create the inscription; and (4) the text that referred to the inscription. Additionally, I created a table to summarize students' webpage components (Table 4.6 in Theme 10, Chapter 4) that allowed me to compare students' use of inscriptions across dyads.

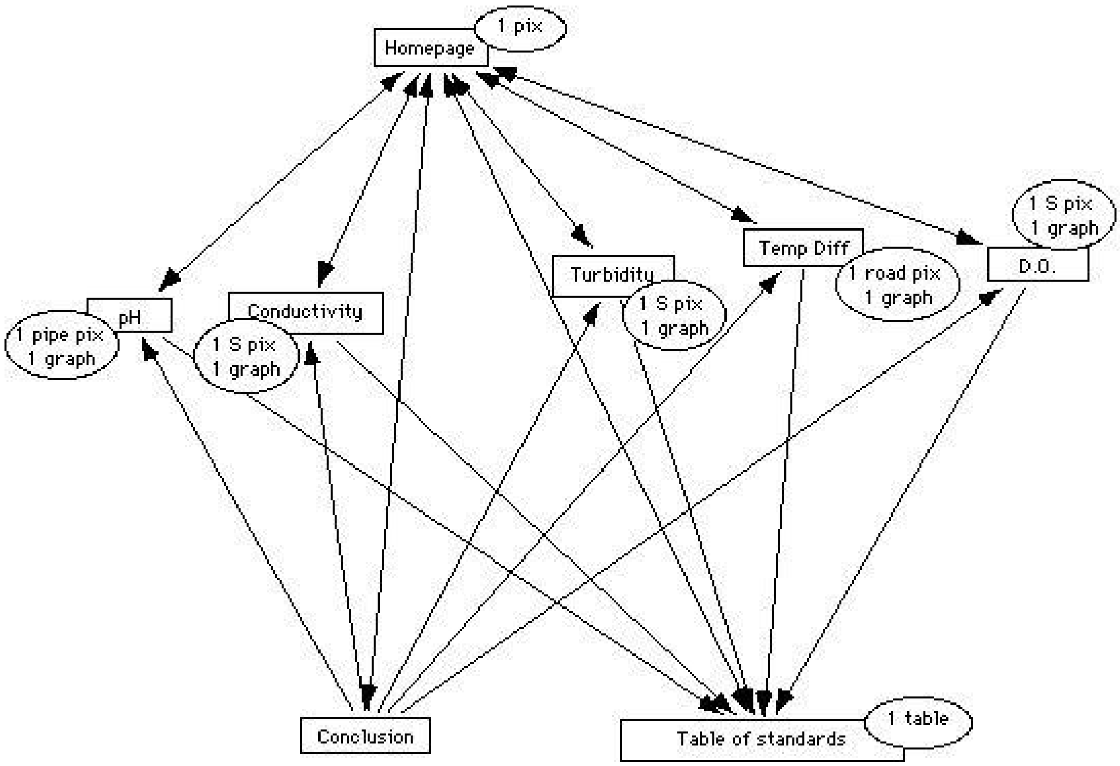

Figure 3.6. The site map of Cythia and Smita's webpages. Each square shows one webpage and each oval indicates the numbers of pictures, graphs, and tables. "S pix" means Stream picture. An arrow pointing from page A to page B indicates that on page A there is a hyperlink to page B. Arrows at both ends indicate that there are hyperlinks on both pages that link to each other.

Data Analysis

The research questions of this study are: (1) What are the characteristics of inscriptional practices demonstrated by seventh graders? (2) How do students' inscriptional practices change over time? (3) What are the characteristics of the inscriptions created by students? (4) What aspects of the learning environment help students create various inscriptions and develop inscriptional practices? To answer these questions, I took several analytic steps suggested by Erickson (1986). Figure 3.7 shows an overview of my data analysis process. As can be seen, some of the analytic steps were used iteratively. The codes, descriptions, findings, or themes generated in some analytical steps were examined by another researcher. In the last step, I shared my findings with the teachers. Among the four types of data sources, classroom activity data and tool-based inscription data were primary data sources and involved in tracer identification and themes generation. After temporary themes were generated, text-based artifacts and interview data were used to test the themes and provided confirming or disconfirming evidence.

Identifying Tracers from Theoretical Framework and Data Management Process

My research questions involve a historical development of students' inscriptional practices. To portray this development process, I identified "tracers" including practices and inscriptions that could be observed and followed over time (Barab, Hay, & Yamagata-Lynch, 2001b; Newman, Griffin, & Cole, 1989; Roth & Roychoudhury, 1993). Tracers could be predetermined based upon a theoretical framework and research hypotheses (Newman et al., 1989) or emerge from a review of an empirical data corpus (Barab et al., 2001b). In the study, I used both ways (i.e. theoretical and empirical) to generate tracers. In Chapter two, I identified four types of inscriptional practices, i.e., constructing, interpreting, reasoning, and critiquing, based on the literature. Another type of practice, presenting, emerged from the data management process (see Table 3.5).

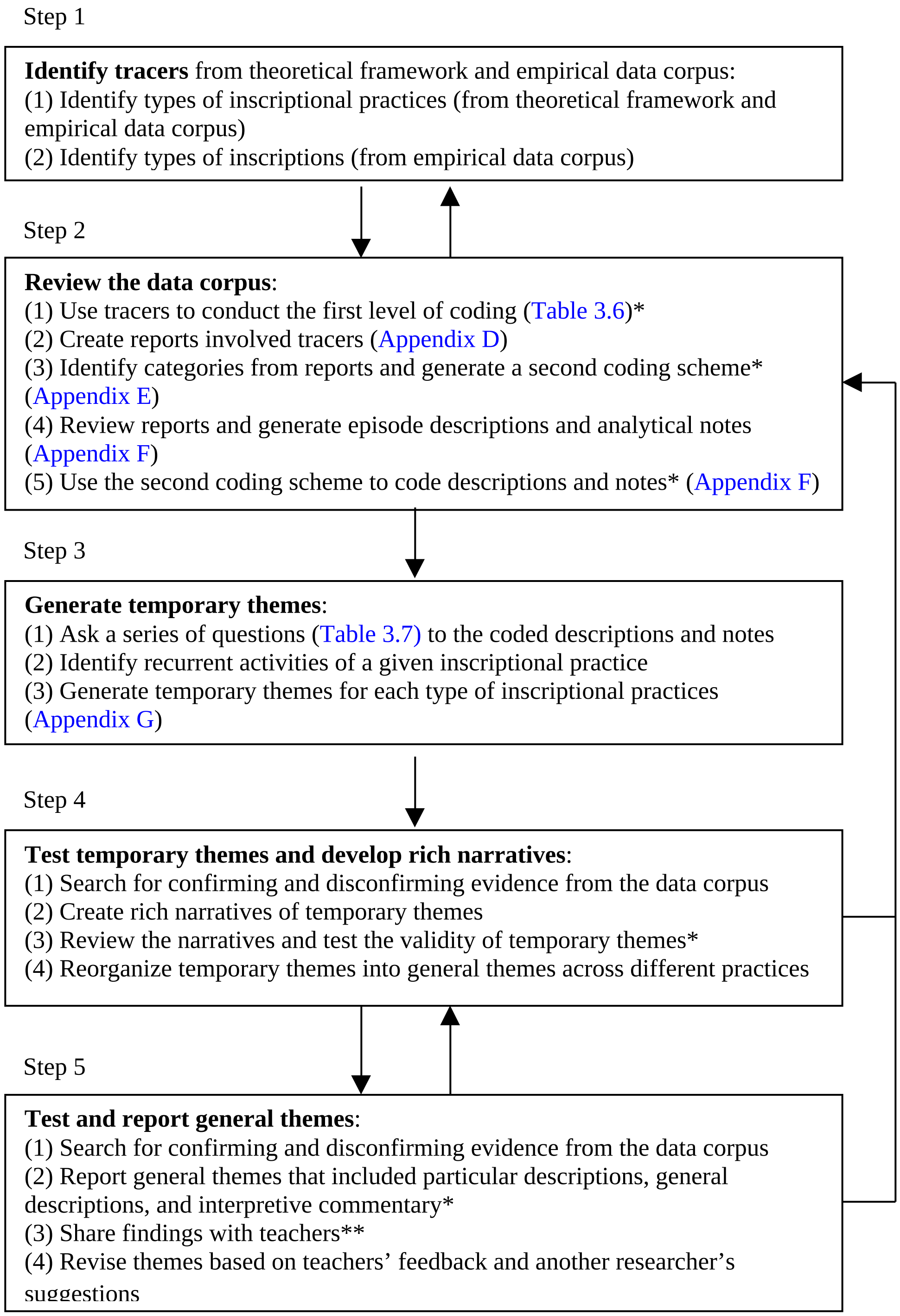

Figure 3.7. Data analysis procedures. * means that another researcher examined the codes, descriptions, findings, or themes in the analytical step. ** means that I shared the findings with the teachers and received feedback from them.

Table 3.5 summarizes the definitions of inscriptional practices and examples identified from the data. Using these conceptually rich practices as tracers allowed me to follow students' enactment of inscriptional practices throughout the water quality unit and across different data categories (i.e., classroom activity data, tool-based inscription data, text-based artifacts, and interview data).

Table 3.5

Inscriptional Practices, Definitions, and Examples

Practice	Definition	Examples
Constructing	Constructing practices involve class members' discourse, actions, behaviors, and information used when they use instruments, such as paper and pencils, computers, or technology to generate, record, and transform signals or readings into a materialized form.	Constructing practices include planning and designing inscriptions (e.g., graphs and tables), recording readings, transforming one inscription into another, incorporating and combing several inscriptions into webpages, and capturing visual information in drawings and pictures.
Interpreting	Interpreting practices involve class members' discourse, actions, behaviors, and information used when they generate meanings out of an inscription and make sense of the phenomena, concepts or data represented by an inscription.	Interpreting practices include examining the consistency of data, identifying patterns from graphs, searching for reasons to explain patterns and data, comparing findings to predictions and standards, and providing meanings to components of an inscription, e.g. relationships in a model.
Reasoning	Reasoning practices involve class members' discourse, actions, behaviors, and information used when they use inscriptions as an initiator of discussions, a mediator between concepts and phenomena, a piece of evidence to support their arguments, or a resource to support their inquiry.	Reasoning practices include using inscriptions (e.g., digital pictures, graphs, tables, and maps) to make predictions, support arguments, illustrate ideas, conceptualize a phenomenon, manipulate inscriptions to gain new understandings, and draw conclusions.
Presenting	Presenting practices involve class members' discourse, actions, behaviors, and information used when they display their own inscriptions to a group of students or the whole class.	Presenting practices include describing and providing meanings to the components of an inscription, explaining the relationships among the components, elaborating on the ideas based on the feedback, and clarifying confusions in a follow-up discussion
Critiquing	Critiquing practices involve class members' discourse, actions, behaviors, and information used when they draw on particular concepts and concerns as criteria to make comments, give feedback, and determine the quality or accuracy of an inscription.	Critiquing practices include asking for clarifications and explanations, indicating missing components, suggesting a change of components and categories, and asking for an answer and a conclusion based on the inscription presented.

Another set of tracers used in this study was the inscriptions the classes used in the unit. Ten types of inscriptions were identified: pH scale, data table, table, stream drawing, graph, model, digital picture, webpage, chemical representation, and map. Tracing the use of inscriptions and associated activities revealed how students' inscriptional practices were similar or different by using various types of inscriptions.

Reviewing the Data Corpus and Using Tracers as Codes

The second step of data analysis was to use the tracers to code the data transcripts obtained from the data management process (including classroom activity data and tool-based inscription data). This step involved two levels of coding. To facilitate coding and manipulating the transcript files, a qualitative data analysis tool, NUD*IST®, was used.

At the first level of coding, I used an episode as a coding unit. Using constant comparative method (Glaser & Strauss, 1963), I coded the transcript files based upon a coding scheme (Table 3.6) that included modes of classroom activities (e.g., recitation, group discussion), types of inscriptions, inscriptional practices, teaching practices, and areas of science inquiry (Krajcik et al., 1998).

Teaching practices were categorized into two types: instruction and scaffolds. Teachers' instruction was given prior to students' enactment of practices when teachers assigned and introduced an inscriptional activity. Teachers provided examples, modeled how to do the task, demonstrated the use of software, or engaged students in discussions about the use of inscriptions through monologues, recitations, or class discussions. Instruction usually contained information about purposes of an activity, procedures of doing an activity, expectations of students' performances, and uses of related learning tools. Scaffold in the study is defined as assistance that allowed students to accomplish tasks they could not do alone (Palincsar & Brown, 1984; Paris, Wixson, & Palinscar, 1986; Wood, Burner, & Ross, 1976). Teachers' scaffolds, such as questioning, structuring, and modeling, were usually given when students participated in inscriptional activities. These scaffolds helped students "bridge the gap between their current abilities and the intended goal of instruction" (Rosenshine & Meister, 1992, p. 26) and allowed students "to participate at ever-increasing levels of competence" (Palincsar & Brown, 1984, p. 122).

Table 3.6

Coding Scheme Used for the First Level of Coding (Coding Scheme I)

1. Administration	**3. Inscription**	**5. Teaching Practice**
1.1 Class	3.1 pH scale	5.1 Introduce inscriptional activity
1.1.1 Class I	3.2 Data table	5.2 Scaffolds
1.1.2 Class II	3.3 Table	*5.2.1 Constructing*
1.2 Student pair	3.4 Stream drawing	*5.2.2 Interpreting*
1.2.1 CF/SP	3.5 Graph	*5.2.3 Reasoning*
1.2.2 CH/ST	3.6 Model	*5.2.4 Critiquing*
1.2.3 AF/DL	3.7 Digital picture	*5.2.5 Presenting*
1.2.4 NB/OK	3.8 Webpage	*5.2.6 Other*
1.3 Water quality	3.9 Chemical representation	**6. Inquiry Area**
1.3.1 WQ I	3.10 Map	6.1 Ask questions
1.3.2 WQ II	3.11 Other	6.2 Design investigations & plan procedures
1.3.3 WQ III		6.3 Collaborate & present findings
2. Mode of Class Activity		6.4 Analyze data & draw conclusions
2.1 Recitation	**4. Inscription Practice**	6.5 Construct apparatus & carry out investigations
2.2 Class discussion	4.1 Constructing	**7. Concept**
2.3 Group discussion	4.2 Interpreting	7.1 pH
2.4 Field	4.3 Reasoning	7.2 Thermal pollution
2.5 Other	4.4 Critiquing	7.3 Conductivity
	4.5 Presenting	7.4 Turbidity
	4.6 Other	7.5 D.O.
		7.6 Other

Once the transcript files were coded, I extracted episodes that involved tracers (i.e., inscriptional practices and inscriptions) from the files and created reports. Reports were intersections of a practice tracer and an inscription tracer, such as a report of all episodes about constructing digital pictures (Appendix D) and a report of all episodes about critiquing models. I read through these reports identified categories for a second level of coding. These categories included (1) tools or resources used to support practices, (2) field experiences, prior knowledge, or conceptual knowledge involved in practices, (3) criteria indicated by the class members about the quality of practices or inscriptions, (4) functions or characteristics of an inscription created by the class members, (5) structures, formats or components of an inscription, and (6) teachers' scaffolds that support students' enactment of practices (Appendix E). I then reviewed the reports, abstracted information around these categories, generated episode descriptions, and analytical notes (Appendix F), and coded them by using the categories. The two coding schemes and coded transcripts and descriptions were examined by a senior researcher to ensure the reliability of analyses.

Generating Temporary Themes

I reviewed the descriptions and analytical notes (Appendix F) and generated temporary themes through induction. Themes were patterns emerged from the descriptions and notes. For each type of inscriptional practices, for example, the pattern-searching process could be initiated by asking a series of questions around tracers. Table 3.7 shows the questions that were used to generate themes for each research question. The series of questions helped me characterize inscriptional practices and unfolded changes of students' practices over time (Santa Barbara Classroom Discourse Group, 1992).

Table 3.7

Questions guiding theme generation

Research question	Questions for generating themes
1. What are the characteristics of inscription practices demonstrated by 7th graders? 2. How do students' inscription practices change over time?	For a given practice: · When does the practice happen in the unit? · How often does the practice happen in the unit? · Under what conditions does the practice enact? · For what purpose do participants enact the practice? · What inscription is practiced? · What resources support the practice to take place? · What regular learning or instructional sequence involved in the practice? · What are breakdowns interrupting the sequence? · How does the regular sequence change over time?
3. What are the characteristics of the inscriptions created by students?	For a given inscription: · When is the inscription used in the unit? · How often is the inscription used in the unit? · Who are users and providers of the inscription? · Under what conditions is the inscription used? · What inscription practices are enacted with the inscription? · For what purpose is the inscription used? · What resources or devices allow the inscription to be constructed?
4. What aspects of the learning environment help students create various inscriptions and develop inscriptional practices	Mode of Class Activity: · In which mode of class activities does an inscription practice happen? · What inscription is used in which mode? Teaching Practice: · How do teachers introduce an inscription and set up an inscriptional activity? · How do teachers provide scaffolds to students' inscriptional practices? Inquiry Process: · In which step of inquiry process does an inscriptional practice happen? · What inscription is used in which step?

By asking the series of questions and following the tracers, I identified recurrent activities of inscriptional practices when reviewing the descriptions and analytical notes. For example, designing inscriptions was identified as a recurrent activity because the descriptions and analytical notes of constructing practices showed that it took place several times throughout the unit. When a description was applicable to an identified recurrent activity, I compared it with the previous description coded by the same category. This constant comparison (Glaser, & Strauss, 1963) helped me start to generate characteristics or properties of a given inscriptional practice. Although I had definitions for each practice based upon the literature, as I constantly compared instances and descriptions, this process led to an ongoing refinement of the definitions of practices.

I then documented the definition of each inscriptional practice, the refinement process and theoretical thoughts. Temporary themes emerged from characterizing recurrent activities and were organized by types of inscriptional practices (Appendix G).

Testing Temporary Themes and Developing Rich Narratives

The fourth step of data analysis was to test temporary themes, develop rich narratives, and generate general themes. At this step, I incorporated the text-based artifacts and interview data into the data corpus. I repeatedly reviewed the data corpus to test the validity of the temporary themes. I sought for confirming and disconfirming evidence across the four data categories. Evidence included quotes from interview transcripts, descriptions from fieldnotes, or quotes from process videos. I created rich narratives of these temporary themes that included evidence and analytical notes. These rich narratives were then reviewed by a senior researcher.

The rich narratives enabled me to identify general themes across different types of inscriptional practices, to examine how different inscriptions were involved in inscriptional practices, and to trace students' learning trajectories throughout the unit. Based upon the suggestions given by the senior researcher, temporary themes were then reorganized to foreground the findings that answered my research questions. A general theme could include data from different inscriptional practices and involve different types of inscriptions. Figure 3.8 shows an example of a general theme, its related temporary themes, and the confirming evidence. In this example, a general theme about students' participation level was made by combining findings from two temporary themes related to constructing and interpreting practices. For each temporary theme, I used confirming evidence from different sources of data to triangulate my interpretations and to increase the credibility.

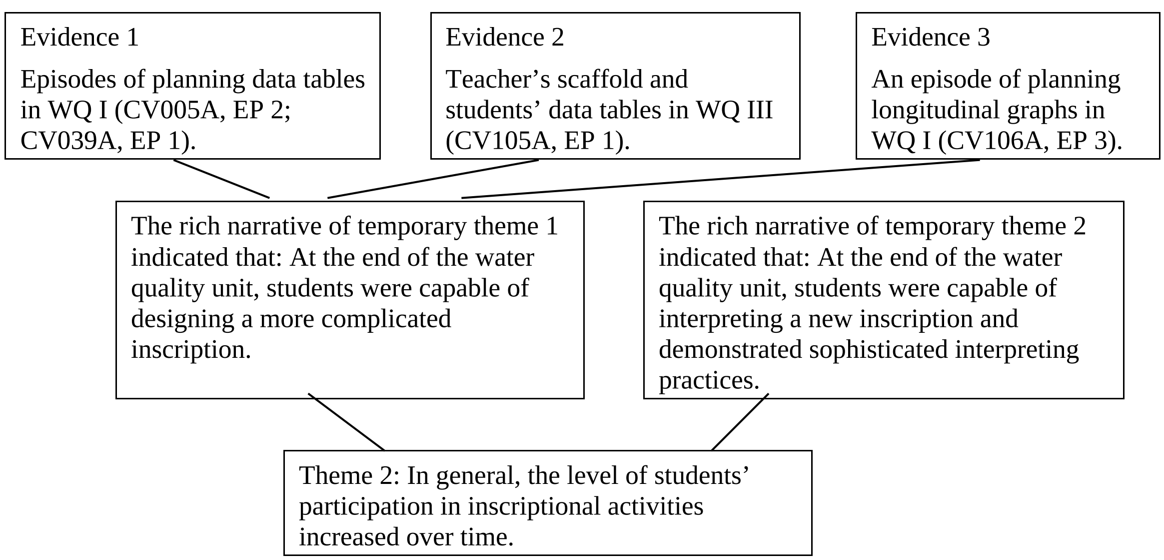

Figure 3.8. A general theme, temporary themes, and related confirming evidence

Testing and Reporting General Themes

After the general themes were generated, I tested the validity of the themes by searching for confirming and disconfirming evidence. Discrepant cases were noted and useful to illustrate the locally distinctive subtleties across student pairs or classes. Some themes were revised or abandoned because of a lack of confirming evidence. A report of themes include three parts: Particular description, general description, and interpretive commentary (Erickson, 1986). Particular descriptions were narrative vignettes or quotes from the classroom videos, process videos, and interviews, which instanced and warranted themes. General descriptions were generated by reporting the linked particular descriptions and describing the overall distribution of instances in the data corpus in summary fashion. The aim of presenting both particular and general descriptions was to provide a warrant for the themes. While a particular description indicated that what the assertion claims did occur at least once, a general description accompanying the particular descriptions provided evidence for the relative frequency of occurrence of a given phenomenon and displayed the breadth of evidence. As will be seen in Chapter four, interpretative commentary preceded or followed an instance of particular description in the text, included interpretations of the instance and discussions of the significance of certain patterns. A commentary was to guide the reader to see how my interpretation and argument were made. These commentaries also presented my point of view and linked the identified patterns to the theoretical framework. The reports were again reviewed by a senior researcher.

I then created a three-page summary of the general themes and shared it with the teachers. During the discussion, we went through each of the themes. I posed questions to teachers in order to confirm my interpretations about the curriculum design and the purposes of having some inscriptional activities. Teachers provided helpful feedback and provided rationales behind the design of some inscriptional activities. Based upon teachers' feedback and the senior researcher's suggestions, I revised some themes and reports. These general themes are reported in Chapter four.

Limitations of the Study

The research questions about the historical development of students' inscriptional practices and the components of inscriptional practices defined in Chapter two lead the study to employ methods that are mostly used by studies in a research tradition of social practice. Framing this study in a specific perspective places limits on the research, such as ignoring students' mental activities and mental models about inscriptions. In this section, I present limitations of the study that allow the reader to make decisions about its usefulness for other settings. Limitations of this study derive from the conceptual framework as well as the methods.

Without using instruments to evaluate students' cognitive skills, this study relies on students' behaviors, discourse, and social interactions to investigate their cognitive activities. For students who are not familiar with using these ways to externalize their understandings, their cognitive growth might be underestimated. Additionally, as a group of students are viewed as a learning community and social meanings are emphasized, individual differences among students are overlooked.

Furthermore, the study is bounded and situated in a specific context that could undermine how broadly applicable this study may be. The class sizes were small (Class I: 12 students; Class II: 15 students) compared to the regular class size (25 students) at public schools in the same school district. Such small classes could have positive effect on students' academic performances (Finn & Achilles, 1999) and allowed teachers to provide more individualized support for learning (Blatchford, Moriarty, Edmonds, & Martin, 2002). This study acknowledges these possible impacts on students' development of inscriptional practices, but without including classes with much larger class sizes as a control group, this study is not able to attribute certain students' learning effects to the class size factor. In addition to the class size factor, other factors such as teacher's pedagogical content knowledge and collaboration between students might also influence students' learning. By viewing classroom life as synergistic, the learning effects caused by these factors are inseparable in this study.

Another limitation comes from the analytical methods that I used to analyze tool-based inscription data. Because this study focuses on students' inscriptional practices when they used different instruments to create inscriptions during an eight-month period of time, I choose not to dissect individual learning technologies (e.g., Model-It, emate, and Netscape® Communicator). I did not analyze features or scaffolds of each learning technology in detail after considering the grain size of my analyses. The methods used to analyze tool-based inscription data therefore would limit the contributions this study could make to the research on educational technology. How features and scaffolds provided by learning technologies support students' demonstration of inscriptional practices could be a possible direction for future research.

Summary

This study focuses on students' inscriptional practices during an eight-month water quality unit and is conducted in two inquiry-based science classes with participation of two teachers and 27 seventh graders. Guided by the theoretical framework developed in Chapter two, this study takes a naturalistic approach to investigate the historical development of students' inscriptional practices. Various strategies, such as collecting multiple sources of data, observing the classes for a long period of time, and providing detailed descriptions of the settings, are used to enhance the credibility, transferability, dependability, and confirmability of the study. Four types of data were collected, i.e., classroom activity data (fieldnotes and classroom videos), tool-based inscription data (process videos, models, and webpages), text-based artifacts (science reports and notebooks), and interview data (student and teacher interviews). Among them, classroom activity and tool-based inscription data were transformed and transcribed into a text form before data analysis. To analyze these data, five steps were taken: (1) Identifying tracers, (2) reviewing the data corpus, (3) generating temporary themes, (4) testing temporary themes and developing rich narratives, and (5) testing and reporting general themes. In the next chapter, I will report the results generated from these analytical steps. Twelve general themes are grouped by four research questions. I will first provide an overview of students' enactment of inscriptional practices and then report the general themes in detail.

CHAPTER 4

RESULTS

The purpose of this research is to investigate seventh graders' inscriptional practices during a water quality unit in an inquiry-based learning environment. Multiple sources of data were collected to answer following questions: (1) What are the characteristics of inscriptional practices demonstrated by seventh graders? (2) How do students' inscriptional practices change over time? (3) What are the characteristics of the inscriptions created by students? (4) What aspects of the learning environment help students create various inscriptions and develop inscriptional competencies?

This chapter begins with an overview of students' enactment of inscriptional practices and follows with evidence and detailed descriptions of themes that emerge from the characterization of inscriptional practices.

Overview of the Enactment of Inscriptional Practices

This section provides an overview of the enactment of inscriptional practices in the water quality unit by counting the number of class periods during which one or more inscriptional practices were demonstrated by students. Although the duration of the enactment of practices within each class period varied, the number of class periods gives a sense about when and how often a practice happened in three sub-units (i.e., WQ I in the fall, WQ II in the winter, and WQ III in the spring). Figure 3.1 provides an overview of the three sub-units.

During the water quality unit, 124 classroom videotapes (each tape capturing one classroom period) were collected among which 78, 24, and 22 were collected from WQ I, WQ II, and WQ III respectively. There were fewer tapes collected from WQ II and WQ III because in these two sub-units the classes conducted water quality investigations and did not introduce new concepts (see Figure 3.1). The numbers of classroom videotapes collected from the two classes were the same in each sub-unit. Episodes related to students' use of inscriptions were transcribed. 46, 15, and 21 classroom videotapes collected from WQ I, WQ II, and WQ III contained these episodes (See Table 4.1). There was a variation in the numbers of videotapes, because in WQ I, the classes spent more time designing new inscriptions and teachers used various inscriptions to illustrate concepts. No new inscriptions were introduced in WQ II. In WQ III, students spent a substantial amount of time creating webpages.

Table 4.1

Summary of Class Videotapes Collected from Class I and II

Sub-unit	Number of tapes collected (N_A)			Number of tapes containing inscription episodes (N_B)			$(N_B/N_A)\%$		
	Class I	Class II	I + II	Class I	Class II	I + II	Class I	Class II	I + II
WQ I	39	39	78	26	20	46	67%	51%	56%
WQ II	12	12	24	8	7	15	67%	58%	60%
WQ III	11	11	22	10	11	21	91%	100%	95%
Total	62	62	124	44	38	82	70%	61%	66%

Additionally, among the 46 tapes in WQ I, 26 of them were collected from Class I, while 20 tapes were from Class II. There were six more tapes collected from Class I in WQ I, because the teacher in Class I (Andrea) used more chemical representations to illustrate processes and phenomena (e.g., dissolving and neutralization) and used maps to explain concepts about watershed. During WQ II and WQ III, Class I and II had approximately equal numbers of class periods involving inscriptional activities.

Table 4.1 shows that the percentages of class periods that involved inscriptional practices increase from WQ I to WQ III. Students demonstrated relatively fewer inscriptional practices in WQ I, because when they developed background knowledge of water quality concepts (i.e., pH, conductivity, turbidity, dissolved oxygen, and thermal pollution) prior to the water quality investigations, many inscriptions were used by teachers for instructional purposes such as illustrating ideas and explaining concepts. Students did not actively participate in the use of these inscriptions. While conducting their science investigations, students used inscriptions more intensively. During WQ II and WQ III, with stronger content knowledge and more experiences in doing investigations students participated more in inscriptional activities. Particularly during WQ III, students were introduced to longitudinal graphs and webpages, so more than 90 percent of the class periods contained inscription-related episodes.

To take a close look at when and how often inscriptional practices happened during three sub-units in each class, the numbers of class periods that involved a specific inscriptional practice were counted (Table 4.2). In WQ I, the two classes focused on constructing inscriptions, although students also reasoned with inscriptions, interpreted graphs, presented their data tables, and critiqued each other's models. During WQ II, the focus of inscription practices shifted from constructing to other inscriptional practices. Students' critiquing and presenting practices in WQ II centered on their models. During WQ III, students spent most of their time creating longitudinal graphs and webpages.

Because the classes ran out of time at the end of unit, they did not present and critique each other's inscriptions.

Table 4.2

Number of Class Videotapes that Involved Inscriptional Practices

	Number of tapes (class periods) that involved inscriptional practices														
Sub-unit	Constructing			Interpreting			Reasoning			Presenting			Critiquing		
Class	I	II	I+II	I	II	I+II	I	II	I+II	I	II	I+II	I	II	I+II
WQ I	16	12	28	7	5	12	10	6	16	7	5	12	4	2	6
WQ II	3	2	5	2	1	3	3	3	6	5	2	7	4	1	5
WQ III	9	11	20	1	1	2	3	3	6	1	0	1	0	0	0
Total	28	25	53	10	7	17	16	12	28	13	7	20	8	3	11

Constructing Practice

Constructing inscriptions involve a range of activities in which class members use instruments, such as paper, pencils, and learning technologies to generate, record, and transform signals or readings into a materialized form. Constructing practices were demonstrated in various inquiry areas (Table 4.3); students constructed inscriptions while making predictions, designing investigations, presenting findings, analyzing data and carrying out investigations.

As seen in Table 4.2, students engaged in constructing practices across the three water quality sub-units. There were total 53 class periods that involved the construction of inscriptions. Approximately half of constructing practices (28 out of 53) happened in WQ I during which students learned to create several types of data tables for their pH and conductivity experiments, and constructed data tables, stream drawings, digital pictures, graphs, and models for their fall water quality investigation.

During WQ II, students did not explore new inscriptions and had another iteration of creating data tables, digital pictures, graphs, and models for their winter water quality investigation. Having prior experiences in creating these inscriptions from WQ I, the two classes spent relatively less time on these inscriptions.

Table 4.3

Inscriptional Practices and Inquiry Areas (Krajcik et al., 1998)

	Number of tapes (class periods)				
Inquiry Area	Constructing	Interpreting	Reasoning	Presenting	Critiquing
Asking questions	6	0	4	2	1
Designing investigations and planning procedures	5	0	0	5	2
Collaborating and presenting findings	18	5	8	13	8
Analyzing data and drawing conclusions	15	12	12	0	0
Constructing apparatus and carrying out investigations	9	0	4	0	0

New inscriptions, i.e., longitudinal graphs and webpages, were introduced in WQ III, so more class periods (20 class periods) contained constructing activities. Among 20 class periods in WQ III, the two classes spent 12 class periods in their webpages, 9 class periods in longitudinal graphs, 4 class periods in digital pictures, and one class period in data tables (Table 4.4). Compared with the amount of time the class spent on digital pictures in WQ I (2 class period) and WQ II (1 class period), students spent more time engaging in constructing digital pictures during WQ III (4 class periods). Although students already knew how to construct digital pictures technically, during WQ III these pictures were used for a new purpose. These pictures were incorporated into the webpages to support or explain the test results. Thus, students had to reconsider what part of stream area or surroundings they should capture in order to create meaningful pictures for their webpages. This suggests that when an inscription serves a different purpose, students might need to enact different constructing practices. This point will be elaborated in Theme 2 and 9.

Table 4.4

Inscriptions and Inscriptional Practices

Inscription	Inscriptional Practices Total number of class period (WQ I, WQ II, WQ III)				
	Constructing	Interpreting	Reasoning	Presenting	Critiquing
Data table	14 (13, 0, 1)	3 (3, 0, 0)	3 (2, 1, 0)	7 (7, 0, 0)	3 (3, 0, 0)
Model	9 (6, 3, 0)	7 (4, 3, 0)	5 (0, 5, 0)	12 (5, 7, 0)	8 (3, 5, 0)
Chemical representation	---	2 (2, 0, 0)	5 (5, 0, 0)	---	---
Map	---	1 (1, 0, 0)	1 (1, 0, 0)	---	---
Table	1 (1, 0, 0)	---	1 (1, 0, 0)	---	---
pH scale	---	---	5 (5, 0, 0)	---	---
Digital picture	7 (2, 1, 4)	---	4 (3, 0, 1)	---	---
Graph	16 (5, 2, 9)	5 (2, 1, 2)	6 (4, 2, 0)	---	---
Stream drawing	3 (3, 0, 0)	---	2 (2, 0, 0)	---	---
Webpage	12 (0, 0, 12)	---	5 (0, 0, 5)	1 (0, 0, 1)	---

Interpreting Practice

Interpreting inscriptions involved a range of activities in which class members generated meanings out of an inscription and made sense of the phenomena, concepts or data represented by an inscription. Most interpreting practices were demonstrated when students analyzed data, and collaborated and presented findings (Table 4.3). Students demonstrated interpreting practices during all the sub-units. During WQ I, students learned to interpret various inscriptions, including chemical representations, data tables, graphs, maps, models, and stream drawings (Table 4.4).

Fifteen classroom videotapes collected in WQ II were transcribed (Table 4.1). Among these tapes, three of them involved interpreting practices (Table 4.2). In two of the three class periods students engaged in interpreting models and in one of them they were interpreting graphs. As will be discussed later, interpreting practices usually took place when students analyzed data. A lower number of class periods with interpreting practices might have occurred because in WQ I students engaged in analyzing data during class time while in WQ II data analysis was assigned as homework which was not recorded by the classroom videos.

WQ III focused on the construction of webpages and longitudinal graphs, so there were only two class periods involving students' interpreting practices. Also, the only inscriptions interpreted in WQ III were longitudinal graphs. When creating webpages, students did not demonstrate interpreting practices because of time constraints. Although they had to incorporate graphs and digital pictures into their webpages, they usually inserted the files without interpreting these inscriptions.

Reasoning Practice

Reasoning practices were demonstrated in various inquiry areas (Table 4.3). Reasoning with inscriptions involved a range of activities in which class members used inscriptions to make predictions, justify their arguments, categorize substances, conceptualize a process or a phenomenon, and draw conclusions. Additionally, students used inscriptions as resources to support their science inquiry and manipulated them to gain new understandings. Reasoning practices were demonstrated across all three sub-units. Students' reasoning practices in WQ I involved a greater variety of inscriptions, including data tables, chemical representations, maps, tables, pH scale, digital pictures, graphs, and stream drawings (Table 4.4). They used these inscriptions to make predictions, draw conclusions and categorize substances.

Table 4.2 shows that students engaged relatively more reasoning practices during WQ II and most of them happened with their models.[1] In WQ III, when students created webpages, they engaged in reasoning practices, such as using digital pictures as evidence to support their arguments.

Presenting Practice

Presenting inscriptions involved a range of activities in which students displayed inscriptions that they created to a group of students or the whole class. In the water quality unit, three types of inscriptions including data tables, models, and webpages were presented. Because models and webpages were used to represent students' understandings at the end of sub-units, most of presenting practices took place in the area of collaborating and presenting findings (Table 4.3). According to the numbers of class periods (Table 4.4), 60 percent of the class periods that involved presenting activities were related to models.

Students presented their data tables and models during WQ I. During WQ II, they had another iteration of creating and presenting their models. In WQ III, the two classes did not have enough time to present their webpages, so there was only one episode

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[1] More than one inscription could be used during a class period, so some numbers in Table 4.2 and 4.4 might seem mismatched. For example, during WQ I, the number of the class periods that contained episodes of constructing practices was 28 in Table 4.2. However, in Table 4.4 as we add up the numbers of

involving presenting practices when one student pair (Cynthia and Smita in Class I) showed the class how they created hyperlinks among webpages.

Critiquing Practice

Critiquing inscriptions involved a range of activities in which students drew on particular concepts and concerns as criteria to make comments, give feedback, and determine the quality or accuracy of an inscription that was constructed and presented by another group of students. Critiquing practices always took place with students' presentations. Among the three types of inscriptions presented, data tables and models were involved in students' critiquing practices (Table 4.4). In general, compared with the amount of time they spent on other inscriptional practices (e.g., constructing, interpreting, reasoning, and presenting), students in both classes spent relatively less time critiquing each other's inscriptions (Table 4.2). In addition, most of the comments, feedback, suggestions and critiques given to the presenters were provided by the teachers.

Students demonstrated critiquing practices during WQ I and WQ II. In WQ I, students gave comments on other students' data tables and models. During WQ II, all critiquing practices centered on their models. Because the classes ran out of time at the end of the unit, they did not critique webpages.

Classes and Inscriptional Practices

The numbers of class periods that contained inscriptional activities are slightly different between Class I and Class II (see Table 4.2). Class I used more chemical

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class periods that involved constructing different inscriptions, the sum is 30. This is because one class period contained episodes about constructing more than one inscription.

representations and maps during WQ I. In WQ II and WQ III, the two classes had similar numbers of class periods involving constructing, interpreting, and reasoning practices, but students in Class I demonstrated more critiquing and presenting practices. As will be discussed later, the two classes enacted constructing, interpreting, and reasoning practices similarly, whereas they demonstrated presenting and critiquing practices quite differently. Therefore, in the following sections, as I present findings about constructing, interpreting, and reasoning practices, I will discuss the patterns emerging from the data of both classes. Yet, I will use each class as an analysis unit when I discuss students' critiquing and presenting practices.

General Themes

Twelve themes related to students' development of inscriptional practices emerged from analyses of multiple sources of data. These themes organized around four research questions are listed below and will then be discussed in detail.

Research Question 1: What are the characteristics of inscriptional practices demonstrated by seventh graders?

1. Inscriptional practices in an inquiry-based learning environment were purposeful and led by an overarching question and ongoing concerns.
2. Different types of inscriptional practices were interrelated; however, this interrelation might not be fully recognized by students.
3. In general, when the audience and the presenters had a consensus about the content of an inscription and the construction process through their previous constructing practices, students' presenting practices mainly included descriptions

of the components of an inscription without providing explanations, elaborations, or definitions about these components.

4. The two classes presented and critiqued models differently. Students' presenting and critiquing practices might be shaped by teachers' instruction and scaffolds.
5. Students modified their models based on the critiques they received if they had opportunities to construct their models during or right after their presentation.
6. The use of inscriptions provided students with opportunities to engage in thoughtful discussions about concepts and inquiry processes.

Research Question 2: How do students' inscriptional practices change over time?

7. Data tables and bar graphs were used across three sub-units. At the beginning of the unit, constructing practices associated with them were an important and salient part of class activities. As students created and utilized these inscriptions in an iterative matter throughout the unit, the construction of these inscriptions was embedded in students' inquiry process.
8. In general, the level of students' participation in inscriptional activities increased over time. At the end of the water quality unit, students were capable of fully participating in designing a more complicated inscription and interpreting new inscriptions.

Research Question 3: What are the characteristics of the inscriptions created by students?

9. Different inscriptions had different capabilities that allowed students to demonstrate different inscriptional practices.
10. Some inscriptions used in the unit were transformed or incorporated into other inscriptions. Through transformation, students reorganized the data into a way

that allowed them to demonstrate some inscriptional practices that might have not be done with the original inscriptions. However, the incorporations were rather physical than conceptual.

Research Question 4: What aspects of the learning environment help students create various inscriptions and develop inscriptional practices?

11. The design of the curriculum allowed inscriptions to become an important part of inquiry and developed continuity of inscriptional practices.
12. When demonstrating inscriptional practices, students drew upon various social, material and conceptual resources including the artifacts created in previous inscriptional activities and their experience from previous inscriptional practices.

Characteristics of Inscriptional Practices

The first research question of this study is: What are the characteristics of inscriptional practices demonstrated by seventh graders? In Table 3.5 and the overview of students' enactment of inscriptional practices, I defined the five types of inscriptional practices, showed the examples of each practice, and described when and how often inscriptional practices were demonstrated by the seventh graders. Additionally, several themes emerged from the characterization of these practices. First, students were guided to enact inscriptional practices purposefully throughout the water quality unit. As multiple interpretations of an inscription were generated by students, the ones related to the driving question and the ongoing concerns (Bowen et al., 1999) of the unit were encouraged by the teachers. Secondly, one inscription could be involved in more than one type of practice (Table 4.4). Digital pictures, for example, were constructed to make predictions and serve as evidence in webpages. Different inscriptional practices therefore could be interrelated by involving the same inscription; however, this interrelation was not fully recognized by students. Furthermore, I mentioned early that the two classes demonstrated presenting and critiquing practices quite differently. In Theme 3, 4, 5, I will use a series of segments to present the differences in students' presentations and the teachers' instruction between the two classes. These segments show that students' presenting and critiquing practices might be shaped by the teachers' instruction and scaffolds. Together the five themes about the characteristics of inscriptional practices suggest that by initiating or mediating class discussions, the use of inscriptions provided students with opportunities to engage in thoughtful discussions about concepts and inquiry processes.

Theme 1: Inscriptional practices in an inquiry-based learning environment were purposeful and led by an overarching question and ongoing concerns.

In the water quality unit, the overarching question driving students' science investigations was "How clean is the water behind our school?" At least three ongoing concerns (Bowen et al., 1999) were repeatedly addressed throughout the unit: (1) water quality and animal survival, (2) causes and effects of the five water quality tests (i.e., pH, dissolved oxygen, conductivity, turbidity, and temperature change), and (3) human impact on water quality. Table 4.5 summarizes the numbers of class periods during which the classes used different inscriptions and engaged in discussions about the overarching question and three ongoing concerns. Among the three ongoing concerns, causes and effects of the five water quality tests were the most addressed concern across different inscriptions. The use of models and digital pictures involved discussions about the overarching question as well as the three concerns. pH scales seemed a better inscription to indicate water quality and animal survival. Although data tables were used frequently throughout the unit (Table 4.4), few discussions about them were centered on the overarching question and the three concerns. As will be shown in later themes, discussions about data tables mainly focused on experimental procedures, outliers, and inquiry processes.

Table 4.5

The Use of Inscriptions that Involved Discussions about the Overarching Question and Three Ongoing Concerns

Number of class periods	Overarching question	Water quality and animal survival	Causes and effects	Human impact on water quality
Data table	2	1	0	0
Model	3	2	12	5
Chemical representation	0	0	0	3
Map	1	1	0	1
Table	1	0	1	0
pH scale	0	5	2	4
Digital picture	2	1	5	3
Graph	1	0	6	3
Stream drawing	1	0	0	0
Webpage	3	0	5	4

A close examination of the class discussions indicates that students were encouraged and scaffolded to demonstrate inscriptional practices that would come up with meaningful predictions, artifacts, arguments, analyses, and conclusions to contribute to their individual and collective understandings about the overarching question and ongoing concerns. As will be shown by several segments, sharing similar views and concerns with other community members promoted particular ways of thinking and using inscriptions and constituted part of community culture (Lave, 1993; Santa Barbara Classroom Discourse Group, 1992).

For example, one type of reasoning practice demonstrated by the two classes was using inscriptions (i.e., maps, pH scales, data tables and digital pictures) and the information represented by them to draw conclusions. The conclusions class members drew from inscriptions were guided by ongoing concerns of the unit. In the segment below, when introducing pH concepts in WQ I, Andrea emphasized that pH is an important indication of water quality because animals could only survive in certain ranges of pH. The reasoning practices students later engaged were led by this ongoing concern.

←| |→
0__________7_____________14
most acidic neutral most basic
6.5-7.5

Figure 4.1. The pH scale shown on the board and used by Class I in their discussions about animal survival.

(CV001A) Andrea (T) and students discuss why pH is important information to know about the health of a stream.
T: pH can change due to the pollution and animals can live only within certain ranges, so if we get above or below, here we start going this way or down this way [pointing to the scale on the board (see Figure 4.1)], certain animals are gonna die. [T draws arrows to indicate above or below (Figure 4.1).] Okay, let's go back to your page 19 [in the textbook] now.
T takes a copy of textbook and turns to the page.
T: Take a look at page 19 on the bottom (Figure 4.2). What kind of organism can live in the widest range of pH? What organism can live in the widest range?
Several students raise their hands.
T: Sally.
Sally: Bacteria.
T: bacteria. Bacteria can live in horrible pH. And so bacteria is gonna be around forever. They were around million years before other animals started to evolve.
T: If we could not do any testing for pH, we could go to a stream. Ours is a little small. We couldn't really see a lot of fish. We could go to a bigger river. We could see what kind of animals were in there and that could be an indication of the pH, right?

T: so if we went there, and what would we look for that may give us an indication of a really excellent water quality? What would we look for? Everybody looks on the chart.
Several students raise their hands. T looks around the class.
T: Is there any one not sure and can't find it? Beth, what would we look for that tells us excellent water quality?
Beth: there are a lot of animals in there.
T: can you be real specific? Take a look at the bottom. What kind of animal will tell us?
Beth: trout, mayfly, nymphs, catfish.
T: okay. So a large variety of animals. 6.5 to 7.5. We went there and see these animals that will tell us excellent water quality.

Most Acid **Neutral** **Most Basic**
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

The following scale is a range of pH levels suitable to support the identified entity of life:

Bacteria 1.0 ....13.0
Plants (algae, rooted, etc.) 6.5 .... 12.0
Snails, Clams, Mussels 7.0 .... 9.0
Bass, Bluegill, Crappie 6.5 .... 8.5
Carp, Suckers, Catfish 6.0 .... 9.0
Largest Variety of Animals 6.5 ... 7.5
(Trout, mayfly nymphs, stonefly nymphs, caddisfly larvae)

Figure 4.2. The pH scale shown in the textbook (Cromwell, Edlhagen, Hartman, Reese, & Zweizig, 2000) and used by Class I in their discussions about animal survival

In this segment, Andrea restated the reason of why pH is important information to know about the quality of a stream (Line 3-6). Based on the information provided by the pH scale in the textbook, students identified the organism that can live in the widest pH range (Line 9-15). Then Andrea asked a question of what kind of animal could be an indication of a really excellent water quality (Line 17-23) that required students to consider the water quality standards (i.e., excellent, good, fair, poor) and make inferences from the pH scale. Beth's first response to the question (Line 27) suggested that she might answer the question by intuition instead of the information provided by the scale.

Andrea's follow-up questions (Line 28-29) guided Beth to use the scale as a reference. Beth then correctly answered the question (Line 30).

This segment shows that sometimes even though the available inscriptions contained necessary information for students to draw conclusions, they might not know what information should be abstracted from the inscription and how they should use the information after it was abstracted. Andrea's scaffold (Line 27-28) first directed Beth's attention to where the information is ("Take a look at the bottom"). Andrea's initial question (Line 20-21) was "what would we look for that may give us an indication of a really excellent water quality?" When the question was rephrased to "What kind of animal will tell us," Andrea specified the information that Beth should look for in order to draw conclusions.

The following segment shows another example of students' reasoning practices in which they drew conclusions from the data that they collected from the pH experiment. With the teacher's guidance, the class tied the purpose of the experiment back to the concern about water quality and animal survival. Additionally, students realized a need to have more than one test to determine the quality of the stream.

(CV012A) Students in Class I are sharing data collected from their pH experiment. Data collected from groups are shown in the class data table on the board. The pH value of windshield fluid ranges from 6.8 to 7.5.
T: If there is windshield fluid and it affects on the stream [pointing to the table], what would you say in terms of pH?
Noah: there're a lot of cars.
Charles: there is no much change in pH.
Austin: well, it depends on the water of the stream.
T: let's say that the water in the stream is just fine and people use windshield fluid and it gets into the stream. What's the effect it's gonna be in terms of pH?
Charles: not much.
T: not much. Could you expand on that a little bit?
Charles: very little.
T: very little in terms of what? What're you talking about?

Charles: they will still be around 7.
T: what would that mean in terms of the aquatic life that would be able to live in the stream?
Beth: it [pH of the stream] wouldn't change that much, so they're probably able to live.
T: okay, so under this circumstance, the largest range of organisms would be able to live in the stream, right?
Students: right.
T: so according to pH, windshield fluid is just fine.
Cynthia: you can put a lot of windshield into a river [giggles].
T: at least according to the pH. Now, what would you speculate, do you think it's okay to dump in a ton of windshield into the water?
Students: no.
T: no, that's why we need do more than one test, because according to pH, it would be fine to dump in windshield. It would be fine to dump in salt. Some of these [substances] would just be fine. [Pointing to the class data table on the board.]
Cynthia: but…
T: but intuitively, hopefully, it might not be fine. And there might be other reasons that we can't put the stuff in in terms of the quality of water.

In this segment, Andrea (T) used the data table and the data represented by it to initiate a class discussion. At least two important conclusions were made in this segment. The first conclusion was about the potential influence of windshield fluids on the health of the stream. According to students' group data, windshield fluid was neutral. Different responses from Noah, Charles, and Austin (Line 6-8) to the teacher's question suggested that students might take different approaches to think about the possible impact of windshield fluids on the stream. As Charles successfully generated a meaningful conclusion, Andrea used several questions to have him to elaborate his answer so that other students could understand how the conclusion was made (11-15).

Andrea's follow-up question (Line 16-17) tied to the ongoing concern about the pH range and animal survival. In response to Andrea's question, Beth made a second conclusion based on the data and the understandings she had been developing (Line 18-

19). Although the second conclusion seemed valid according to the data they had, it conflicted with intuition (Line 20-32). To resolve the conflict, Andrea indicated a need to search for other reasons (Line 33-34). In saying so, Andrea signaled that the water quality should be determined by several tests instead of one. This was how students were going to answer the overarching question of the unit.

Students' various responses to the teacher's question (Line 6-8) indicate that different conclusions could be made even though students used the same data and the same inscription that were available. As shown in Bowen et al. (1999), multiple interpretations of the same inscription also happened to scientists. Students might draw on different aspects of data or different conceptual understandings to generate conclusions. However, a conclusion might not be meaningful in the context of a water quality unit unless it contributed to the understandings of ongoing concerns and the overarching question. Students' reasoning practices that led to meaningful conclusions were therefore encouraged. In the segment, for example, Charles's and Beth's conclusions were taken up and elaborated. Beth's response suggested that she understood the first conclusion made by Charles. Base on the conclusion and her understandings about pH, she could further make a causal statement about how windshield fluids affect the aquatic life, even though the conclusion seemed to contradict their intuition.

Another ongoing concern—causes and effects of water quality tests—was addressed throughout the unit across the use of different inscriptions (Table 4.5), particularly when students developed their background knowledge, analyzed data and created their models. Students' initial understandings about causes and effects of water quality tests came from classroom activities in the first six weeks of WQ I (see Figure 3.1). During the six weeks, students conducted pH and conductivity experiments in order to investigate the pH values and conductivity levels of substances that might get into the stream. These experiments helped students recognize potential causes that affected water quality of the stream. These potential causes later became part of their explanations for the test results.

Additionally, causal relationships were a crucial part of models. When students constructed models, including both causes and effects of a water quality test to create a comprehensive model was repeatedly addressed during modeling sessions. The segment below happened in Class I during WQ II, when students brainstormed possible driving questions. After Ellen generated a question about causes of high conductivity level, Andrea (T) suggested them to develop a question that would include both causes and effects of a specific test (Line 3-11).

(CV093A)

Ellen: What are the causes of high conductivity level?

T: okay, what are the causes of high conductivity levels? That kind of hooks up with this [another driving question proposed by students]. One of the things that we're able to present, we found that some people were focusing on causes and some people were focusing on effects. But I'd like us to do for our models, please write this down, is to look at the causes and the effects. To look at both, to model both. And using our water quality booklets, so you can use these when you're creating your model. Looking at the background to see what is that… I'd also like us to focus maybe more on people. What do people do that can impact the water quality and what's the effect of that? So we end up with both of these.

In this segment, Andrea suggested resources that could be used when students created models. She also indicated her expectation of students' models: including both causes and effects. This ongoing concern was later brought up again when students presented models and became one of the criteria for students to examine each other's model (see Theme 4).

Inscriptional practices that were encouraged and scaffolded in this inquiry-based learning environment were directional, purposeful and centered upon certain questions and concerns (e.g., animal survival, causes and effects of water pollution, and human impact). Sometimes students might not recognize these questions and concerns. They could still demonstrate inscriptional practices and perform their understandings through practices, such as including reasonable components in their models and generating explanations and conclusions from them (as Noah did in their pH data discussion). However, these components, explanations, and conclusions might not be necessary or significant, and more importantly, were not meaningful in the context of water quality. Through encouraging students to generate certain conclusions, the teachers promoted students to share similar views and concerns with other community members and developed particular ways of using inscriptions.

On the other hand, not all inscriptions that students constructed allowed students to draw meaningful conclusions. Students had to think about the purposes that an inscription could possibly serve when constructing it, otherwise the inscriptions they created might not allow them to demonstrate certain interpreting and reasoning practices. In Theme 2, I illustrate such interrelations among different types of inscriptional practices.

Theme 2: Different types of inscriptional practices could be interrelated; however, this interrelation might not be fully recognized by students.

Among the ten types of inscriptions used in this unit, six types of them (i.e., data tables, models, digital pictures, graphs, stream drawings, and webpages)[2] were constructed by students (Table 4.4). All these six types were involved in two or more inscriptional practices. Two inscriptions (i.e., data tables and models) were even involved in all five types of inscriptional practices. In this inquiry-based environment, therefore, there was continuity of using an inscription between different types of inscriptional practices.

For example, digital pictures were constructed to make predictions so students had to consider what features they should capture while creating digital pictures in order to make meaningful predictions (a related segment will be presented in Theme 9). Additionally, digital pictures were used to support arguments students made in their webpages by the two target student pairs in Class I.[3] When engaging in this type of reasoning practices, both pairs formulated an argument and then searched for evidence to support it. In the evidence-searching process, they modified their argument based on the availability of the evidence. The argument students finally made with the pictures might not be relevant to those presented in the same webpage. The following segment shows an

[2] Tables were constructed by the teachers to summarize how phosphate and nitrogen get into water and what impact these chemicals have on conductivity.
[3] Target students in Class II were also supposed to insert digital pictures to explain their test results in webpages. Because they ran out of time at the end of the unit, the two pairs did not complete their webpages with all required elements (see Table 4.6).

example in which Cynthia and Smita chose digital pictures to support an argument about dead grass increasing the conductivity level.

(CV122A) Cynthia and Smita are looking for digital pictures that could be used in their conductivity webpage.
Smita: we're gonna use the litter and we're gonna say that is dissolved substances.
Cynthia: okay.
Smita: I know where the picture is. I have a picture.
Smita searches for picture and finds a picture of grass.
Smita: see all this lawn, when it dies, they increase the conductivity.
They copy the image and insert the image to the conductivity page.
Smita: let's make it smaller. Okay.
Cynthia resizes the picture and changes the font.
Smita types in the caption: "all of this lawn will one day die causing"
Cynthia: will die.
Andrea (T) stops by to check their progress.
T: so, you guys are almost done?
Smita: we still have a lot though.
T: they will cause high conductivity level because? [Reading the caption on the screen.]
T: do you have another picture? Do you have another picture for this? So this is spring or fall, and we have pictures of winter or something whenever it's dead, right? So you know what? You can split it and put a smaller one, nice and green, and then winter, dead.
Smita: we don't have a picture of winter.
T: I have a folder [in Teacher Station] that says winter stuff on that.
Smita: okay, sure.
T: it's in the digital thing. That says winter.
Smita: okay.
Smita and Cynthia resize the picture.
Smita: Make it smaller.
Smita and Cynthia split the cell into two. They then find a dead grass picture from picture folders in the teacher's station and insert two pictures into their webpage (Figure 4.3).

Prior to searching for pictures, Smita already formulated an argument about litter and knew what picture she needed (Line 3), but she did not find a picture that showed exactly what she wanted. Similarly, Charles and Stefon did not find pictures they needed and wet out to take more pictures (CV120A). It seems that students did not think much about how they would use these pictures when they took them, so they had to either go out to take more pictures or select a picture that could serve a similar purpose. Among the available pictures, Smita chose a grass picture (Line 6-7) to explain an increase in conductivity during the winter. To better support the statement that "all of this grass will die," Andrea suggested them to insert a picture of dead grass (Line 18-21). They took up the teacher's suggestion and used two pictures to show the seasonal changes of grass (Figure 4.3).

Figure 4.3. Digital pictures used in Cynthia and Smita's conductivity webpage

Cynthia and Smita's segment shows that students were able to use digital pictures as evidence to support their arguments about test results. However, the argument shown in the figure captions were made to match the pictures that were available, so they might not be consistent with the arguments described in the data analysis shown in the same webpage (Figure 4.4).

Analysis:

In the fall we had predicted that the conductivity would be around 500 mg/l (poor) at all three locations. We predicted this because people fertilize their lawn in the fall. We were correct because the conductivity was poor. At location A the conductivity was 585.3 mg/l, at location B it was 575.3 mg/l, and at location C it was 564.3 mg/l. All of these are poor. In the winter we got even higher poor numbers. We got higher numbers because there was a lot of salt that was put onto the roads in the winter that could have run-off into the stream. In the spring we predicted poor conductivity levels because the condominium owners (there is a complex right next to the stream) fertilize their lawns and it could easily run-off into our stream. Our results for spring were: 564.5 mg/l at location A, 542.6 mg/l at location B, and 596.1 mg/l at location C. These were all poor, as we had predicted.

Figure 4.4. The analysis paragraph shown in Cynthia and Smita's conductivity webpage. Hyperlinks to the standard page were colored and underlined.

In their conductivity analysis (Figure 4.4), Smita and Cynthia explained that the conductivity level was higher in the winter because of salt on the road. They attributed the high conductivity level in the spring to the use of fertilizers. There was no discussion about dead grass increasing the conductivity level in the winter. To support the argument made in their analysis, Cynthia and Smita should have used pictures of salt on the roads, run-off, or fertilizers and lawn. This inconsistency could be contributed to the different concerns students had when they engaged in constructing and reasoning practices about digital pictures. The digital pictures were not intentionally constructed to serve certain reasoning purposes. Students just searched for available evidence to support arguments relevant to the test, even though these arguments were different from those discussed in their analysis. This indicates that the interrelation among inscriptional practices could also be shown across different inscriptions, when an inscription was created by incorporating several inscriptions. As digital pictures were inserted into a webpage, the meanings of digital pictures were partially determined by the rest part of the webpage. As Roth and McGinn (1998) argued, the meaning of an inscription could arise in the context of other inscriptions. Constructing practices associated with digital pictures might interact with students' reasoning practices demonstrated with webpages, because the availability of digital pictures could determine the argument made in webpages.

Another example that shows the interrelation among inscriptional practices took place in modeling sessions. When students in Class I constructed models, the teacher expected them to create a comprehensive model by including major causes and effects of a water quality test. This expectation later became criteria for students to present and critique models. In the following segment, to help students demonstrate critiquing practices, Andrea first reviewed the ongoing concern students should keep in mind when they constructed models (Line 2-24). She then indicated that these concerns could also be used to examine the quality of models (Line 21-24).

(CV099A)
T: Those of us who are watching make sure that you're looking for… what are we creating a model and thinking of?
Students have no response.
T: When we create our model, and let's say it's turbidity. We're looking for two things.
Charles: uh…
T: creating your model, what do you keep in mind?
Alex: people.
T: not necessarily specific object. But if you're thinking about thermal pollution or turbidity or dissolved oxygen, we're trying to?
Stefon: find the causes and effects.
T: thank you. Okay, so we're looking for what causes things and once those happen what effects they have, specifically effects on what?
Stefon: people.
A student: me.
Charles: living organisms.

T: living organisms and regard to? Is this about decomposition? What's this about?
Charles: water quality.
T: okay, water quality. So we're looking for causes and effects and how they relate to water quality. They can also affect living organisms in the water and stuff like that. Those of us who are in the audience listen carefully for causes and effects, look at a model for causes and effects. And then if you see that there might be something that's missing, we're all here kind of water quality experts, give feedback to the presenters about what they're missing. Also give positive feedback about the good stuff that they have. For those who are presenting, presenters make sure that you keep in mind that's what we're looking for. We're looking for causes and we're looking for effects. Okay, so go ahead, guys.

Looking for causes and effects of a water test was an ongoing concern that was repeatedly addressed throughout the modeling sessions in Class I. But when Andrea asked students about it (Line 2-4), some students still focused on specific objects or variables. Andrea then reminded students about two important concerns of the unit, which were animal survival and water quality (Line 13-20). She concluded that these three concerns were the criteria to examine the model presented (Line 23-26) as well as the focus of students' presentations (Line 27-29). This segment shows that the same set of criteria and concerns could be used for constructing, presenting, and critiquing practices. The three types of inscriptional practices were interrelated and informed each other.

In summary, different types of inscriptional practices were interrelated when they were demonstrated with the same inscription. The interrelation could also be shown across different inscriptions, when one of the inscriptions was created by transforming or incorporating other inscriptions. However, students might not recognize or foresee the potential interrelation among inscriptional practices, so some digital pictures they constructed were unable to serve reasoning purposes that they had to accomplish later.

More scaffolding might be needed to help students recognize this interrelation so that they could construct useful inscriptions that could be used for the enactment of other inscriptional practices.

In the following three themes, I focus on students' presenting and critiquing practices. As I described in Chapter three, presenting practices were not identified as a type of inscriptional practice from my literature review but from the data management process. There seems little research in science education about students' presenting practices. Yet, according to science studies (e.g., Latour, 1987), using inscriptions to present findings is an important practice for scientists to convince their colleagues about what they found from their investigations. The findings about presenting practices might contribute to the understandings about what middle school students' presenting practices look like and how educators could help students benefit from presenting and critiquing each other's inscriptions.

Theme 3: In general, when the audience and the presenters had a consensus about the content of an inscription and the construction process through their previous constructing practices, students' presenting practices mainly included descriptions of the components of an inscription without providing explanations, elaborations, or definitions about these components.

Presenting practices included describing and providing meanings to the components of an inscription, explaining the relationships among the components, elaborating on the ideas based on critiques or feedback they received, and clarifying confusions or questions in a follow-up discussion. Throughout the unit, three types of inscriptions, data tables, models and webpages were presented (Table 4.4). Below I use three examples taken from Class I to illustrate that when the audience and the presenters had developed common understandings about what to construct and how to construct, students' presenting practices involved fewer explanations, elaborations, and justifications.

After students designed their data table for their water quality investigations, groups presented their tables to the class. Students' presentations of an inscription (i.e., a data table and a model) in Class I usually began with a description of the content represented, the categories or the structure of an inscription. The segment below shows an example in which Charles presented a table for the water quality investigation. Notice that he did not explain why he and Stefon chose to include certain categories.

(CV039A) Students work in pairs to design a data table for their water quality investigation. They then draw their tables on the board and present them.
T (Andrea): okay, let's take a look. We start from here [Charles's table], so Charles and Stefon.
Charles: we have [location] A, we have first test, second test, third test and the averages (Figure 4.5).
T: okay, so A, B, C and you have your tests coming down.
Charles: yes.
T: you have turbidity right here. For turbidity, you don't need 1, 2, 3. You only need to leave a large space like these [point to Ellen's table]. But this will work, right?
Charles: yeah.

test	a 1	a 2	a 3	a A	b 1	b 2	b 3	b A	c 1	c 2	c 3	c A
pH												
D.O.												
Temp												
Condct.												
Turb.												

Figure 4.5. A data table for the water quality investigation created by Charles and Stefon

In this segment, Charles described the categories they had in their table (Line 5-6). Andrea particularly pointed out one characteristic of the structure that they had five water quality tests on the first column of the table (Line 7) while some groups had testing locations on the first column. As Charles and Stefon’s table did not take the special data format of turbidity into consideration, Andrea made a correction and used another group’s table as an example (Line 9-11).

In this brief presentation, Charles did not (and was not asked to) explain how they created the table (how they did) or why he had these categories (why they did), in large part because the class designed the table together and had discussed the categories that they had to put into the table (see the designing segment in Theme 7). This suggests that students might demonstrate fewer presenting practices when the audience and the presenter had a consensus about the content or the structure of an inscription through their previous constructing practices. On the other hand, when the meanings of components of an inscription varied among groups, students provided more detailed explanations about the structure and content of their inscription. The following segment shows an example.

When Charles and Stefon presented their model to the class in WQ I, they defined objects and variables (Line 2-7), explained relationships among variables (8-10), and demonstrated the functionality of their model (Line 14-27).

(CV075A) Charles and Stefon show their model (Figure 4.6) in the plan mode.
Charles: our driving question was: How do people and animals affect the conductivity? So we started off with three things: people, water and animals.
Stefon. [Switch to the build mode.]
Stefon: okay. From people, we went into more detail, like people who go to the park and scare away animals. We also set factories, because people build factories. [Moving the cursor to indicate which variable they are referring to.]
Charles: As people scare away animals, there will be less animal waste and more factories. And more factories will be more pollutants in the water and the higher the conductivity.
Stefon: In conclusion, we found that overall the more people there are, the worse the water quality.

Stefon switches to the test phase and opens meters.
Charles: so when there's little people here…
Charles foregrounds the people meter, rearranges the meters, and plays a simulation.
Charles: So there's less people [adjusting the meter] the conductivity is between low and medium. After there's more people, the conductivity is between medium and high.
Cynthia: and the water quality?
Charles: and the water quality [adjusting the people meter]…yeah, the water quality is a lot higher with less people. When there're more people, it's [water quality] about medium.
Stefon: okay, like another one with animal waste, there are less animals, there's less animal waste will enter into the water. So everything depends on how people are, so if there're a lot of people, the water quality is really bad.
Charles: okay, the end.

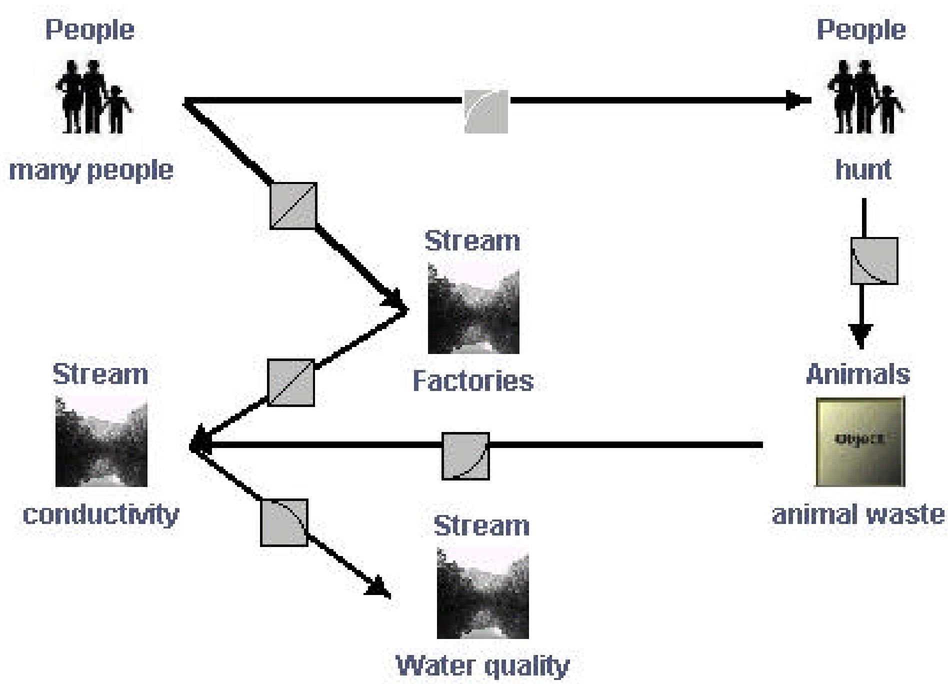


Figure 4.6. Charles and Stefon's WQ I model in the build mode

In the presentation, Charles and Stefon first stated their driving question, described the objects they had in the plan mode (Line 2-3), explained their choices of variables (Line 5-7), explained the relationships between variables (Line 8-10), drew a conclusion in terms of the whole model (Line 11-12), and played a simulation to elaborate on the relationships (Line 15-26). Compared to their brief presentation about the data table, this presentation provided more details about components of an inscription. In addition to giving names, Charles and Stefon defined what each variable meant. They also explained why they included certain variables in the model. Although student groups had variables that used similar names in their models, these variables did not necessarily share the same meaning. For example, the people variable in Charles and Stefon's model represented people "who go to the park and scare away animals," while the people variable in Cynthia and Smita's model referred to people who pollute the stream. This segment suggests that without common understandings about components of an inscription between the presenters and the audience, students who were presenting might engage in presenting practices that involved more defining, explaining and elaborating.

Charles and Stefon's model presentation did not include descriptions of how they created a variable or a relationship because students had learned the construction process through the teacher's demonstrations. How to construct a model by using Model-It was a common understanding among students. In both classes, students rarely explored more features in technological tools and their construction of inscriptions usually did not go beyond the teachers' demonstrations.

There was one exception when Cynthia and Smita applied the idea of hyperlinking to their background paragraphs in webpages. When Andrea modeled the construction of webpages, she demonstrated how students could make hyperlinks between the homepage and test pages. Charles and Stefon's webpages were an example that followed the teacher's demonstration and contained back and forth links between their homepage and test pages. The hyperlinking pattern is shown by a site map in Figure 4.7. Yet, Cynthia and Smita did more links among five tests and standards (Figure 3.6). When Andrea (T) saw what Cynthia and Smita had done, she wanted them to share this idea to other students. In the following segment, Cynthia presented how the linking could be done (Line 10-12), and Andrea suggested that this idea could be used in other parts of webpages (Line 13-16).

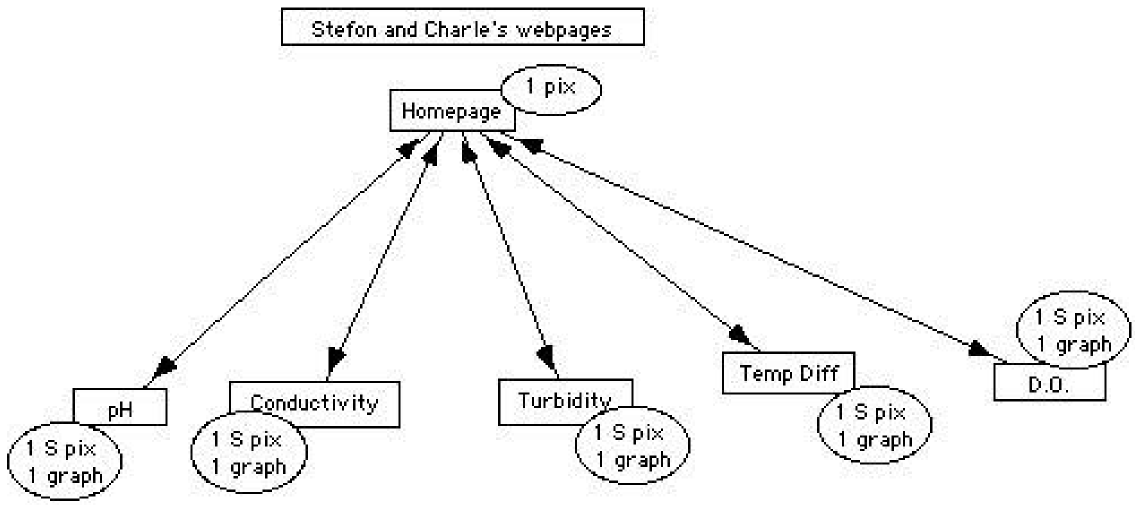


Figure 4.7. The site map of Charles and Stefon's webpages.

(CV122A)
Cynthia: hey, you guys, we have something, a little link thing, you might like to figure out. You can do intralinks between things, so if in background you mention another water quality test, you can make that a link to that page.
Students stop working on the computer and turn to Cynthia and Smita.
Stefon: ye...s.
T: so tell them what your link is.
Cynthia: it was pretty cool. They might have done that.
T: I don't know. So you link to another test…
Cynthia: well, on our temperature thing in the background, we said "cold water could hold more dissolved oxygen in the water" then we have dissolved oxygen hyperlinked.
T: you know what else you can do that? In your analysis, let's say that you're talking about temperature difference was high here because turbidity was high somewhere. You can link to turbidity, right? You can do that in your analysis, too, right?

Cynthia: oh, yeah.
T: to see the graph for turbidity, high in section C, go click over there if they wanna see that. So make connections.

Before Cynthia showed the details of how their group did the hyperlinks, she was aware that other students might have already known it (Line 8), so her presentation might not be necessary. She then used their temperature page as an example to explain how they linked the background to another test page (Line 10-12). It seems that Cynthia did not realize that making links was a powerful way to show connections. The teacher expanded on this linking idea and indicated that they could link the test analyses to each other (Line 13-16) and graphs (Line 18-19).

This presentation happened because Smita and Cynthia found a new way to construct webpages that was not recognized by other students in the class. This shows that some presenting practices were demonstrated in order to reveal what other students did not know. The common understandings between the presenters and the audience were considered when students presented their inscriptions. Some students as presenters were aware of the existence of common understandings and attempted to adjust their presenting practices based on these understandings. In the next theme, I include more evidence to elaborate on the possible interaction between common understandings and presenting practices and demonstrate the differences in presenting and critiquing practices between the two classes.

Theme 4: The two classes presented and critiqued models differently. Students' presenting and critiquing practices might be shaped by teachers' instruction and scaffolds.

As mentioned early in this chapter, students in Class I and II presented their models differently. Students in Class I presented their models in all the three modes of Model-It (i.e., plan, build, and test) whereas students in Class II presented their model in the test mode only. Some presenting practices therefore demonstrated only by students in Class I and the regular sequences of presenting practices were different between the two classes. Presenting a model in different modes seemed to allow students to describe their objects and variables in detail and provide layers of meanings to the components of the model.

Both classes presented models in WQ I and WQ II. The regular sequences of students' presenting practices demonstrated in each class did not change across sub-units, but there were differences between the classes. During WQ I and WQ II, students groups in Class I presented their models in all three modes of Model-It. They first described their driving question, displayed their objects in the plan mode, defined their variables and explained the relationships in the build mode, and finally tested the model. Charles and Stefon's model presentation shown in Theme 3 was a typical example. Four types of presenting practices demonstrated in Charles and Stefon's presentation were: (1) Describing components of an inscription (Line 5-7); (2) explaining relationships among components (Line 8-10); (3) providing reasons to include certain components (Line 5-10); and (4) elaborating on ideas based on critiques or feedback given by the audience (Line 21-23).

On the other hand, students in Class II only showed the test mode of their model in both sub-units, so they usually did not define the objects and variables in their model. Groups in Class II began a presentation with their driving question, explained the relationships they had and ran a simulation to test the model. Below I use Ally and Denny's presentation (Class II) in WQ I as an example. Their presentation focused on relationships in the model. As their model was presented in the test mode only, they did not provide descriptions or definitions to individual variables and objects but explained each relationship in detail. The segment below shows an example.

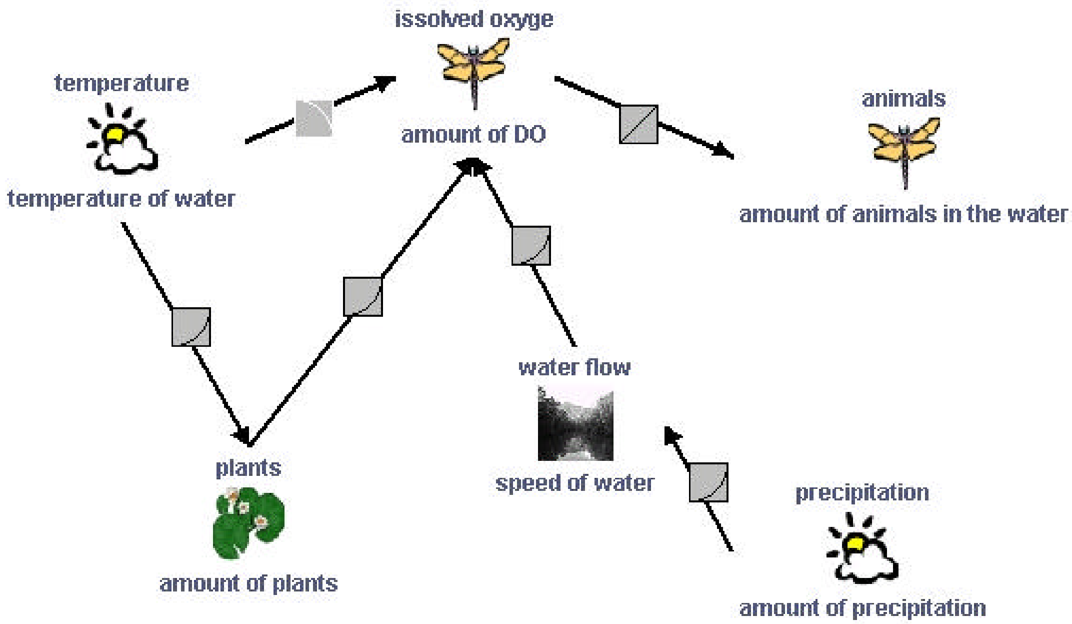


Figure 4.8. Ally and Denny's WQ I model in the build mode

(CV078C) Ally and Denny present their model (Figure 4.8) in the test mode.
They open up the file, open meters, rearrange meters, and play a simulation.
Denny: our question is how much, oh, what affects the DO.
Ally: and when the amount of precipitation goes up, then the water flow goes up which affects the amount of DO.
T (Celia): Okay.
Students resize the simulation graph.
Denny: the amount of plants in the water affects the DO.
T: that's affected by what?

Ally: the amount of plants.
T: yeah.
Ally: that's affected by temperature.
Denny: by temperature, because in warmer water, more plants grow up. So if you raise this [temperature],
Ally: means the temperature goes up
Denny: and the amount of plants goes up.
Ally: and the amount of DO goes up.
Ally: If the temperature goes up, it affects the plant which affects the DO.
Denny: the DO goes down, because warmer water can't catch that much DO.
Ally: okay, then the amount of precipitation…
Denny: affects the water quality, because more water runs into the stream, the faster water flow in the stream. So the lower amount of precipitation, the water flow in the purple goes down.
T: okay.
Denny: similarly when you raise it, it goes up.
Ally: and then, the amount of DO affects the amount of animals in the water.
T: okay.
Ally: more DO, there's more animals can survive, because they need DO.
T: all right, you're good.

Ally and Denny began their presentation with their driving question (Line 3) and then explained the causal relationships between variables one by one while playing the simulation (Line 4-28). For each relationship, they stated the independent and dependent variables and indicated why the relationship was established (Line 13, 19, 21, 28). This sequence is different from the one demonstrated by Charles and Stefon.

In the two presentations (Charles and Stefon; Ally and Denny) shown above, both student groups explained relationships among variables of their model. They indicated what the independent and dependent variables were and described how the value of a dependent variable would change if the value of an independent variable increased or decreased. The way they explained their relationship was consistent with the textual description provided by the relationship editor on Model-It (Figure 4.9). For example, the description at the bottom of the editor shows, "As temperature-temperature of water increases Dissolved oxygen-amount of DO Decreases BECAUSE cold water holds more DO." This description included changes of an independent and its dependent variables, and a BECAUSE statement. In their presentation, Ally said, "If the temperature goes up, it affects the plant which affects the DO" and Denny added, "the DO goes down, because warmer water can't catch that much DO."

However, the nature of explanations provided by the two groups was slightly different. For some relationships, Ally and Denny provided reasons of why there was a relationship between the two variables (Line 13, 19, 21, 28), while Charles and Stefon tended to describe the changes of meters when they demonstrated relationships in the test mode (Line 17-19, 21-23). On the other hand, Ally and Denny focused on explaining individual relationships, whereas Charles and Stefon drew conclusion from the whole model (Line 24-26).

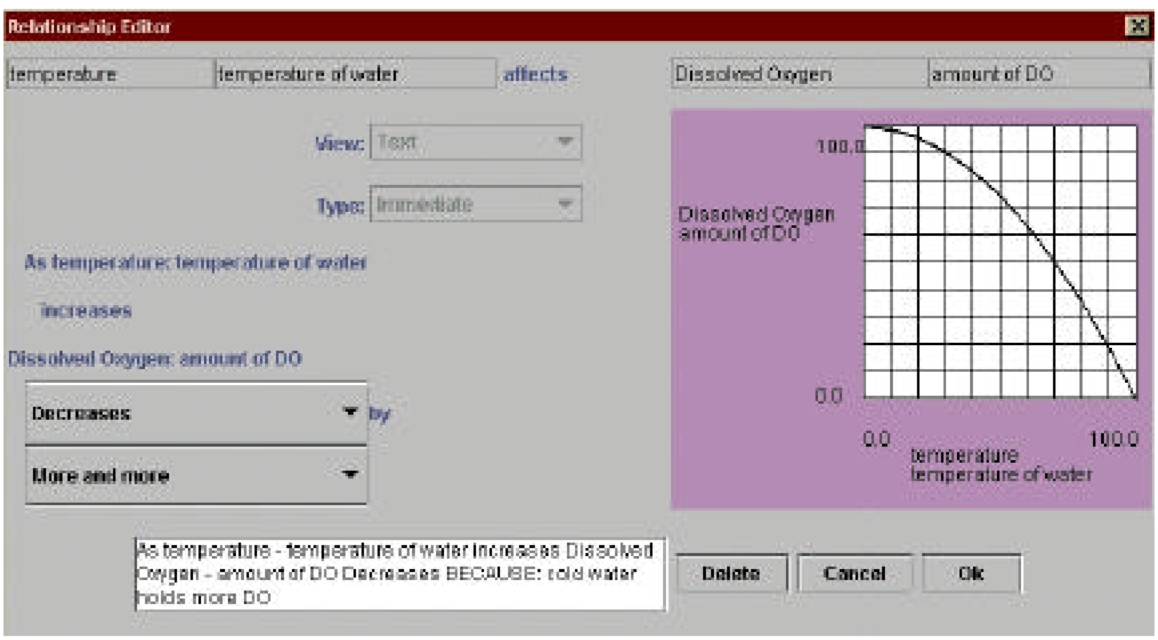


Figure 4.9. The relationship between temperature of water and dissolved oxygen created by Ally and Denny

In the two presentations, Charles and Stefon demonstrated more types of presenting practices. However, how students presented their models might not be related the quality of their model. The two models (Figures 4.6 and 4.8) contained the same numbers of variables and relationships, but the variables and relationships in Ally and Denny's model were more accurate and meaningfully in terms of the concepts that were emphasized in the unit. All of the components in Ally and Denny's model were major factors about dissolved oxygen and represented the concepts they had learned in the unit, although they did not include a water quality variable. In Charles and Stefon's model, the people hunting variable was not a major factor in terms of water quality that was later critiqued by the teacher and other students. Also, as this variable increased with an increasing number of people, the animal waste decreased which led to a lower conductivity level. This result would contradict the result caused by another series of relationships with the increasing number of people (i.e., the relationships between people and factories and between factories and conductivity). Therefore, compared to Charles and Stefon's model, Ally and Denny's model was better in terms of content accuracy and model functionality. The variety of students' presenting practices therefore was not an indication of the quality of their model.

An analysis of teachers' instruction might provide possible explanations to the differences in presenting practices between the two classes. Below I show the instruction each teacher gave prior to students' presentations. Both teachers provided scaffolds when students were presenting, and the scaffolds were consistent with their instruction shown below. The following excerpts indicate that the two teachers had different expectations about what to present and how to present.

The instruction given by Andrea (Line 2-15) before students' presentations focused on "going through the model step by step."

WQ I Model presentation Day 1, Class I (CV075A)

Charles and Stefon are the first group to present. [The presentation is shown in Theme 3]

Charles: what do we show them? Should we do our test?

Andrea: what we're gonna do is this. When you present, go through the model. Give us a start with your driving question, so we know what you try to model.

Charles: okay, should we go to the build first?

Andrea: Show us your test and we'd like to see the meters and the graph. Explain to us and show us how it works and talk about your objects and things. The rest of us, what we're trying to do is critique it. We try to be critical in a scientific way.

WQ II Model presentation Day 1, Class I (CV099A)

Andrea: everyone listens. When everyone is presenting, make sure you start by telling us what your driving question is. You know explain what you're trying to model. And then go through your model step by step.

On the other hand, the instruction given by Celia (Line 16-29) emphasized whether the model worked.

WQ I Model presentation Day 1, Class II (CV076C)

Celia: okay, today we're going to have presentations of your model. If you and your partner come up here, remember how you practiced, who is gonna say what and how you're gonna present your model. I'm gonna ask you some questions. It's gonna take few minutes when a group comes up here for them to adjust the meters, so that it comes into one screen. All right? So I'm gonna ask that people who have had no problem with their models opening it so far come first. Do you wanna try?

Allan and Elaine set up their model on the teacher's station.

Celia: why don't you go to test and set up all the graphs?

WQ II Model presentation Day 1, Class II (CV100C)

Celia: now as you're thinking and setting up your model, you wanna be sure that you present your question, okay? What your driving question is, what you build your model around. And then explain how your model works. Run the model and then show us the graph, okay? And that will be helpful.

These excerpts show that each teacher gave similar instruction across the sub-units but there were different focuses between teachers. Andrea emphasized components of a model as well as “how it works” (Line 8-9). She wanted students to go through the model (Line 5) and present it “step by step” (Line 12-13). As shown in Charles and Stefon’s presentation, they presented the model in every mode and provided explanations for objects, variables, and relationships. On the other hand, Celia focused on whether a model worked (Line 18-19, 26-28). She asked Allan and Elaine to present the model in the test mode, and the analysis shows that all presentations in Class II focused on explaining relationships in the test mode. It seems that what students presented to the class and how they presented were shaped by the teachers’ instruction.

In Theme 3, I suggested a possible interaction between common understandings and presenting practices. Students in Class I tended to provide more explanations and elaborations when the presenters and the audience lacked common understandings about the components of an inscription. However, this seems not a case in Class II. Students in Class II also lacked common understandings about variables created by different groups, but they did not define their variables in presentations as shown in Ally and Denny’s presentation. It seems that my previous interpretation about students’ presenting practices in Class I was not fully supported by Ally and Denny’s presentation.

The analysis of the teachers’ instruction provides more information for me to elaborate on Theme 3. Teachers’ instruction indicated their expectations to students’ presenting practices, and by following the instruction students demonstrated certain presenting sequences and chose to explain certain components of a model. This suggests that whether there were common understandings and what common understandings existed between the presenters and the audience might not be recognized by students but the teachers. Analyses of students' presentations show that some explanations or elaborations would have not been provided without teachers' questioning, although some students were aware of possible common understandings while presenting (e.g., Cynthia's presentation of hyperlinks).

If common understandings between the presenters and the audience interacted with students' demonstration of presenting practices, another question that should be clarified is: Who did students consider as the audience when they presented their model? Analyses of students' presentations suggest that students usually viewed the teacher instead of other students as the audience. In both classes, teachers gave most of feedback, comments and critiques. Throughout Ally and Denny's presentation, the teacher gave short supportive responses (e.g., okay, yeah). Several student groups (including Ally and Denny) talked to the teacher instead of the whole class when they were presenting. When Celia gave instruction prior to students' presentations, she did not mention the role of students who were not presenting during presentations, but reminded students that she would ask some questions. Therefore, in a learning environment, students usually viewed teachers as the audience, and what common understandings should be developed or given through the presentation were mainly determined by the teachers.

There were also differences in students' critiquing practices between the two classes. Similar to the patterns shown in presenting practices, students in Class I appeared to demonstrate critiquing practices more frequently and some types of critiquing practices were only demonstrated in Class I. The analysis of teachers' instruction and scaffolds shows that Andrea indicated how students should present and critique models, while Celia emphasized how the presenters should do. Students in Class II did not receive any specific instruction or scaffolds about how they should give feedback or critique a presentation.

In each class period that involved students' presentations, Andrea (T) gave specific instruction about how students in the audience should participate in presentations. As the segment shown in Theme 2, Andrea reminded students that their models were to represent their understandings about causes and effects of a given water quality test (Line 2-12), and suggested students to look for missing components (Line 23-25). The instruction invited all students to take part in presentations even though they were not presenters.

Additionally, Andrea provided scaffolds for critiquing practices during presentations. She provided a series of questions to engage the whole class in critiquing the model presented. For example, in WQ II, after Ellen and Marie's model presentation, Andrea (T) guided students to comment on the model. Ellen and Marie's model was built to answer a question about turbidity.

(CV099A)
T: do they have causes and effects?
Charles: uh…they have causes.
Smita: they have a lot of causes.
Charles: they have one effect.
T: what's the effect?
Charles: the water quality.
T: okay, are there other effects that they could add to their model?
Austin: the animals.
T: okay, the animals that we talked about already.
Cynthia: why don't they have fish?
T: they lost the half of their model.
Students talk about their experiences of losing models because of a technical problem with the program.

T: any other effects that we can put in with this? What else are affected when the turbidity level is high?
Austin: if the water gets murky, people get sick.
Charles: thermal pollution.
T: so they could be thermal pollution, if the turbidity increases, right?
Austin: the more people will die.
T: so they can add more people.
Charles: the more people, the higher the turbidity. They have construction and stuff.
T: although I think that's kind of representing in terms of you started out with a lot of oil, cars and the amount of soil, because trees are cutting down. But some of the effects like thermal pollution could be added.

In this segment, students' critiquing practices were scaffolded by Andrea's series of questions. As Ellen and Marie's model contained all the major causes, students' critiques focused on the effects that were missing in the model. Several students volunteered their ideas (Line 19, 21, 17, 18). Charles's comment suggested a possible relationship that Ellen and Marie could add (Line 32). By giving feedback and comments on other students' models, students demonstrated and reviewed their understandings about a water quality test.

Ellen and Marie were the first group presenting in WQ II. After Ellen and Marie's presentation, students did not voluntarily give feedback or comments on their model until Andrea asked the question about causes and effects (Line 12). It suggests that students needed guiding questions to engage in critiquing practices. The series of questions Andrea posed provided a set of criteria for students to evaluate a model and framed a presentation as an opportunity for a whole class to review concepts and demonstrate inscriptional practices.

In summary, there were differences in presenting and critiquing practices between the two classes, but within a class, students' practices were similar across sub-units.

According to an analysis of the teachers' instruction and scaffolds given before and during students' presentations, it seemed that teachers had different expectations to students' presenting and critiquing practices that in turn might shape students' inscriptional practices.

Throughout the unit, students created models twice and were expected to modify their first model to create a more complicated model in their second exposure. Did they really do that? What is the value of having students presenting and critiquing their models? In Theme 5, I indicate in what situations students might benefit from giving and watching presentations.

Theme 5: Students modified their models based on the critiques they received if they had opportunities to construct their models during or right after their presentation.

Students constructed models twice in the unit. Based on the critiques they received, students were expected to revise and modify their WQ I models in the second exposure of Model-It. Students in both classes did not do so, in large part because the program version was changed. Students were not able to open their first model during WQ II. Additionally, there were three months between the first and second model constructions. It is unlikely that students could remember all the critiques, as the analysis of their notebooks shows that none of them wrote down the critiques they received in WQ I. Furthermore, the analysis of students' models indicates that some students, who created their second model for the same driving question, did not take the critiques and feedback into consideration while creating their second model. Therefore, a comparison between students' first and second model constructions suggests that students might not benefit from receiving feedback and critiques.

However, analyses of classroom activity data, process videos, and students' models collected from Class I show that in some situations, students revised and modified their models based on the critiques. Students in Class I had a small group presentation during WQ II in which two groups of students presented their models to each other. In the segment below, Cynthia and Smita presented their models to Charles and Stefon and modified their models as they were receiving feedback from Stefon and Charles.

(CV095A) Cynthia and Smita show their model to Charles and Stefon. Their model is about thermal pollution. The model is shown in the build mode.
Cynthia: okay, factories dump chemicals, more thermal pollution. More hot water, more thermal pollution. More rain water, more thermal pollution, and more plants dead, more thermal pollution.
Stefon: do you have people somewhere in there?
Cynthia: no.
Smita: what do you call this?
Cynthia: yeah, what we should do?
Smita: factories and people.
Charles: the amount of people.
Stefon: and you should also have sidewalks, 'cause just rain doesn't mean anything. The rain could be the same temperature as the water.
Stefon: you should probably have people.
Charles: how much rain could affect that?
Charles: it could only affect it if there's a lot of people
Cynthia and Smita are adding people and sidewalk objects.
Charles: I think you guys need people.
Stefon: you could just say there's a person.

In this segment, Charles and Stefon indicated what was missing in the model (Line 6) and suggested Cynthia and Smita to make some changes (Line 12-13, 18-19). The students gathered around Cynthia and Smita's computer during the presentation, so Cynthia and Smita could revise their model when they received feedback. Their final model included people and sidewalk objects.

Additionally, during WQ II, after all student groups in Class I presented their models, the class spent approximately twenty minutes revising their models based on the feedback they just received (CV101A). These two examples show that revisions would be made and that students could benefit from presenting and critiquing models if they had opportunities to modify their models during or right after their presentation.

Presenting more examples about the use of inscriptions in the two classes, Theme 6 is an overarching theme that concludes the findings from Theme 1 to 5. This theme suggests the value of using inscriptions in science classrooms.

Theme 6: The use of inscriptions provided students with opportunities to engage in thoughtful discussions about concepts and inquiry processes.

In the previous five themes, I use segments to illustrate that students engaged in discussing pH levels and animal survival, using digital pictures to explain their test results, identifying causes and effects of a given water quality test, and explaining causal relationships in their models. These segments show that using inscriptions could initiate and mediate thoughtful class discussions. When engaging in these discussions with inscriptions, students applied, reviewed, and externalized their understandings about concepts. In this theme, I include more evidence to show that the use of inscriptions provided students with opportunities to engage in thoughtful discussions about concepts and inquiry processes.

Inscriptional practices involved not only the structure of an inscription and the data represented by it, but also the inquiry process and relevant concepts. In WQ I, creating data tables was part of designing an investigation. Among the 13 class periods that involved constructing data tables in WQ I (Table 4.4), the two classes spent four class periods creating data tables prior to their pH and conductivity experiments, and four class periods making data tables for their water quality investigation. Through creating these data tables, students reviewed procedures of the investigation, decided what information should be collected, defined measurement to make, and managed data collection. The following segment shows a typical example. Ally and Alan reviewed procedures of their pH experiment (Line 9, 15, 35-37) and brought up their understandings about pH (Line 20, 39-40) as they created a table for their pH experiment.

(CV006C, EP 1) Students in Class II plan procedures for their pH experiment. Celia (T) wants them to “include what data table would look like to gather the information that you need.” Alan and Ally work together.
Ally: let’s make a chart.
Alan: yes.
Ally: so it could be like something [substances] in the first column. [Sketching a table on her notebook.]
Alan: okay.
Ally: Oh, so what kind of data are we getting out of it? Are we getting numbers, color or what will we get?
Alan: We’re getting pH level.
Ally: in numbers?
Ally looks at another girl in her table. The girl confirms her question, “It’s number.”
Ally: okay, so we can have like trial 1, trial 2…[draw columns on her notebook.]
Alan: oh, good.
T talks to the class: You don’t fill in any numbers, but what are the categories you will place into your data table?
Alan: oh. [He turns to Ally.]
Alan: so we need neutral, basis, and acidic.
Ally asks T: are we supposed to have like this? [Ally shows T her table.]
T: yes, yes. Something like this.
Ally: what else do we add to it though?
Alan: then from this side, we try to put like neutral, basic, and acidic and draw a line. Put a check if it’s…
Ally: you wouldn’t know what they are until you fill it out.
Alan: yeah. But after we’re doing the graph, we…
T: this is a good start.
Ally: we wouldn’t know if it’s basic or acidic until you…
Alan: so you did it. This is just a graph that we’re able to use, and so…
Ally: and then, here basic or acidic [Writing these words on her notebook]. Basically, we’re like this. Put your substances down, would like whatever. Do you see what I’m doing? Do you understand?
Alan: yeah.

Ally: you put substances down, and you put that [trial 1] down, you put that down, you put that down, write average, and then basic or acidic, and put that down.
Alan: okay, so we're doing…we figure out what they are and in the end.
Ally: and the trial pH level whatever it is. Is it acid middle? Or whatever is put here.

Ally first had a question about data format (Line 9-14). She was then confused about creating a table without any data (Line 26), so Alan's suggestion about having a column about neutral, basic and acidic (Line 24) did not make sense to her. With the scaffolding provided by the teacher and Alan, Ally was able to conceptually go through the experiment and took up Alan's suggestion, even though she was not certain about the pH range of acid (Line 39). Their final table is shown in Figure 4.10.

Substance	Try 1	Try 2	Try 3	Average	Basic or Acidic

Figure 4.10. The pH data table created by Ally and Allen

In this segment, Ally and Alan's understandings about pH and the experiment were provoked and their confusions were revealed when they designed a data table. Ally's constructing practice was constrained by her limited understanding about the procedures of the experiment. Furthermore, if she could not figure out the pH range of acid while recording data, her constructing practices (i.e., recording data) would have interrupted by her limited conceptual understandings about acid, base and neutral.

To illustrate how students' conceptual knowledge was involved in their inscriptional practices, below I present two segments that show how students' understanding about turbidity and thermal pollution was externalized through constructing models and a group discussion. When engaging in inscriptional practices with models, students exchanged information, shared and clarified ideas, gave and received feedback. Models became artifacts of their emergent understandings about water quality.

In the first segment, Stefon and Charles engaged in a discussion of whether they should make a relationship between two variables, sun and turbidity. Notice that the textual description provided by Model-It helped them realize that the relationship between sun heat and turbidity was a simple causal relationship.

(PV169, Build Mode, 9:25 AM) Charles and Stefon's model is to answer the question of "What are the effects and causes of thermal pollution?" They create a relationship between turbidity and thermal pollution in the build mode and start discussing whether they should connect turbidity to the sun variable.
Stefon: actually, you got to say the sun. You got to connect it to the sun.
Stefon: should we connect to these two [turbidity and sun]? [The cursor is moving between turbidity and sun.]
Stefon: the sun heats up the stream.
Charles: the stream is turbid.
Stefon: so why don't just connect this [sun] to that [turbidity]? Everything will be fine.
Charles: so sun goes to turbidity?
Stefon: because sun is the cause and it affects the turbidity and it also affects thermal pollution.
Stefon: it causes the heat. It puts the heat into the turbidity.
Students create a causal relationship between sun and turbidity.
Stefon: oh, wait, that's wrong. [Reading the textual description provided by the relationship editor] As the sun heat increases, turbidity increases.
Charles: yah.
Stefon: That's wrong. Cancel.

Stefon and Charles understood that sun heat affects thermal pollution when the stream is turbid (Line 8-14), but a simple causal relationship between sun heat and turbidity did not represent what they meant. The textual description provided by the tool helped students realize that the relationship between sun heat and turbidity was not causal which led Stefon to cancel the relationship (Line 17-20). Stefon and Charles were not the only pair who had difficulties representing their understandings about sun heat, turbidity, and thermal pollution. As shown in the segment below that occurred in the same class period, all three groups modeling the same question about thermal pollution could not figure it out. Andrea (T) used this common confusion as a learning opportunity and gathered the three groups to discuss the relationships among sun heat, thermal pollution, and turbidity. Through a big group discussion, students shared ideas (Line 34-52) and clarified their confusion.

21 (CV095A, 9:41 AM) T notices that the three groups [Annie/Carla, Cynthia/Smita,
22 Charles/Stefon] who are creating models about thermal pollution have the same
23 difficulty in making connections among sun heat, turbidity and thermal pollution.
24 She gathers them together to discuss a solution. Andrea first asks students “what
25 can the weather and the sun do?” Students volunteer their ideas that sun could
26 directly warm up the stream, warm up the particles in the stream, and hit
27 sidewalks and pavement.
28 T: let’s hold this idea that it hits the sidewalks or parking lots or roof tops. Okay
29 now this is the question that I posted to them yesterday. We have some days with
30 sunshine in February, right?
31 Stefon and Charles: yap.
32 T: and if we have sunny days in February and sunny days in July. How might
33 those compare in terms of their effects on thermal pollution?
34 Carla: not really, I mean if there’s whole stream.
35 Several students are talking at the same time.
36 Charles: it wouldn’t change, would it?
37 T: well, I don’t know.
38 Charles: if the stream is really cold, the water would be very cold, too. It
39 wouldn’t be that much difference, ‘cause in July, the water will be warm, but it
40 heats it up more, too.
41 T: okay.
42 Annie: if it’s winter, water would be colder. And if the sun heats it up, it probably
43 heats it up as much as it does in the summer.
44 Charles: but the stream is already hot, it’s not gonna be heated up.
45 Carla: but it might rain more
46 Stefon: sometimes I remember sometimes in the winter, if it’s sunny, it’s probably
47 colder outside.
48 T: what about the temperature of the roads, the buildings, and the sidewalks?
49 Charles: maybe colder.
50 Annie: they heat up in summer.

Charles: there’re seasons. You need a season variable. That will connect to your sun variable that will connect to your turbidity variable.

Students’ responses to Andrea’s question (Line 25-27) indicate that they had some understandings about how sun heat might directly or indirectly warm up the stream and cause thermal pollution. They also realized that sun heat does not always cause thermal pollution (Line 34-36). Andrea’s questions about the weather in different seasons (Line 32-33) became crucial for students to re-think about the relationship between sun heat and thermal pollution. Her questions led a productive discussion among students (Line 34-52) that clarified the ideas and deepened their understandings about thermal pollution. At the end of the segment, Charles realized that what they needed was a season variable that could mediate the relationship between sun heat and turbidity.

Teachers had students to create models to externalize their understandings about water quality. As shown in the previous segment, through constructing models, students’ confusion about certain concepts was revealed. The discussions that helped students clarify their confusion might have not taken place if each student pair had worked on a different question. In WQ I, student pairs modeled their own questions. They did not have opportunities to work as a big group and shared common difficulties as shown in the segment above. In WQ II, 6 groups in Class I modeled two questions (i.e., thermal pollution and turbidity), and formed two big groups to discuss their common issues with their models. Their models accommodated the ideas they got from big group discussions. In a sense, each model was co-constructed by the three groups.

Additionally, giving and watching presentations provided students with opportunities to reveal their confusions or questions about concepts, investigations and the use of technological tools. After some model presentations, class members engaged in discussions about the confusions or questions raised by the presentations. Different from other presenting practices that were enacted by the presenters, this type of presenting practices involved all class members. It was demonstrated by both classes during WQ I and WQ II. Among 12 modeling sessions that involved presenting practices (Table 4.4), 9 sessions had class discussions after presentations. The segment below shows that after watching Alan and Elaine's model presentation Jade had a question in terms of the causes of turbidity (Line 2-3).

(CV076C)
Jade: they [Alan and Elaine] have human, they have litter for human. One variable is turbidity. One is litter. What does litter cause turbidity?
T: uh…what is turbidity due to?
Jade: like, erosion.
T: Litter will be included as turbidity, but you're right, turbidity is erosion or things like that.
Abby: suspended particles.
T: yeah, suspended particles and litter could be suspended trash. I guess turbidity in my mind would be more the natural and litter would be more the social. So separating those two would be better.
Alan: the increase of litter increases turbidity and also …turbidity, cutting down trees…
T: so cutting down trees will affect turbidity as well?
Elaine: yeah.

This segment suggests that a model presentation could initiate a discussion about concepts. After Jade posted her question, the teacher did not provide an answer but questioned her about the possible causes of turbidity (Line 4). Jade's response indicated that she knew a major cause of turbidity (Line 5) and just could not figure out why litter could be one. Abby joined the discussion and provided a definition of turbidity (Line 8).

Based on the definition, Celia explained why litter could cause turbidity and indicated that both erosion and litter could cause turbidity but came from different sources (i.e., natural and social). Alan and Elaine then provided another cause of turbidity which was cutting down tree (Line 12-14); however, the relationship between cutting down trees and turbidity indeed was indirect and erosion would be the mediating variable in the relationship. This segment shows that engaging in presenting practices not only revealed the presenters' understandings about a topic but also brought up other students' understandings about the topic.

In summary, the use of inscriptions could initiate class discussions and externalize students' understandings (as well as confusions) about concepts and inquiry. Students' confusions and questions could then become opportunities to learn if the classes had follow-up discussions and activities to clarify them and further explore the topic. Also, inscriptions allowed students to demonstrate their emergent understandings.

From Theme 1 to 6, I showed the characteristics of students' inscriptional practices. In the next two themes, I will demonstrate students' learning trajectories of constructing and interpreting practices in answer to my second research question.

Historical Development of Inscriptional Practices

The second research question of this study is: How do students' inscriptional practices change over time? By using inscriptional practices as tracers, I was able to trace the historical development of inscriptional practices in the eight-month water quality unit. Within the time frame of the unit, not every inscription was practiced multiple times (Table 4.4), so the two themes presented below only involve the inscriptions that were practiced iteratively in the unit. In Theme 7, I will use a series of segments to illustrate how students' constructing practices of data tables changed over time. This theme will show that as students created and utilized data tables in an iterative manner throughout the unit, the construction of them was embedded in the unit and became an integral part of doing science in the two classes. Additionally, students increased their participation in designing a more complicated graph and interpreting new inscriptions. Theme 8 will illustrate the processes from peripheral to central participation in interpreting practices (Lave & Wenger, 1989). These processes indicate students' emergence and development of inscriptional practices.

Theme 7: Data tables and bar graphs were used across three sub-units. At the beginning of the unit, constructing practices associated with them were an important and salient part of class activities. As students created and utilized these inscriptions in an iterative manner throughout the unit, the construction of these inscriptions was embedded in students' inquiry process.

During WQ I, the classes spent a substantial amount of time planning, constructing, and modifying data tables and bar graphs. They discussed qualitative or quantitative data that should be included in data tables, discussed conventions or rules used for a bar graph (e.g., x and y axes in a graph), and decided the categories or structures of a table or a graph. These practices were intensively scaffolded by the teachers during WQ I. As students had more and more opportunities to engage in these practices, their participation increased and teachers' scaffolds faded out. To demonstrate how these constructing practices changed over time, below I use students' construction of data tables as examples. I present a series of segments to illustrate students' learning trajectories when they constructed data tables.

Prior to the construction of an inscription, planning seemed crucial for the seventh graders to successfully construct an inscription. As novices at conducting science inquiry, these seventh graders had no experience in creating inscriptions to serve given purposes. The following two segments taken from Class I show how students constructed their first data table for the pH experiment. In the first segment, when the teacher asked students where they could record the data collected from their pH experiment (Line 4-6), students' responses (Line 7-13) suggested that they had limited experience in creating tables.

(CV005A, EP 2) Procedures of the pH experiment are written on the board after class discussions. Andrea (T) wants students to think about what should be used to record their data.
T: We wanna test and we wanna record. We know what we're gonna do the test now, and this [record] is what we wanna work with. We're going to record the data. What are we going to record in? [T circles the procedures, test and record.]
Carla: graphic notebook.
T: oh, that's where we're going to record.
Carla: oh.
T: in what will we record it in our graphic notebook?
Charles: number.
Noah: pencil.
Student: quantitative.
T: it's quantitative data with our emate. We could also include qualitative data, right?
Cynthia: we're gonna have to make a…uh like a table of it.
T: we need to create some kind of table.
Cynthia: can we do that in computer?
T: we can. You can. A data table. We need somehow to create a data table. Why do we wanna do that? Annie.
Annie: because … organize?
T: yes, we wanna organize our results. We wanna organize them. [T points to the procedure on the board.]
T: okay. This is what I want you to do. With the person next to you, I want you somewhere in your graphic notebook to create a data table. Think about everything that has to go in there. Take all the stuff. See what you come up with. I'm not gonna give you a data table. We're gonna create one together. So just do a sloppy copy somewhere in your book and what you wanna put in this data table. Then we'll share and we'll see uh… hopefully between all of you will get an idea what kind of data table. [T points to the procedures on the board again.]

In response to students' answers, Andrea rephrased her question (Line 10), but it seemed that students still did not fully understand the question or had no idea about using tables to record data. Although Cynthia suggested using a table, she seemed not certain about it (Line 15). Andrea confirmed Cynthia's answer and further asked for the purpose of using a data table (Line 19-23). Annie gave a correct answer, but she was also not confident about her answer (Line 21). When Andrea assigned the task, she indicated where students should draw the table, but did not provide specific information about the format or the possible content of the table (Line 24-30). As can be seen in the next segment, some students did not know what a data table was supposed to look like (Line 32-33). Based on students' constructing practices demonstrated in groups, Andrea provided more information about what should be included in their table (Line 39-44).

(CV005A, EP 2) Students work in groups to design their pH table. T is in a table with four girls. One girl's (Carla) idea is to use a pH scale and indicate different substances on the scale.
T: you could do that afterward, so you can make 0 to 14 you were talking about, and the stuff all on the line.
Carla draws something on her notebook and shows it to T.
T: Carla, I think that's a great idea after we get the data. That's one way, remember we said graphing, somehow we need to represent our data. That will be one excellent suggestion. Okay. But first we need to collect our data. We need to have spaces to put…We [T raises her voice and talks to the class] need to have spaces to put 3 times, right?
Students: yeah.
T: and the averages. Come up with some kinds of table, talk with each other. If you're not sure, the two of you could start to talk as a table.

At the end of the first segment, Andrea did not explain what a data table was supposed to look like. It is not surprising that Carla used a pH scale as a table (Line 32-

33). Andrea's suggestion about having space for three trials and averages became important (Line 40-44) for students to successfully create an appropriate data table for their experiment. Students' final pH tables show that they took up the teachers' suggestion. Four groups presented their data tables and all of them were quite similar that contained columns for predictions, three trials, and the average. Cynthia and Smita's table in Figure 4.11 is an example.

Substance	Prediction and observations	pH level Test 1	2	3	Average

Figure 4.11. Cynthia and Smita's data table for the pH experiment

These two segments about planning a data table for the pH experiment show that students' initial constructing practices were guided by the teacher and the teacher's scaffolding was crucial for these novice inscription constructors to engage in planning and constructing practices. Class II showed a similar pattern. To trace students' learning trajectories, the series of segments presented in this theme are all taken from Class I.

After students created their pH data table, they also constructed two data tables for conductivity experiments before planning a more complicated data table for their water quality investigation. This complicated data table had to include data from five water tests and each test had three trials from three locations. In the following segment, Andrea and students in Class I designed their data table together during WQ I. Having created three data tables for their experiments, students were able to decide what data and categories should be included in their table (Line 5-21). Andrea used a series of questions to scaffold students' planning practices. Notice that understandings about the procedures of their water quality investigation were required to design an appropriate data table. That is, the context of inquiry should be considered when designing an inscription.

(CV039A, EP 1)
T: The first thing we wanna do is to design a data table. To go outside to collect data that we can put in for all 5 of the chemical tests.
T: okay, what are the tests that we have first of all? What's one?
Charles: pH.
T: pH. And others?
T records students' ideas on the board.
Noah: temperature.
T: temperature.
Smita: dissolved oxygen
T: dissolved oxygen
Smita: conductivity.
T: what's the last?
Noah & Smita: turbidity.
T: turbidity. okay.
T makes a list of 5 tests on the board.
T: what we need to do is create a data table that's going to include all these 5 tests. Is going to include…what else?
Students have no response for seconds.
T: so we need to set up the 5 tests.
Austin: oh, three locations.
T: yes, three locations. So we have 5 tests, we have A, B and C for locations [writing the information on the board]. And what else do we need?
Smita: we should do each times three.
T: and we need to do each times three. [Writing on the board] Three locations, three trials, and what else?
Charles: the averages.
T: the averages.
Smita: three trials per location.
T: three trials per location, so three for A, three for B, and three for C.
Charles: three trials per location, per test.
T: per test, plus average for each location per test. So you need to design a data table. I'd like you to talk…you can talk at your table on paper. Play around and

see what kind of data table you can come up with. That's gonna accommodate all the stuff that we need to include.

When students constructed their first data table for the pH experiment, the categories of the table were suggested by the teacher. As their experiences in designing increased, in this segment, they volunteered their ideas about what should be included in their table, which included five tests (Line 5-15), three locations (Line 21), three trials for each location (Line 24) and the averages (Line 27). All these ideas were relevant to the procedures of their investigation and meaningful in the context of their inquiry.

Because not all test data were quantitative and collected by probes, in the following segment, Andrea reminded them to consider the different types of data collected from the five tests (Line 36-38). When students began thinking about how to modify their table in order to accommodate different types of data, their confusion and questions about the investigation were revealed (Line 39-44). The teacher used it as an opportunity to review procedures of the turbidity test (Line 45-48).

T: okay, let's me help you out a little bit though. You realize that these ones [pH, temperature, conductivity, D.O.] we're gonna actual numbers, right? And this [turbidity] we won't.
Charles: we don't need three times for that, right?
T: uh…
Charles: could you just take a look at it and write down, take a look at it and write down?
T: how did we already agree that we're gonna collect this data?
Charles: the coffee filter.
T: yeah, we're gonna sample from each location and we'll strain that through coffee filter, so that is gonna be a little different. So maybe instead of having three boxes for A, B, and C, we'll just have one bigger box and you can put things like that [draw a box with particles on the board] if you want.
T: save a space to write. Beth?
Beth: do we need to have predictions?
T: that's an excellent question. In all of the tests we done so far, we have had predictions that's part of the data table. This time we're going to make

predictions separately. That's one thing we're going to do on Monday. Thank you very much. So on our data table here, we won't have a spot for predictions.

Andrea's scaffolding about the turbidity data (Line 36-37) led to Charles's question. The brief discussion between Andrea and Charles (Line 38-46) indicates that Charles was not prepared for recording different types of data into his table. Andrea's follow-up scaffold (Line 43-46) clarified Charles's confusion and pointed out close relationships among investigation procedures (using coffee filters), data types (drawings of filters), and inscriptions (having bigger boxes in the data table).

In addition, in their previous data tables, students had a column for prediction (see Cynthia and Smita's pH data table in Figure 4.11). Beth's question (Line 48) shows that she had internalized the idea of having predictions in a data table. Andrea's response to Beth's question (Line 49-52) signaled that the question was legitimate and meaningful in the context of designing a new data table. Later Andrea showed them what a prediction paragraph looked like, so students would write up their predictions for the five tests separately.

In these segments about planning and designing, the complexity of data tables increased (i.e., more tests, more locations, and more data readings) and the structure of data tables was modified to record different types of data based on how they were going to collect their data. Students' participation in designing new inscriptions increased as they had engaged in constructing several data tables. During WQ II and WQ III, students did not engage in more constructing practices with data tables. Teachers assigned the data table as homework and the instruction was as simple as shown in the segment below.

(CV105A, EP 1)

T: Now I have to tell you what homework is tonight. What you need to do is the following. Number one, make sure you make a data table in your composition book. A sloppy copy of the data table. You need to have a data table generated.
Students: Is it similar to the one we had before?
T: just like the other one, including trials, averages.

This segment shows that the teacher's scaffold in the construction of a data table faded out in WQ III. The class did not go through the construction process again and the teacher just reminded them to use the previous one as template (Line 6).

In WQ I, the use of data tables and practices associated with them were an important and salient part of class activities. The classes spent substantial time planning, creating, and modifying them. After students created and utilized data tables in an iterative manner throughout the unit, the use of data tables was embedded in unit and became an integral part of inquiry.

This theme shows the learning trajectory of students' constructing practices with data tables. More questions arise in terms of the historical development of students' inscriptional practices. What did students' constructing practices look like if they had opportunities to create new inscriptions in WQ III? How did other types of inscriptional practices change over time? Theme 8 will use some examples taken from classroom videos to answer these questions.

Theme 8: In general, the level of students' participation in inscriptional activities increased over time. At the end of the water quality unit, students were capable of fully participating in designing a more complicated inscription and interpreting new inscriptions.

At the beginning of the unit, constructing a new inscription was intensively scaffolded by the teachers as shown in Theme 7. In WQ III, students drew on their prior experience in constructing practices and actively participated in designing a new inscription such as longitudinal graphs and webpages. To illustrate students' constructing practices in WQ III, I use a segment to show how students constructed a longitudinal graph together. Prior to this segment, students had created bar graphs twice, but their graphs included data from only one season (see Figure 4.12).

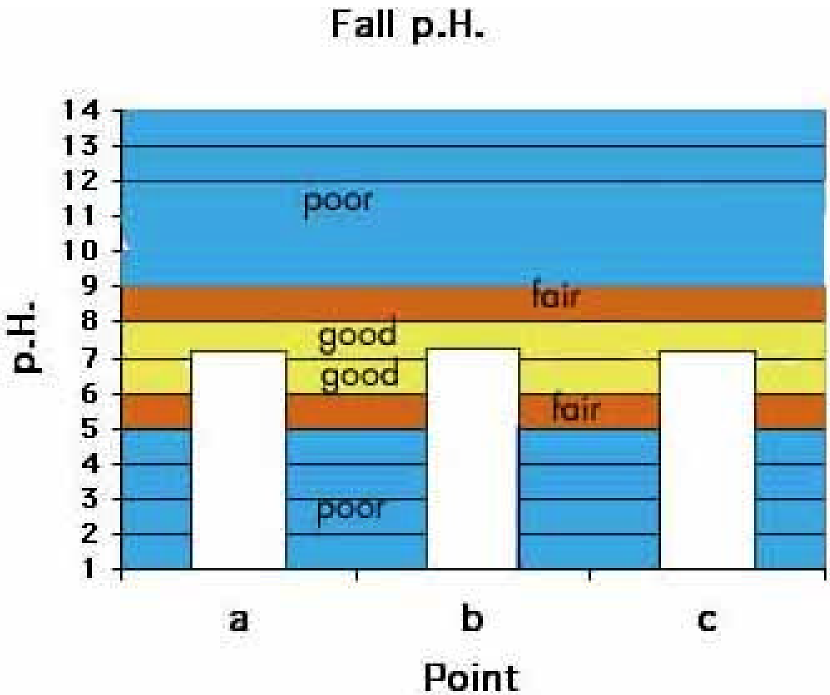
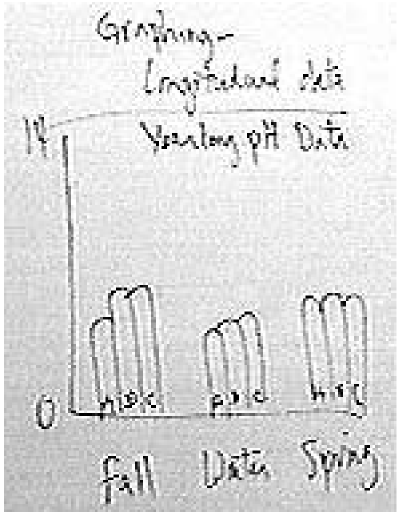


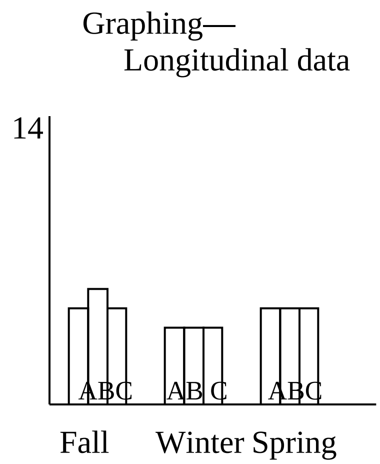
Figure 4.12. A pH bar graph created by Nathan in WQ I. The background of the graph is color coded. Different color areas show the ranges of water quality standards. (7: excellent; 6-8: good; 8-9 and 5-6: fair; >9 and <5: poor)

In a longitudinal graph, they were supposed to represent their data across the three seasons. The difficulty and complexity of an inscription increased. In the segment below, Andrea first defined what a longitudinal graph was (Line 4-6). Based on the definition, the class discussed what longitudinal data they had and how they should construct a longitudinal graph. Notice that the class demonstrated a very different discursive pattern compared to those shown in their discussions during WQ I. Although a longitudinal graph was new to them, students not only provided ideas about what data should be included as they did during WQ I, but they also had suggestions and comments on the format and structure of the graph.

(CV106A, EP 3) [T writes down "Graphing—Longitudinal data" on the board, and asks the class if anyone knows what "longitudinal" means. Charles makes a guess about "long" in the word.]
T: longitudinal data is data that's taken from the study that occurs for a long period of time. We've been doing a longitudinal study this year. What's our long period of time?
Charles: the water quality of the stream in three different seasons.
T: three different seasons. Okay. So what we're gonna do this time, instead of just graphing the averages of the three locations. We're gonna graph over the whole year. [T sketches x and y axes on the board without units and numbers.]
T: so let's say this is umh…you can title it, year long pH data. [Title the graph on the board (see Figure 4.13)] okay. What do you think we could do? Sally.
Sally: month one and two.
T: we could do month one, month two, month three. What else could we do?
Stefon: fall, winter and spring.
T: fall, winter and spring.
Charles: A, B and C.
T: A, B, and C [on the x axis], we might get messed up with our old graphs.
Charles: each A, B, and C under like, maybe spring.
Carla: can we do the graphs like we did? Different colors, it's a bar graph, but has different colors.
T: yes.
Carla: we can do that thing.
T: We're gonna combine all those ideas. Fall, winter and spring [label the x axis], pH…
Cynthia: can we do it on separated graphs?
T: no, instead of just doing separated graphs, then doing longitudinal, we put our spring data on a longitudinal graph. So what kind of bar graphs can we have here?
Cynthia: we can have like three colors, we have for fall, winter, and spring. For like fall we have…
T: Annie, do you have any idea?
Annie: we can have different bars for fall, the seasons.
T: so we'll have a triple bar graph whenever we had, right? And this will be A, B, C, A, B, C, A, B, C. If you get this, and you say oh, I can go home and do that on my computer. Do that for homework for one of your tests. If you don't get this…
Carla: is this overall?
T: this will be over the whole year, fall, winter and spring.



(a)



(b)

Figure 4.13. The longitudinal graph drew by the teacher on the board: (a) A snapshot taken from the class videotape, and (b) a recreated version of the graph.

Although students had never constructed a longitudinal graph, they drew on their experience of constructing bar graphs (Line 15, 17, 20-21). Carla (Line 19) and Cynthia (Line 24, 27-28) had comments on what they thought would be a better graph to show seasonal data based on their experience in creating graphs. Compared with the discussions the class had when designing pH data table, this segment shows a very different discursive pattern. There were more back and forth dialogues between students and Andrea. Andrea's responses and guiding questions were shorter than those in previous class discussions. Annie provided a specific suggestion about the format of the graph (Line 30) that was taken up by Andrea. This shows that at the end of the water quality unit, students were capable of fully participating in designing a more complicated inscription. Even though Andrea had the authority to decide what comments or ideas should be used for their longitudinal graph, students had confidence in expressing their ideas and deciding the content and format of an inscription. More importantly, most of their ideas were appropriate, important and meaningful for designing an inscription to serve a given purpose. The graph sketched by Andrea on the board (Figure 4.13) shows that students' ideas were taken into consideration.

Not only did students increase their participation in constructing practices but also in interpreting practices. Interpreting practices usually took place when students analyzed their test results. Several types of interpreting practices demonstrated by students included examining the consistency of data represented by inscriptions, identifying patterns, searching for reasons to explain data, and comparing data to standards, predictions, and conceptual definitions). During WQ I, the teachers provided instruction and a guideline sheet to support students' data analysis process. The following segment is an example when Celia (T) modeled how students analyzed their temperature data collected from the two ends of the stream and their testing locations. She indicated that students could first report the data (Line 5-10) and then presented possible reasons that attributed to the temperature differences. These possible reasons included people dumping warm water (Line 11, 18), technical problems (Line 13-15), human errors (Line 14, 21), and decomposition (Line 18-20).

(CV052C)
T: We don't have a mile apart, but we do have our two extremes as that we're testing. So that's how we're going to assess the temperature difference along the stream. Plus we have all these mini points in between, right? It still doesn't negate why do we take temperature, 'cause we need for DO. But we also need it to then back up that there is section 1 and 7 and there is not much pollution. Because what if, what if you took the temperature at your point of the stream, let's say section 3, you could say, well overall, the temperature seems to be very good when I compare section 1 and 7. There's only point 5 difference. However, in my section 3, I notice that there was a 6 degree difference. At that point, there may be something that is entering and sending warm water into the stream. But overall it seems that the temperature of the stream is okay. I must investigate

what's happening here. Or perhaps is that biggest degree difference perhaps my probe isn't working. See, it could either be a problem or could be human error, or could be software or hardware error, right? If you see everywhere along the stream, there's only point 5 degree difference, and you have six, then you can't know for sure. But in your analysis paragraph you can suggest, I either have something that's being dumping in my point, or I have a lot of decomposition going on, so that water is generating heat, because when things decompose, you do generate heat. Right? There's a lot of activities going on. Or my probe isn't working or I messed up. I have to be more careful next time. You don't get marked down because something didn't work or you messed up. You're just gonna be more careful next time. As long as you can recognize, umh…, how did I get 6 degree difference, right?

Celia's instruction in WQ I was very detailed and using a specific test as an example so that students could have a concrete idea about data analysis. During WQ II, she did not provide such detailed instruction but briefly reviewed the guideline sheet. Although the teacher's scaffolds faded out, according to the analysis of group discussions, students were able to draw on different resources to demonstrate interpreting practices.

The following segment took place in Class II during WQ II and shows that interpreting practices required substantial conceptual knowledge and field experience in the stream. When Nathan and Olisa tried to figure out the reasons to explain their data, they drew on resources including background knowledge they learned about the tests, inscriptions or data collected from previous investigations (Line 13-22) and observations they made from the stream (Line 24-25).

(CV052C, EP 5) Nathan and Olisa calculate the averages and record them in their data table. Both of them have their notebook as the discussion is going.
Nathan: for point A, pH test 1, what did you get? Average or whatever?
Olisa turns to the table page.
Olisa: for point A, you mean like trials or overall average.
Nathan: overall average.
Olisa: 7.22
Nathan: okay.

Olisa: for point B, 7.15.
Nathan: uh.
Olisa: for C, 7.20.
Nathan: okay.
Olisa: so fertilizer, is fertilizer basic?
Olisa turns to the pH lab page (See an example in Figure 4.11).
Olisa: so fertilizer, wait, fertilizer is acidic.
Nathan: are there different kinds though?
Olisa: yeah, that’s true.
Nathan: they’re probably most acidic
Olisa: yeah, ‘cause it’s [fertilizer] like 5.61.
Nathan: yeah.
Olisa: the average for fertilizer. So fertilizer won’t affect it. So is…soap is basic.
Nathan: what kind of soap?
Olisa: Dawn and Tide.
Nathan: yeah, that was basic.
Olisa: and sand, a lot sand will get in, because of the sand bar. Point B is where the sand bar is, is kinda close to neutral, so I don’t know, maybe just a little bit.

This segment happened at the end of WQ II. Olisa and Nathan searched for causes of their pH test results. Olisa first suspected that fertilizer might cause the slightly basic pH (Line 12), but her pH experiment result showed that fertilizer was acidic (Line 13-17). (A pH reading of 7.20 indeed could be viewed as neutral. Several students in both classes including Olisa regarded neutral as a point on the pH scale instead of a range.) By checking her pH data table, she found out that other substances such as soap and sand might get into the stream and cause the stream water basic (Line 20-24). Olisa then brought up her observations about the location and tried to justify her argument about sand getting into the stream (Line 24-25). This segment suggests that during WQ II students were able to demonstrate interpreting practices without teacher’s prompts. Additionally, the data table created in the pH experiment and students’ observations of the stream were resources for them to demonstrate interpreting practices.

As longitudinal graphs were introduced in WQ III, students not only adjusted their constructing practices but also interpreting practices to participate in the activities associated with this type of inscriptions. Longitudinal graphs (Figure 4.14) showed data across three seasons and allowed students to demonstrate interpreting practices such as identifying patterns or trends of data. Identifying patterns was to search for similarities and revealed differences among data readings. Based on the similarities and differences they identified, students then discussed factors or causes that might affect the test results. So identifying patterns was an important step for students to make sense of data and helped them go beyond simply reporting or describing data.

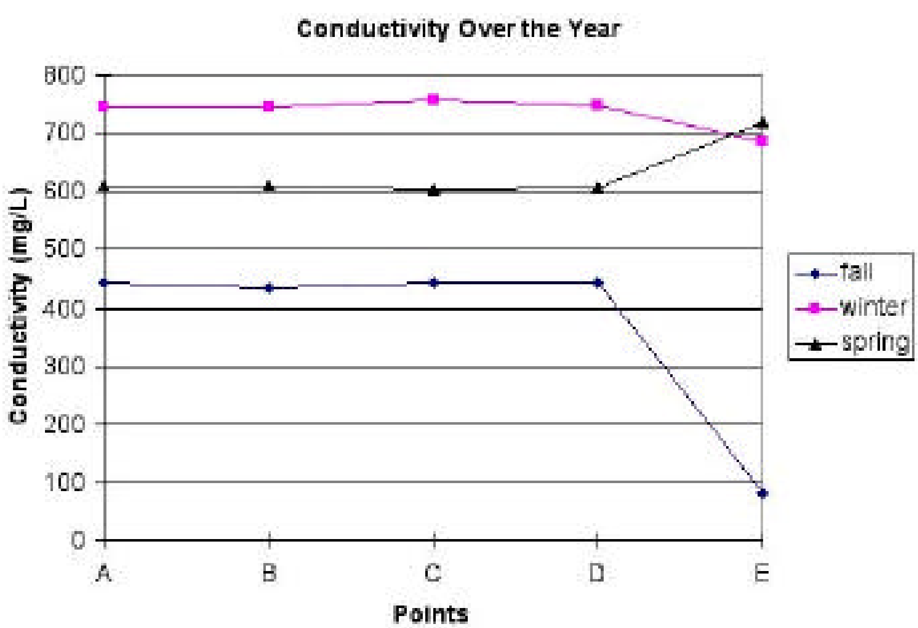


Figure 4.14. Ally and Denny's longitudinal graph of conductivity

Similar to how they did when designing this new type of inscription, students drew on their prior experience in interpreting and analyzing data to generate meanings out of their longitudinal graphs, even though they did not use longitudinal graphs before. The following segment shows students' initial attempt to identify patterns by viewing their longitudinal graphs together. Abby, Alan, and Mason first described what they saw from these graphs (Line 5-15). They tried to see patterns of seasonal changes across five tests. However, in some tests the spring data were the highest, but in some tests the fall data were the highest. After checking the guideline sheet (Line 21-22, 25-26), Abby focused on one test and discussed what might be reasons that caused the seasonal change of conductivity (Line 27-30).

(CV113C) Mason and Abby in Class II lay out all their longitudinal graphs on the floor. Elaine and Alan join their discussion.
Jade: What are you guys doing?
Abby: we're trying to find a pattern from the lines.
Mason: [looking at the graphs] yeah, the conductivity is going up.
Alan: these all go down [pointing to two graphs].
Abby: I look at everybody's graph. They all look like this for temperature. [Note: Students in Class II all graphed the same temperature data.]
Alan: it goes like spring, winter, fall. Spring is the highest.
Abby: but this one, spring, wait, spring is always going straight across except for DO and temperature. This is like no pattern. No pattern.
Mason: it goes every time you test it, it goes up. See, fall is the lowest.
Abby: okay. with this.
Mason: it always goes down.
Abby: but this one, you can't tell.
Mason: 'cause there's no pattern.
Abby: right, there's no pattern.
Abby: there's no pattern here. [Pointing to another graph]
Abby: okay, so our patterns for DO and conductivity. What's your pattern, Alan? Can I see your patterns?
Abby: where is that sheet?
Abby takes a look at the guideline sheet and begins taking notes.
Abby: there's a pattern in conductivity.
Mason: conductivity and DO.
Abby: okay, here [the guideline sheet] says what might explain, changes from season to season. 'cause for the conductivity graph, every time…
Mason: 'cause there's fertilizer.
Abby: okay, season to season conductivity goes up, fall, winter, spring. Fall is the lowest, then winter and spring, because in spring there's fertilizer.
Mason: winter has salt.

Prior to students' group discussions, the teacher told students to "see patterns," but she did not indicate how students could identify a pattern and what counted as a pattern. Initially Abby and Mason attempted to identify common visual features or trends shown in all their longitudinal graphs, such as the data lines moving up and down. Their attempt was not successful as the tests showed different seasonal changes. In this segment, the guideline sheet became an important resource that contained questions to structure the pattern-searching process. The sheet asked students to "look at each of the test results and see if there are any patterns." It also contained several questions: "Are there changes from season to season? If yes, what might explain these changes? Do the changes increase or decrease water quality? Why?" According to the sheet, instead of looking for patterns across all tests, students should look at each of the test results and describe changes from season to season. After Abby read the sheet, the pair focused on one test, and their discussion went beyond describing data shown in the graph and involved reasons that might attribute to changes from season to season. When demonstrating these interpreting practices, Abby and Mason drew on their background knowledge about conductivity and their prior experience in interpreting graphs. For example, fertilizers and salts (Line 27-30) were substances that they tested in their conductivity experiment. Notice that students did not use their notebooks or science reports in order to know when the substances were used in a year and what impact these substances had on the stream. They might have internalized some background knowledge that allowed them to demonstrate interpreting practices.

The analyses of classroom activity data suggest that students' participation in interpreting practices and the accuracy of the conceptual knowledge that students drew on in their practices both increased throughout the unit. Furthermore, comparisons between students' analysis paragraphs in WQ I and WQ III showed that their interpreting practices improved substantially in terms of integrating ideas from different resources and presenting their ideas about why there were seasonal changes. Smita's pH analyses in WQ I and WQ III are a typical example, which are presented below without any edit.

Smita's pH analysis in WQ I:

> Location A
> At A the pH was near or very close to excellent. The pH was 6.9. There were no acidic or basic substances in the water. For one of the three tests at the spot we even got a pH reading of 7, the perfect reading. The ph should hopefully continue to stay in this range.
> Location B
> Because there were no carwahses at this time of year, no acid rain, or any other occurrence that affects pH the reading was excellent. At 7.4 we were very close to perfection.
> Location C
> At C the pH reading was, again, very close to excellent. I have formed an idea about the stream. I think that there are so many acidic and basic substance that the water has become neutral. This could be why the reading was 7.2
> [Teacher's comments: predictions? Like what substances? Explain.]

Smita's pH analysis in WQ III:

> For pH I had first predicated that the pH would be between 6.5-7. Because I saw no reason why it shouldn't be. All through winter I predicated that the pH would be neutral. The pH stayed at an excellent range through most of winter. Numbers, however, continued to rise by a small amount at each season we tested. In the fall the pH at location A was 6.89, Location B had a pH of 7.4 and the pH at location C was equal to 7.2. These numbers are all in the excellent range to determine standards. Having the pH be so neutral was, in some ways, a surprise. An excellent standard for pH most likely means that there are no harmful chemicals in the water. This is because regular distilled water has a pH of 7. Various chemicals such as soap and fertilizer are either higher or lower, depending on whether the chemical is an acid or base. However there are other ways in which a stream's pH can be adversely affected. In the wither the pH rose by the slightest amounts. Although all excellent, a=7.71, b=7.78 and c=7.75, we still saw a small increase. The numbers increased even more in the fall. Location A, B, and C were all equal to 7.9 this standard is good. After considering the other data my partner and I found that the conductivity levels were exceptionally high. Reaching its peak in winter. As we talked about in out background information, conductivity is the amount of dissolved substances in the water. Among these substances is salt which had a pH of 7. In the winter a lot of salt is dumped on the roads. This would make winter data excellent. In the fall people

use high bases and acidic substances which, when mixed together, cause a neutral pH. The same goes for spring.
[Teacher's comments: good.]

In WQ I, Smita discussed each location separately in her pH analysis. For readings of location B and C, she presented possible reasons (i.e., no substances or acidic and basic substances mixing together) for the neutral readings (Line 7-15). In WQ III, Smita's argument was more coherent and she was able to provide a specific example about salt to elaborate her idea (Line 36-37). Furthermore, she referred her analysis to the background information (Line 34-36) and used other test results (i.e., conductivity and previous pH experiment) to support her argument (Line 26-28, 37-39). Although she did not explicitly mention any specific inscription used for her analysis, in terms of creating a science report, she demonstrated sophisticated interpreting practices by connecting her analysis to background information, other test results, and a previous science experiment.

Together the segments shown in this section suggest that the level of students' participation in inscriptional activities increased over time and demonstrate transitions from peripheral to full participation (Lave & Wenger, 1991). At the end of the water quality unit, students were capable of integrating and drawing on various resources (including their prior knowledge and experience in practices) to participate in designing a more complicated inscription and interpreting a new inscription.

From Theme 1 to 8, I discussed about students' enactment of inscriptional practices. In Themes 9 and 10, I will focus on the characteristics of the inscriptions created and used by the two classes. These two themes indicate what inscriptions could possibly be used in an inquiry-based environment and how they could be used in order to help students demonstrate competent inscriptional practices.

Characteristics of the Inscriptions Used by Students

The third research question of this study is: What are the characteristics of the inscriptions created and used by students? In the previous themes, I showed some inscriptions created by students, including models, data tables, bar graphs, longitudinal graphs, and digital pictures. In Themes 9 and 10, I will focus on the characteristics of these inscriptions and their capabilities to afford certain practices to take place. These findings provide insights into how educators and researchers could exploit the potential use of inscriptions in order to encourage students to demonstrate some favorable inscriptional practices, such as conceptually integrating multiple inscriptions.

Theme 9: Different inscriptions had different capabilities that allowed students to demonstrate different inscriptional practices.

Analyses of classroom activity data and students' artifacts indicated that different inscriptions were involved in different inscriptional practices. For example, longitudinal graphs were used to describe seasonal changes of test results as shown in Theme 8. To examine the consistency of results across three trials and different groups, the classes usually used data tables. Models allowed students to represent their understandings of a specific topic by transforming their conceptual knowledge into a series of causal relationships. Digital pictures and stream drawings captured stream features that helped students make predictions, interpret test results, and support the arguments they made in webpages. The decision of how the inscriptions were used in the unit was made by the design of the curriculum as well as the capabilities and characteristics of inscriptions.

Below I present examples of students' use of data tables, stream drawings, and digital pictures to illustrate how the capabilities of different inscriptions allowed students to demonstrate certain inscriptional practices.

Data table: Examining the consistency of data

During WQ I, after students conducted pH and conductivity experiments and recorded data in the data table, the teachers created a class table on the board that allowed students to share data and compare data across groups. Throughout the unit, each class created four class data tables to share their data collected the pH experiment, the conductivity experiment, and water quality investigations in the fall and winter seasons. As Celia said during the interview, "in a data table you're…when you go to analyze numbers, it's helpful to have everything that's the same in one category so right now it makes it easier for comparison." That is, data tables organized data in a way that helped students compare data across groups and make sense of the data.

Although scientists usually use graphs to identify outliers (Smith, Best, Stubbs, Johnston, & Archibald, 2000), seventh graders in this study always used data tables to identify outliers because these students dealt with relatively simple sets of data. The following segment shows an example. Throughout the class discussion, Celia referred to the class data table (Figure 4.15) several times (Line 3, 15, 17, 22) and directed students' attention to outliers, data across groups, and possible technical problems and human errors. Guided by Celia's questions Class II engaged in interpreting practices including identifying outliers, examining the consistency of data, and searching for possible explanations of the data.

(a)

Group	1	2	3	4	5	6
Ammonia	10.03	10.81	9.98	10.02	9.9	9.2
Antifreeze	10.07	10.86	---	9.74	9.86	9.50
Windex	9.91	10.27	9.58	9.58	9.59	9.13
Down	7.54	6.36	7.45	7.15	6.76	5.92
Sally's water	9.36	9.8	9.25	9.18	9.25	8.96
Acid rain	2.76	2.39	2.40	2.56	2.95	1.72
Tide	10.04	10.54	10.09	10.35	9.96	9.33
Sand	8.5	8.31	8.61	8.73	8.43	8.12
Distilled water	4.07	4.25	4.57	4.26	4.61	4.10
Peat moss	5.7	5.45	4.23	5.13	5.11	4.89
Salt	6.29	7.16	5.0	7.91	7.12	7.23

(b)

Figure 4.15. The class data table used to share pH data collected from groups (CV013C): (a) A snapshot taken from the class videotape, and (b) a recreated version of the table.

(CV013C) Celia (T) creates a data table on the board and records the data students collected from their pH experiment.
T: all right. Let's take a look at these data. The numbers actually are pretty consistent. There're few outliers. What do we consider data that's an outlier that doesn't fit them all?

Several students raise their hands.
T: Nathan.
Nathan: like an example?
T: yeah.
Nathan: if we had 10.2 and 10.3, the outlier would be like 14 or something.
T: so far. The averages are pretty much the same. Do we see any outlier in this data? Olisa?
Olisa: I think maybe in the salt column. We had 5.0 and someone else had 7.91, so there is a difference between them. I think 5.0 may be the outlier.
T: how about in the peat moss group?
Alan: yeah.
T: that's certainly an outlier. [Circle the numbers which are considered as outliers (see Figure 4.15).]
T: okay, sand, tide. Is there any other extreme outlier here that we could say? Elaine?
Elaine: I guess acid rain, the 1.72, 'cause most of them are higher.
T: yeah, that might be kinda lower. This whole column here [student group 6] is reading on the low range, except here and salt. They're probably the closest to what should be. So a couple things could comfort that. What may comfort the differences here?
Ashton: put some…like…buffer solution.
T: we could have added something to the solution that may have countered active with the low pHs. Olisa?
Olisa: the probes could have not been…
Nathan: calibrated.
Olisa: collaborated.
T: calibrated. You're right, if it's not collaborating with you. But that's right. It may be the reading was off that didn't hold its calibration. Sure, absolutely, that could have happen that we have been working around that probes are not working. Ned?
Ned: samples over the weekend.
T: like over a weekend or something like that. Another reason?
Jade says something that is irrelevant to their discussion.
T: let's stick on this one. What about human error?
Students: yeah. That could be.
T: perhaps you weren't waiting or you're a little too quick.
T: you may not have been careful. So there're all different reasons and certainly the other is that maybe the equipment didn't work properly. Uh…there're couple problems here.

In this segment, students in Class II took a close look at numbers shown in the same row (Figure 4.15), compared the numbers, and identified the numbers that they thought were out of a normal range. Celia posted a series of questions (Line 4-5, 11-12, 15, 19, 24-25, 39) to guide the discussions. Without these questions, the students, as novice science investigators, might have not known what they should do in order to determine whether their data were in a range of "what should be" (Line 24-25). Celia's questions directed students' attention to certain aspects of the data represented in the data table and sequenced the process of interpretation. The first thing to do was to take a close look at the data and identify outliers (Line 3-14). Several outliers were found in different substance columns (Line 15-21). The data table (see Figure 4.15) not only allowed the class to examine the consistency of data by comparing data of the same substances, but it could also help them see whether data collected from a specific group tended to be higher or lower (Line 22-24). Then the class discussed possible causes of these outliers and engaged in another type of interpreting practices, searching for reasons to explain data. Students volunteered their ideas about why there were outliers (Line 26, 31, and 36). This discussion might have expanded on their discussions about the causes of the outliers and analyzed what kind of human or technical error might cause a certain type of outliers.

What did students interpret in the segment? The pH data or the data table? Although data tables used by the students did not show visual patterns as graphs did, data table represented and reorganized the raw data in a way that allowed class members to easily visualize and compare data collected from different groups. This in turn helped them examine the consistency of data. Therefore, students did not interpret the raw data but the data represented by a data table. If the data table had a different format or had different categories, students might have came up with different findings about the data. In a sense, how an inscription represents and transforms data allowed as well as constrained students to generate certain meanings out of the inscription and to demonstrate certain inscriptional practices.

Stream drawing and Digital picture: Developing referential links among stream features, concepts and test results

Different from graphs and data tables that represented quantitative data, digital pictures and stream drawings captured visual information. In WQ I, students created a drawing of their stream section. According to "Guideline sheet for stream drawing, predictions and procedure" handed to students, they needed to (1) use a scale to include the entire length and width of the stream section (1 inch on the drawing = 1 foot of the stream), (2) mark three locations from which they would collect water quality data, and (3) color the drawing. An analysis of classroom videos indicated that teachers addressed all the three criteria to the classes during the planning session.

Drawing seemed an intuitive activity to students. When teachers introduced this type of inscriptions, students had no question about how to represent a tree or their stream. Yet a stream drawing was more than a sketch of their stream section showing trees, grass and water. As the guideline sheet indicated that making predictions, choosing three locations, and creating a stream drawing were three related learning activities, students needed a useful drawing that helped them make predictions and mark three locations with a variety of stream features. Thus, in addition to the three criteria shown in the guideline sheet, teachers guided students to consider what features should be captured, what perspective (i.e., top view or side view) was used, and how detailed a drawing should be. Capturing visual features of the three locations (e.g., grass, bubbles and waterfalls) was important because these features could provide explanations for their test results. For example, an area with waterfalls might have higher amount of dissolved oxygen, and soap bubbles could suggest higher pH and conductivity. Thus, creating a stream drawing was not to draw whatever they wanted, but to purposefully capture certain features that would have impact on their test results. This indicates that an inscription has inherent characteristics, like stream drawing capturing visual information. But what visual information should be captured in a stream drawing and how detailed a drawing should be were determined by teachers and the design of the curriculum and guided by the overarching question of the unit. Hence, the decision of how an inscription was used in the unit was made by considering the inherent characteristics of the inscription as well as by the design of the curriculum.

However, some visual features were not easy to be drawn, such as the depth and water movement of the stream. So the teachers designed a "physical features data table" for students to record visible features in text. These features included stream type (i.e., meandering, straight, braided), stream flow, recent weather, and observations. Some details might not be captured by either a drawing or a physical feature data table, and some students realized this limitation. When I asked Cynthia why she was taking a picture at a specific location (CV041A), she answered, "because when we're describing it, it might be hard to describe how there is kind of like a sandy bank there, how there is like soap bubbles down there. It's hard to draw them on the picture, so we're gonna take some pictures, I think, so we can explain more about what we mean." Her answer indicated that she understood that one advantage of having digital pictures was to capture the details that might not easily be recorded in drawings or described in text.

Using digital cameras to capture visual information was not difficult for students (Rivet & Schneider, 2001). Both teachers used about 10 minutes to demonstrate how to use the camera. When taking digital pictures, students had some minor technical questions such as how they could trash the pictures or view previous pictures, but the questions were quickly answered by teachers or peers. Similar to how they constructing stream drawings, while taking digital pictures students had to consider what should be captured and why they wanted to capture these features. The following quote is taken from a planning session (CV042C) during WQ I. In the session, Celia stated the purpose of taking these pictures (Line 1-4) and modeled how to use stream features to make predictions for test results (Line 5-8).

(CV042C) The picture you want is, so that when you come back here tomorrow when you look at it on the computer with your partner, you can then go ahead and decide on predictions for A, B and C, section of your stream, for each of the tests: pH, temperature, conductivity, turbidity, and dissolved oxygen, okay? A lot of time when you go out there, you look at the part of the stream, and you know, yep, exactly that's what it is that you're going to, you're gonna judge that DO is gonna be low because you see xxxx, because it's still, because it's shallow, because it's warm. But a picture also is more than a thousand words, so we wanna also see if these pictures help you either more so that when you discuss together tomorrow and come up with predictions for each of those tests if they help you.

Celia indicated that students should take pictures purposefully, so that these pictures could be useful for them to make predictions. When students took pictures of the stream in WQ I, they did keep the purpose in mind, as Olisa said (CV042C), "if they [digital pictures] turn out good, we might be able to take a look at it and see like foam or something down there. We might have got them on the pictures. If it's not there in the winter and we see there was it in the fall, and we can maybe figure out if there is like nitrogen or phosphorus in the water or something."

Analyses of students' group discussions indicate that by showing the stream features in detail, digital pictures supported students to make referential links among concepts, stream features, and test results (Rivet & Schneider, 2001). These referential links were similar to those proposed by Kozma et al. (2000). When using digital pictures to make predictions, students identified stream features shown in pictures, discussed whether these features would have impact on the stream quality, and predicted the test results based on the quality standards and their understandings about how a test (e.g., conductivity and turbidity) was measured. The following segment shows a typical example in which Ally and Denny (Class II) discussed features they saw from the pictures and made predictions for water quality tests.

(CV043C) Celia reminds students that the pictures they took are prompts, which help them make predictions in their part of the stream. She then shows them where picture folders are. Students work in pairs and use Graphic Converter to view their pictures.
Ally: do you want to do each test or do it together?
Ally: should we do each point separately or the whole stream?
Denny: separately.
Denny and Ally open a picture file of one testing location. They first predict turbidity results.
Denny: excellent? [Looking at the screen.]
Ally: but there's stuff here [pointing to the screen].
Denny: it's like…[Moving toward the screen to take a close look at it.]
Ally: Can I see another one and then we can compare to that one?
Denny: okay. [Open another picture file.]
Ally: I think turbidity will be fine. What else? D O?
Denny: well, it's moving [He is not looking at the picture. He makes this comment based on what he observed yesterday], so I guess it's pretty good.
Ally: so will it be excellent?
Denny: I think it's good, 'cause there's no plant there. So it's good.
Ally opens a picture of the second testing location.
Ally: I think it looks pretty bad, isn't it?
Denny: well, you can't see the bottom.

Ally: look at all that stuff. It looks weird. I think the turbidity is bad. I say it's really poor.
Denny: I think it's not that terrible. Fair, maybe.
Ally: D O?
Denny: I think there's something in there.
Ally: you're right. D O is good.
Ally and Denny open another picture, but they cannot tell from which perspective the picture was taken. They do not know how to rotate a picture.
Celia assigns homework and the class is dismissed.

In this segment, Ally and Denny made predictions by viewing the digital pictures they took a day before. They opened pictures that were taken for five testing locations. Based on what they saw from the pictures (Line 11, 19) and what they observed a day before (Line 16), they made predictions for the tests. Ally and Denny knew that certain features in the stream indicated whether the water quality would be excellent, good, fair or poor. For different tests, therefore, they looked for different features shown in digital pictures. They made predictions about dissolved oxygen based on whether the water was moving (Line 16) and whether there were plants in water (Line 27). When predicting turbidity, Ally and Denny focused on whether there was something in the water (Line 23-24, 27).

This segment shows that digital pictures could be useful in showing features of the stream and that students could make predictions based on the visual information represented by these pictures. Their discussions about predictions involved understandings about tests and related concepts. For example, when they predicted turbidity, Denny and Ally's discussions about whether there was something near and in the water suggest that they understood turbidity was determined by the amount of suspended substances in the stream.

However, analyses of this segment and other class activity data also show limitations of using digital pictures as the only resource to make predictions. Resolution of the pictures was determined at the moment the pictures were taken. If the pictures did not show enough details, students' reasoning practices could be interrupted. As shown in Line 11-13, Ally saw something in the stream, but she was not certain about it, so they needed other pictures to validate Ally's idea. Similarly, Olisa and Nathan (CV043C) had difficulties identifying some features from a picture. When they enlarged the picture, it looked blur due to the resolution, so they had to decide whether they wanted to ignore these features or tried to search for other pictures to confirm what they saw.

Additionally, some stream features that supported students to make certain predictions might not be captured by digital pictures. For example, Ally and Denny did not take pictures that clearly showed the speed of current, so Denny's comment on water movement (Line 16) was made by his observation instead of what he saw from digital pictures. Also, some of students' digital pictures (4 out of the 15 digital pictures collected from target groups) closely focused on their testing location without much information of surroundings (see Figure 4.16 for an example). When they viewed these pictures on screen, they could not determine whether the pictures were upside down. As the position of a picture was unknown, students could not decide the location of nearby grass or trees and the direction of the current. Without this information about surroundings, making predictions became difficult.

Therefore, digital pictures could be helpful for students to make predictions and to construct referential links among concepts, observations, and features of the stream represented by pictures. Yet, digital pictures should not be the only resource for predictions because of certain limitations. Students could combine other resources such as stream drawings and the physical feature data table when engaging in making predictions.

Figure 4.16. A digital picture taken by students

Additionally, students' constructing practices of digital pictures did not become more purposeful throughout the unit. During WQ II and WQ III, when taking pictures they did not consider capturing visible features that would help them make predictions or analyze data. They just took pictures for the locations where they collected data. During WQ II, when I asked Stefon and Charles (Class I) how they decided what pictures to take in the stream, Stefon answered (CV087A), "we wanna take pictures for each one of our locations." Similarly, in WQ III, Ally asked her partner Denny (Class II) how many pictures they should take, Denny answered (CV105C) "five, because we have five points." Then they took a picture for each point. Because students did not purposely capture certain features in their pictures and did not keep records with them (e.g., where and why a picture was taken), it was not surprising that when they browsed the picture folders to search for appropriate pictures to create webpages (CV120A, CV121C, CV122A, CV123C), they could not recognize which pictures were taken from their stream section and did not remember why they took them. Some pictures were useless for the webpages so during the webpage sessions some students went out to the stream to take more pictures.

Teachers' scaffolds about the purposes of creating these visual inscriptions might be crucial. Compared with teachers' detailed instruction about digital pictures given in WQ I, the instruction provided during WQ II and WQ III was relatively simple and mainly included procedural information. For example, in WQ II, before students went out to the stream, Andrea said (CV087A),

> What you need to do when you get a camera is to write down someplace, what number of the camera you have. I'll come in in the end of the hour. I'll download the pictures and I'm gonna throw them into a folder and say A period and then you can use those pictures for your webpages. I'll suggest that just take three or four pictures. Don't take ten.

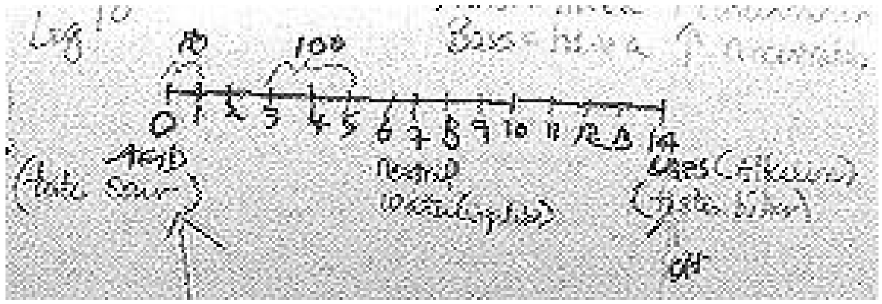
Students might have needed some reminders about why they had to take pictures and how these pictures would help their inquiry and be useful for their webpages.

How these seventh graders created digital pictures during WQ II and WQ III implies three interesting points in terms of the use of an inscription and its associated practices. First, although an inscription had potential capabilities to support students' demonstration of certain inscriptional practices, these capabilities might not be exploited and the expected practices might not be enacted if students did not recognize the purposes of using these inscriptions. As indicated in Theme 8, students could still construct inscriptions without knowing the purpose or ongoing concerns; however, these inscriptions might not be useful or meaningful. Second, teachers' scaffolds faded out when students became experienced inscription constructors and users. However, in this case, teachers' scaffolds about why the pictures were taken and how they would use the pictures might have faded out too soon. Third, similar to the point illustrated in Theme 2, inscriptional practices associated with the same inscription were interrelated. If students did not recognize or foresee the potential interrelation among constructing and reasoning practices of digital pictures, some pictures they constructed might not be able to serve reasoning purposes that they had to accomplish later.

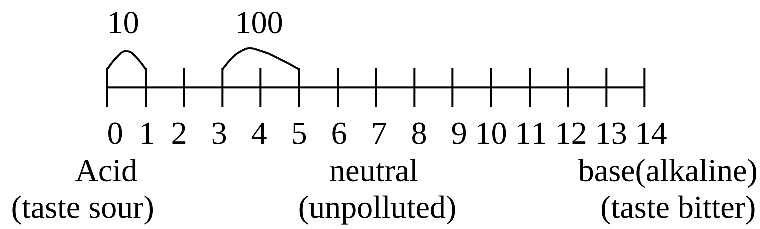
Chemical representation: Rearranged to gain new understandings

Chemical representations are content-specific and could be viewed as conceptual constructs. Interpreting practices with these inscriptions were mainly to unwrap the conceptual information underlying them, such as giving meanings to the symbols used. Additionally, chemical representations constitute a symbolic system that contains elements to be manipulated, combined, and transformed to construct meanings. These capabilities allowed students to rearrange chemical formulas to develop new understandings.

In the segment below, Celia (T) attached pH concepts to a pH scale (Line 3-15) and then guided students to manipulate chemical representations that in turn help students gain new understandings about what neutral is (Line 16-33). Two types of reasoning practices were demonstrated in this segment. From Line 3 to 19, the teacher defined acid and base by using a pH scale as a reference. Then based on what they learned about acid and base, students manipulated the chemical representations to figure out the chemical meaning of neutral (Line 20-33).



(a)



(b)

Figure 4.17. The pH scale used by Class II in their discussions about neutral, acid and base: (a) A snapshot taken from the class videotape and (b) a recreated version of the scale.

(CV002C) A pH scale (Figure 4.17) and chemical representations of hydronium and hydroxide ions, H^+, OH^-, are shown on the board.
T: okay, [pH is determined by] how many hydronium ions. So I'm actually looking at how many these [pointing to H^+] I have in substances along in the pH scale.
T: now, actually, acid here [pointing to the pH scale] has the most hydronium ions. Sometimes you hear it referred commonly as hydrogen ion, okay? So we say acids have a high concentration of hydronium, another way to say it is hydrogen, ions. And a base has a high concentration of, do you know what that's called?
A student says something and others giggle.
T: it's good thinking. It's called the hydroxide ion, okay. So bases have a high concentration of hydroxide ion.
T: so very little hydroxide ion down in this [acid] range and very little hydrogen ion down in this [base] range, okay?
T: what do you think neutral is?
A girl: have them both.
T: what do you think neutral is?
Alan: the concentrations of hydrogen and hydroxide ions are the same.
T: absolutely, very good. So I have an equal concentration of these ions. That's equal, so that's neutral. What do you notice about H and OH?

Olisa: there is an O in one, not in another.
T: there is an O in one, not in another. What else?
A student gives an answer.
T: they are different charges, right? They are differently charged. What else do I know about it?
T: I mean, take a look at these two. Did they point a trigger or something in your mind?
Olisa: oh, that's ….
Ned: water or something.
Karen: water is H2O and there is an OH and a H.
T: yes, you got it. Water is H2O and actually I can tell you water does…break down into ions. Okay, that's water.

In the first part of the segment, the pH scale represented continuity of pH values and became a device for class members to visualize how the concentration of hydrogen ions determined if a substance was an acid or a base. When defining what an acid is, Celia referred to the scale several times (Line 4, 6, 14). By attaching conceptual information to the pH scale, Class II conceptualized an acid as a substance with a high concentration of hydrogen ions located at one end of the scale. Similarly, the chemical meaning of a base, i.e., a substance having a high concentration of hydroxide ions, could be visualized by placing it on the pH scale.

After introducing what acid and base are, Celia guided students to figure out what neutral is. Students' responses to Celia's question of "what neutral is" (Line 17, 19) indicated that they were able to apply the conceptual knowledge that was just introduced by the teacher. They realized that a neutral substance contained both hydrogen and hydroxide ions and that had the same concentrations of the two ions. Celia further directed their attention to the chemical representations of these two ions (Line 20-21). Olisa focused on the surface features shown in the symbols (Line 22). Some students successfully visualized that water's chemical formula is a combination of the chemical representations of the two types of ions (i.e., H and OH) (Line 30-31) that could help students understand why the pH value of distilled water is 7. Therefore, reasoning practices of inscriptions involved manipulating and combining them and through these manipulations, new conceptual understandings might emerge.

In summary, inscriptions used in the unit had different capabilities to support students to demonstrate different inscriptional practices. How an inscription was used and practiced was determined by its inherent characteristics as well as the design of the curriculum. By using different inscriptions, the seventh graders in this study demonstrated a variety of inscriptional practices.

Another characteristic of the inscriptions used by students is related to how these inscriptions were created. Latour (1987) indicated that scientific inscriptions are often transformed into other inscriptions, which are again translated, forming cascades of inscriptions. Similarly, inscriptions used by students in the unit were not always constructed by raw data but through transformations and incorporations of other inscriptions. In the next theme, I will present how the seventh graders transformed or incorporated inscriptions into another.

Theme 10: Some inscriptions used in the unit were transformed or incorporated into other inscriptions. Through transformation, students reorganized the data into a way that allowed them to demonstrate some inscriptional practices that might have not be done with the original inscriptions. However, the incorporation of inscriptions was rather physical than conceptual

Data tables were the only inscriptions that recorded raw data. Class data tables, simplified data table, bar graphs, and longitudinal graphs were created by using averages recorded in data tables. Students transformed the data recorded in data tables into other types of inscriptions, such as bar graphs, longitudinal graphs, and class tables. Usually, the purpose of transforming data was to share data, represent data into another readable way, analyze data, and draw conclusions.

When creating class data tables, students basically took the data from their group table and filled them into the new data table. The process was very similar to recording raw data into a data table (see Figure 4.10). If students understood what each category of the new table meant, they did not have problem transforming a data table into another. Figure 4.15 shows a class data table. The format of class data tables (Figure 4.15) was very similar (or even simpler) to the ones used by individual groups, so students had no problem understanding this transforming process. As shown in Theme 9, by viewing this transformed inscription, students could identify outliers, examine the consistency of data across groups, and discuss possible reasons that cause the outliers. These practices were unlikely demonstrated with individual group tables.

Another example of transformation was the simplified data table. It was constructed in Class I to "represent the data so it's just easier to read" (Andrea, CV012A). The table template was designed based on class discussions (Figure 4.18). Students worked in groups, took the data from their pH experiment, and filled in the template.

The purposes of transforming a data table into a new format were to facilitate analyzing data (i.e., comparing the consistency of data across groups and identifying outliers), discussing possible causes of these outliers, and visualizing common characteristics among tested substances. As Andrea stated in her interview,

> It's [Having different representations of data] kind of a carefully designed yet a flexible approach to trying to understand data, looking for patterns and relationships. And some of the students like Charles yesterday, even jumped out and said, "Wow, look. You know, you can see that all the cleaning supplies are base." Well, that's unusual. A lot of students can't do that, but once we take the data table and put the bases there and put the acids there then lots more students can say "Hey, you know, these are all soaps." It's just another level of trying to help them move towards deeper understandings.

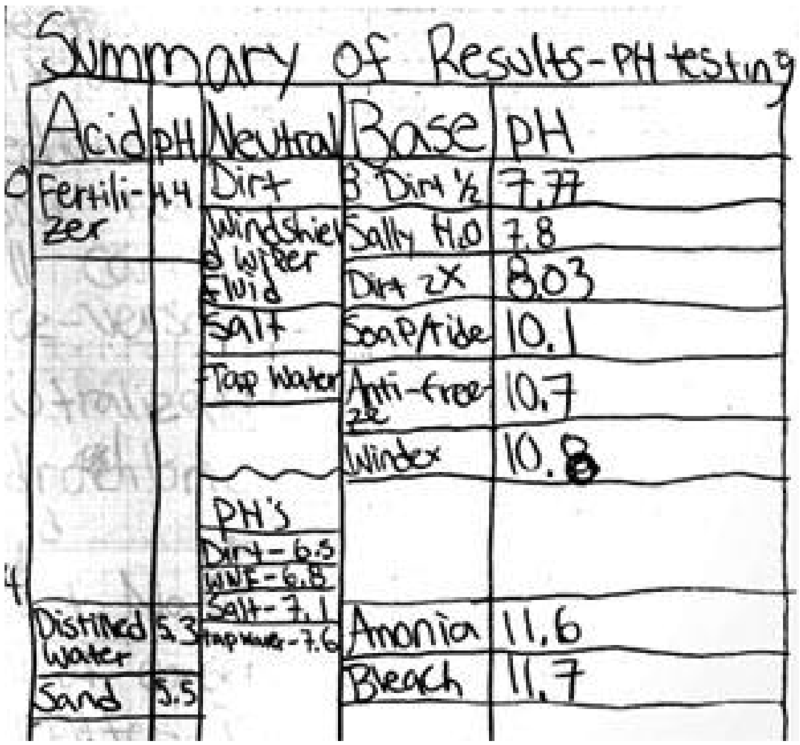


Figure 4.18. Cynthia's simplified data table used to summarize pH data

The simplified data table grouped substances into different categories. In doing so, students could easily identify the common characteristics of bases and acids. According to Andrea, therefore, transforming one inscription into another form or representing data in different ways allowed students to visualize some patterns and relationships. That is, when transforming data from one inscription in to another, students reorganized the data into a way that allowed them to demonstrate other inscriptional practices that might have not be done by the original format.

Additionally, two large scale inscriptions, science reports and webpages, contained several different types of inscriptions. Students incorporated graphs, data tables, and stream drawings into their science reports and inserted graphs and digital pictures into their webpages.

An analysis of students' science reports indicated that the incorporation was rather "physical" than "conceptual." Students rarely made references to graphs, data tables, and stream drawings in text. Among the 24 reports collected (8 target students turning in 3 reports throughout the unit), students analyzed 5 tests in each of their reports (total 120 analyses). In these analyses, only Cynthia and Denny explicitly mentioned their graph in one of their test analyses in their WQ I reports. At the end of her temperature change analysis (WQ I report), Cynthia wrote, "Maybe by looking at my graphs, and reading my background information, you can try to figure it out for yourself!" (The teacher's comment: You're supposed to do this). In his graph analysis (WQ I report), Denny wrote, "If you look at the graphs you can see how little change there is between points. This is good." The comment Cynthia made did not really help the reader understand her analysis. On the other hand, Denny used his pH graph as evidence to support his analysis about pH data. However, Denny's case in WQ I was an exception, and none of the students referred to any of the inscriptions in their WQ II and WQ III reports. Additionally, among the 24 reports, 4 reports showed inconsistent data in data tables and data analyses. This indicated that some students did not use data tables for analyses and might have kept other data records, which were not included in reports.

According to students' Checklist and Fall Analysis Guidelines, each science report should include certain components, which should appear in the order suggested by the guidelines. The first part of all target students' reports was background information. Then they showed the stream drawings, data tables and physical feature sheets as part of data reporting. Graphs should appear with data analysis. 18 of the 24 reports had all five test graphs together and then showed analysis paragraphs for the five tests, while other six reports (4 collected from WQ I and 2 from WQ II) placed each test graph right after each test analysis paragraph. Where students placed the graphs in their reports might suggest how they thought these inscriptions should be used (Lemke, 1998). If graphs were regarded as part of the analysis, a reference or a piece of evidence to support the analysis, each graph should be placed near its analysis, as seen in many magazines, papers and journals. Based on how target students placed their graphs in the reports, it seems that most of them did not consider graphs as a complement of their analysis paragraphs. These findings about students' science reports suggests that students might not appropriate their inscriptional practices in terms of integrating graphs and tables into the reports.

Although the analysis of science reports suggests that students just physically combined graphs, stream drawings, and data tables together without making references in text, an analysis of classroom videos tells a slightly different story. When analyzing their test results, two target student pairs did check their stream drawings to compare stream features among the three locations so they could provide reasons for different test data collected from the locations. Three target pairs used data tables as a primary source of their data, and used graphs to visualize the standard ranges. During WQ II, two pairs checked their WQ I graphs, so they could make sense of their WQ II data. The evidence from class videos suggests that all target student pair did refer to more than one inscription while analyzing data and use them as resources. However, how they used these inscriptions was superficial. They usually took a glance at them without engaging in discussions about how these inscriptions supported their analysis. Therefore, students might need scaffolds to help them demonstrate more reasoning and interpreting practices when incorporating several inscriptions into one and to help them capture these reasoning processes in their reports by using referential phrases such as "as shown in the graph."

Webpages were another inscription that incorporated several types of inscriptions. Students' webpages constructed in WQ III contained longitudinal graphs, a table of standards, and digital pictures. Because the classes ran out of the time, students' webpages might not include all of these inscriptions. Table 4.6 is a summary of students' webpage components. An example of a water test webpage can be seen in Figure 4.19.

Table 4.6

Summary of Students' Webpage Components

Webpages	Index		pH		Conductivity		Turbidity		D. O.		Temp change		Standard table	Conclusion	
Inscription	G	P	G	P	G	P	G	P	G	P	G	P	Table	G	P
Cynthia & Smita	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0
Charles & Stefon	0	0	1	1	1	1	1	1	1	1	1	1	n.a.	n.a.	
Ally & Denny	0	1	1	0	1	0	1	0	1	0	1	0	n.a.	0	0
Nathan & Olisa	1	0	0	0	0	0	1	0	0	0	0	0	n.a.	0	0

Note. G: Graph; P: Digital picture of the stream and surroundings; n.a.: Not available; because of time constraints some students did not construct all 8 pages.

Among the three types of inscriptions used in webpages (i.e., standard tables, longitudinal graphs, and digital pictures), incorporating longitudinal graphs and a table of standards into webpages involved more technical issues instead of conceptual ones. Prior to their webpage sessions students already created the graphs and standard tables which could be simply inserted into the webpages. To insert graphs into their webpages, students first converted their graph into a picture file, saved it into the same folder with their html files, and then inserted it into a webpage. To create a table of standards, students created a table template and then filled in the standards. Some students had questions about converting graphs into picture files, but these questions were solved with the help of teachers, other students or the researcher.

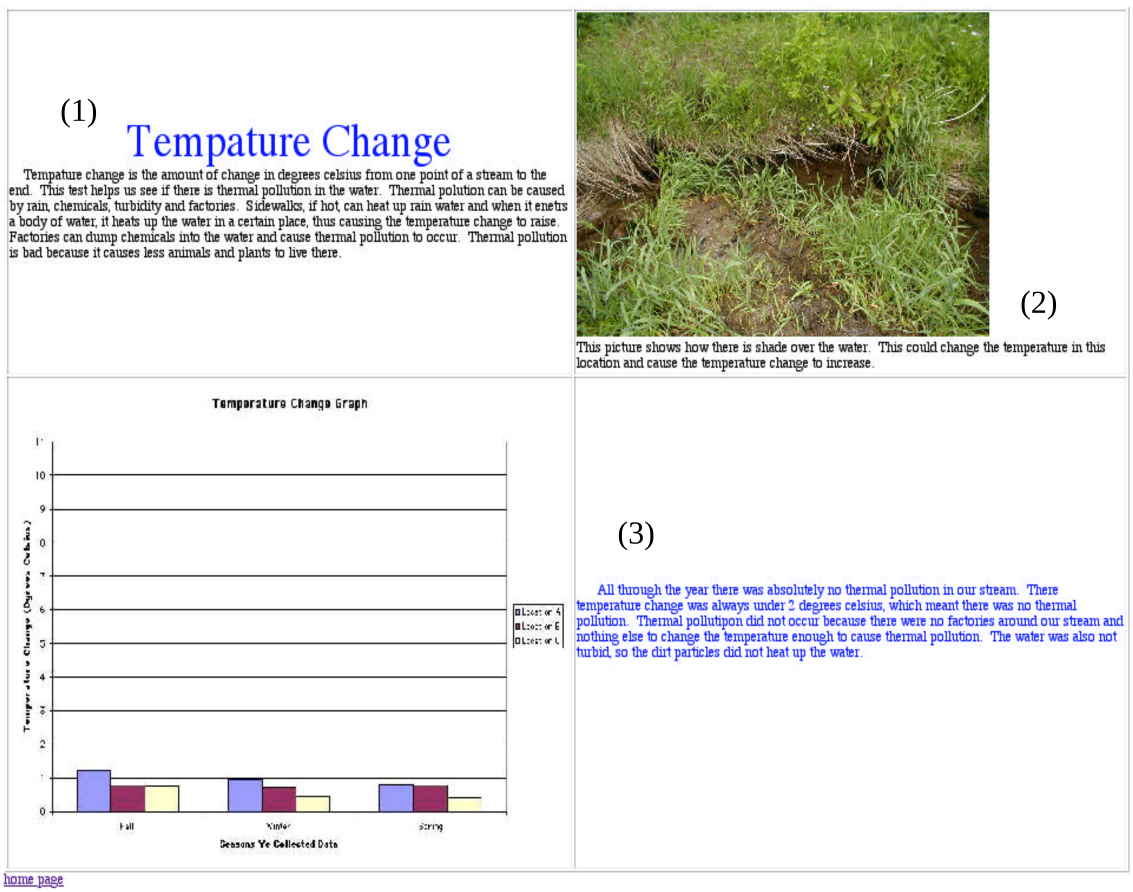


Figure 4.19. The temperature change webpage created by Stefon and Charles.[4] The numbers (i.e., (1), (2), and (3)) are added by the researcher.

[4] Notice that the argument made in the picture caption about shade was not mentioned in the analysis paragraph. This again shows inconsistent arguments made by students in the same webpage. (1) The background paragraph is shown in Theme 11. (2) The caption below the grass picture: "This picture shows

On the other hand, with more than 10 pictures taken throughout the unit, students had to decide which picture was relevant to their webpages. As part of a large scale inscription, the meaning of a picture was determined by the context of its use. When pictures were inserted into a webpage, they became an explanatory tool or a piece of evidence rather than a visual description. Students had to consider using pictures that could support, explain, or justify arguments they made in other parts of the webpage. However, as shown in Theme 2, students made arguments based on the pictures available that might be inconsistent with the argument made in the same page.

Therefore, some inscriptions used in the unit were transformed or incorporated into other inscriptions. Through these manipulations, students reorganized and represented the data into a way that allowed them to demonstrate some inscriptional practices that might have not be done with the original inscriptions. Students were capable of creating a large scale inscriptions by incorporating various inscriptions, but the incorporation was physical instead of conceptual.

The previous ten themes characterized students' inscriptional practices, traced their learning trajectories, and examined the use of various inscriptions created by students. These themes demonstrated various inscriptional practices that could be enacted by the seventh graders. In the next two themes, I will shift the focus of my discussions from students' learning to the design of the learning environment. I will examine the curriculum features and resources to answer two questions: What resources

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how there is shade over the water. This could change the temperature in this location and cause the temperature change to increase." (3) The longitudinal analysis: "All through the year there was absolutely no thermal pollution in our stream. The temperature change was always under 2 degrees celsius, which meant there was no thermal pollution. Thermal pollution did not occur because there were no factories around our stream and nothing else to change the temperature enough to cause thermal pollution. The water was also not turbid, so the dirt particles did not heat up the water."

do students use to carry out inscriptional practices? What features of the inquiry-based learning environment help they develop these inscriptional practices?

<u>Design of the Learning Environment</u>

The last research question of the study is: What aspects of the learning environment help students create various inscriptions and develop inscriptional practices? Features of the curriculum design and three types of resources, which will be described in detail in the next two themes, are identified to answer this question. These findings could contribute to the understandings about developing a learning environment in which students engage in authentic inscriptional practices

Theme 11: The design of the curriculum allowed inscriptions to become an important part of inquiry and developed continuity of inscriptional practices.

To understand how the learning environment helped students develop inscriptional practices, I identify salient features of the curriculum. Before I discuss these features, I would like to present the rationale behind the curriculum design provided by one of the teachers who was a curriculum designer as well.

> We're trying to have students be a part of the process. The goal is for them to understand how to design, come up with a good question, how to design an experiment and everything that entails that, which means thinking about procedures, how to create data tables, how they're going to collect the data. And so in the water project in seventh grade, we kind of carefully take them through those steps, and you'll see as we get farther along, um, we'll step back a little bit and say to the students "Okay, what do we need to do next?" And hopefully they'll say, "Okay, well, we need to think how we're going to collect data." (Andrea, Teacher's interview #2)

In response to an interview question of why having students to create a data table, Andrea stated that the teachers intentionally helped students participate in science inquiry, such as developing a good question, designing an experiment and procedures, creating data tables, and collecting data (Line 1-4). Additionally, the inquiry process was sequenced and scaffolded (Line 5-6). Teachers' scaffolding would be gradually faded out as students engaged in inquiry in an iterated manner (Line 6-8). Andrea's statement echoed four salient features of the curriculum that were presented in previous themes: (1) embedding the use of inscriptions in students' science inquiry, (2) providing scaffolds to support students' inquiry process, (3) sequencing tasks and the inquiry process, and (4) engaging students in science inquiry in an iterated manner.

Throughout the unit, the use of inscriptions was not assigned as an isolated task to accomplish; rather, it was embedded in a context of inquiry. Inscriptions were used to record data, analyze data, draw conclusions, and present findings. As shown in Table 4.3, inscriptional practices were demonstrated in various inquiry areas. Embedding the use of inscriptions in students' science inquiry signaled that inscriptions were an important and inseparable part of science inquiry and mirrored scientists' use of inscriptions.

Additionally, teachers' scaffolds were crucial to support students' enactment of inscriptional practices. Teachers modeled inscriptional practices, indicated their expectations, posted questions, sequenced the tasks, and suggested students to draw on resources based on students' learning performances. Analyses of the segments presented in previous themes suggest that teachers' scaffolds initiated and mediated many of students' inscriptional practices and promoted students to increase their participation in these practices.

Furthermore, sequencing and iterating the inquiry process developed continuity of practices that enabled students to develop their inscriptional practices in sophistication and increased their participation in inscriptional activities throughout the unit. For example, to make analyzing data feasible to seventh graders, the teachers structured the process of data analysis into four steps: (1) Reporting results at each testing location; (2) Comparing the results with the standards; (3) Figuring out why; explaining and discussing data by tying in background information with data; (4) Comparing results with the predictions. These four steps were emphasized by the teachers during class and written in a guiding sheet for students to review. These steps became guidelines when students analyzed data and encouraged them to engage in various interpreting practices, including examining the consistency of data, identifying patterns, figuring out why, and comparing data to standards, predictions, and conceptual definitions. Each of the steps led students to use different inscriptions and engage in different interpreting practices. For instance, data tables were used to describe both raw and calculated data. Longitudinal graphs were particularly useful when students reported the seasonal changes including identifying patterns shown in the graphs (see Abby and Mason's segment in Theme 8). Graphs helped student make a comparison between the results and the standards, because standards were colored on the background of the graphs (Figure 4.12). The inscriptions constructed in early experiments such as the pH and conductivity data tables became resources and part of students' background knowledge, and facilitated students to make explanations about the data (see Olisa and Nathan's segment in Theme 8).

During each sub-unit, students went through the same four steps but in a more sophisticated way, so there was continuity of practice developed throughout the unit similar to the findings shown in Tabak (1999). As Andrea told students during WQ II data analysis (CV089A),

> What we're trying to do is take experiences that we had in the Fall, with data analysis and writing, you did pretty well. But now go to a next level. That's what we're working on now. It would be a different version of the same idea.

Smita's pH analyses shown in Theme 8 suggest that although both of her analyses reported data, compared data to standards, and explaining results, Smita's interpreting practices became more sophisticated by making a coherent argument, providing examples, referring to the background information, and relating pH to other tests.

Additionally, students internalized the four steps and began their data analysis while constructing inscriptions. During WQ II, when Charles and Stefon averaged and graphed the data which they just collected from the stream, Charles commented on their D.O. data, "There's something weird with our DO. It went down in waterfall, but it got worse" (CV087A). Charles noticed that their data did not make sense, because according to his observation on the stream, the D.O. in the location down the waterfall was supposed to be higher. He began to interpret data as they created graphs without any prompt from the teacher. In addition, when four target student pairs wrote data analyses for their webpages in WQ III, they did not need the guideline sheet to remind them what should be included in their analyses. They were able to search for resources and include all the information required according to the four steps. These changes in students' interpreting practices might have not been made if the process of data analysis was not sequenced and iterated.

Therefore, the design of the curriculum helped develop continuity of practices and allowed inscriptions to become an important and inseparable part of inquiry. While the curriculum design features decided the sequence and structure of classroom activities throughout the unit, social, material, and conceptual resources supported students to accomplish the inscriptional tasks. In the next theme, I will discuss different types of resources that supported students to enact inscriptional practices. These resources were not always provided by authorities (e.g., the teachers and textbooks); they could be the artifacts created by students. In doing so, students developed their inscriptional practices and knowledge on a basis of their own knowledge productions.

Theme 12: When demonstrating inscriptional practices, students drew upon various social, material and conceptual resources including the artifacts created in previous inscriptional activities and their experience from previous inscriptional practices.

Students' inscriptional practices were not done in isolation but supported by various social, material, and conceptual resources. Social resources included teachers' scaffolds and peer interactions. A series of segments presented in previous themes suggest that teachers' scaffolds, such as modeling, questioning, demonstrating and elaborating, were crucial for students' enactment of inscriptional practices. Additionally, students benefited from interacting with peers. They exchanged information, shared and clarified ideas, and gave and received feedback. The big group discussion during modeling session discussed in Theme 6 is one of the examples.

Material resources, including textbooks, curriculum materials (e.g., guideline sheets), learning technologies, and the inscriptions students constructed early in the unit, also played an important role when students engaged in inscriptional practices. For example, in Theme 1, the pH scale in the textbook helped students draw a conclusion about pH range and animal survival. Guideline sheets contained questions to structure students' interpreting practices (Theme 8). The textual description provided by Model-It helped them realize that the relationship between sun heat and turbidity was not a simple causal relationship (Theme 6) and appropriated students' discourses about causal relationships (Theme 4). Furthermore, inscriptions students constructed early in the unit, such data tables and graphs, were used as templates when students created more sophisticated inscriptions (Theme 7). The data table created in pH and conductivity experiments provided data to support students' explanations of their test results (Theme 8).

As conceptual resources, students' experience and knowledge developed from previous inscriptional practices provided them with understandings about certain ways to organize, transform, and link data or concepts that could be applied to a different context with a different type of inscription. The longitudinal graph segment in Theme 8 shows such an example in which students drew on their prior experience in constructing bar graphs to engage in designing a new inscription.

Additionally, students' modeling experience became a conceptual resource when they created webpages. The following segment took place in WQ III when Andrea (T) demonstrated how to use Netscape Composer® to create webpages. To engage students in writing background information for each test page, Andrea indicated the similarity between constructing a model and writing the background (Line 7-23).

(CV104A) During the webpage demonstration, Andrea (T) indicates that each of
students' test webpages should include "background" about the test.

T: background would be, I think that there will be a lot of thermal pollution, maybe ten degrees difference, because what kind of background will you put in there?
No student answers the question.
T: think about Model-It. What is the whole purpose of Model-It? Show what?
Students: relationships.
T: relationships, okay. So if you thinking we're gonna have high temperature differences, what do we need to talk about temperature?
Stefon: thermal pollution.
T: if you think there's going to be thermal pollution, okay, that's the effect. Then what's the background you wanna say? Think about relationships. Think about working backwards.
Cynthia: there's like turbidity in the water.
T: so that's one of the reasons or the causes, right? So in Model-It, think of the things you put in Model-It, causes and effects. Remember all of your models were supposed to show the causes of something and the effects of something. These reasons are going to say why, what are the causes, so as the result the effect is what you're predicting, right? Go and look at your fall and your winter predictions and take a look at my feedback. If you lost points, make adjustment, so you don't lose these points. If you've done a really good job, look at that and say I wanna do that again.

To help students understand what information should be included and how the information should be organized in the background, Andrea reminded students of their modeling experiences (Line 7-8). One salient characteristic of modeling was to create causal relationships between variables. Stefon and other students' responses indicate their recognition of this feature (Line 8, 10, 12). Andrea then reinforced the idea of showing causes and effects in their background as students did in their models (Line 16-18). She further suggested other resources such as predictions they made in previous sub-units and her feedback that would be helpful for students to write their background.

In this segment, modeling was regarded as a particular way of representing and linking conceptual information that was to create causal relationships among variables. By reminding students of this characteristic of modeling, Andrea indicated the similarity between creating a model and writing background information for a webpage, so that students could realize the expectation of the task and engage in constructing practices with webpages without difficulties. Students' modeling experience and practices became a conceptual resource that helped them engage in constructing a new inscription, webpage. The following temperature background was written by Stefon and Charles in their temperature change webpage (the webpage shown in Figure 4.19).

> Tempature [Temperature] change is the amount of change in degrees celsius [Celsius] from one point of a stream to the end. This test helps us see if there is thermal pollution in the water. Thermal polution [pollution] can be caused by rain, chemicals, turbidity and factories. Sidewalks, if hot, can heat up rain water and when it enetrs [enters] a body of water, it heats up the water in a certain place, thus causing the temperature change to raise. Factories can dump chemicals into the water and cause thermal pollution to occur. Thermal pollution is bad because it causes less animals and plants to live there.

This background paragraph shows that Stefon and Charles did take up the idea of showing causes (i.e., rain, chemicals, turbidity, and factories) and effects (e.g., less animals and plants to live) of thermal pollution. Although their description did not follow the discursive pattern used in Model-It, i.e., as one variable (a cause) increases/decreases, another variable (an effect) increases/decreases, they described the process of how a specific cause made temperature change.

Together the examples discussed in this and previous themes show that students drew on various resources when they engaged in inscriptional practices. Particularly, throughout the unit, students developed their inscriptional practices on a basis of their own knowledge productions (i.e., inscriptions and associated practices) constructed early in the unit. As material resources, inscriptions created early in the unit provided students with concrete ideas about structures that inscriptions could have, purposes that could be served by an inscription, and data formats that could be transformed by an inscription.

As conceptual resources, inscriptions and associated practices provided students with experiences and understandings about certain ways to organize, transform, and link data or entities that could be applied to a different context.

Summary

Grounded in social theories of learning, this eight-month, classroom-based study characterizes students' inscriptional practices, traces their learning trajectories, examines the use of various scientific inscriptions, and analyzes learning supports and resources provided by teachers and the learning environment. The results show that in the inquiry-based learning environment, students drew on various resources to demonstrate different types of inscriptional practices that were led by an overarching question and ongoing concerns. Not all inscriptions were involved in all types of inscriptional practices; different inscriptions had different capabilities that allowed students to demonstrate certain inscriptional practices and that provided students with opportunities to engage in thoughtful discussions about concepts and inquiry processes. The decision of how an inscription was used in the unit was made by considering the inherent characteristics of an inscription as well as by curriculum design. Throughout the unit, students' participation in constructing and interpreting practices increased over time and their practices became more sophisticated. Their presenting and critiquing practices seemed to be shaped by teachers' instruction and scaffolds. Features of the curriculum allowed inscriptions to become an important and inseparable part of inquiry and developed continuity of inscriptional practices.

In the next chapter, I will discuss how these findings contribute to understandings about developing a learning environment in which students engage in authentic inscriptional practices and provide insights into theoretical claims regarding the value of using scientific inscriptions at the middle school level.

CHAPTER 5

DISCUSSION AND IMPLICATIONS

Drawing upon a naturalistic approach, this study investigates students' development of inscriptional practices in two seventh grade classes during an instructional unit that emphasized water quality and relevant concepts. The findings show that seventh graders could demonstrate competent, purposeful inscriptional practices when they were scaffolded by the teachers and the curriculum in a learning environment where the inscriptional activities were sequenced, iterated, and embedded in scientific inquiry. Additionally, through constructing, interpreting, reasoning about, presenting, and critiquing inscriptions, students could externalize their conceptual understandings, review the inquiry process, share ideas, clarify confusions, and make sense of data. Engaging students in inscriptional practices might be beneficial for them to construct understandings about concepts and inquiry. Although without a control group this study is not able to attribute students' development of inscriptional practices to specific factors, by exploring various inscriptional practices that seventh graders were able to demonstrate, this study provides insights into theoretical claims regarding the value of using scientific inscriptions at the middle school level and the impact it has on science learning.

This chapter begins with a discussion of the main findings. This discussion follows the organization of themes in Chapter 4 and answers the research questions about the characteristics of students' inscriptional practices, the historical development of inscriptional practices, the characteristics of inscriptions used by students, and the design of the learning environment. I then indicate the implications for teaching that could be drawn from this study. Finally, I provide possible directions for future research on students' learning of inscriptions.

Discussion of Findings

Characteristics of Inscriptional Practices

In their review of graph comprehension research, Shah and Hoeffner (2002) indicated that cognitive research has mostly focused on interpreting and reading graphs rather than constructing graphs. According to the literature review in Chapter 2, there seems less emphasis on presenting and critiquing practices with inscriptions in science education research. By characterizing students' practices in constructing, interpreting, reasoning, critiquing, and presenting inscriptions, this study aims to contribute to the gaps in the literature. This study finds that the seventh graders in inquiry-based classrooms used inscriptions across various inquiry areas throughout a water quality unit. With the teachers' scaffolds, students purposefully constructed inscriptions to serve certain reasoning purposes and were encouraged to generate meaningful predictions, explanations, and conclusions from the inscriptions to answer their driving question. Additionally, the use of inscriptions provided students with opportunities to engage in thoughtful discussions about concepts and inquiry processes.

These findings suggest that using inscriptions could have positive impact on students' understandings about concepts as well as scientific inquiry. The first six themes in Chapter 4 show that using inscriptions provoked discussions about relevant concepts and inquiry processes. The focuses of these discussions varied across different inscriptions and types of inscriptional practices. For example, when designing data tables, the classes engaged in discussions about experimental procedures and data formats in order to include all required categories. When creating a longitudinal graph, the classes focused on how to represent changes across a year into a visual pattern. As an object of practices, an inscription makes the content of conversations and the entity it inscribes (e.g., a concept or an experimental procedure) concrete and visible. Students could attach information to an inscription and modify its format and content to reflect upon their emergent understandings. As Penner (2001) argued, "developing scientific understanding can be viewed as the appropriation of tools allowing students to build on their current knowledge while engaged in socially mediated activity" (p. 28). Inscriptions could be such tools. Additionally, different types of inscriptions (e.g., graphs, models, and tables) as different notation systems could promote ways of knowing and doing science. That is, engaging in inscriptional practices might have epistemological impact on science learning (Balacheff & Kaput, 1997). Possible interactions between inscriptional practices and students' epistemological understanding about science could be explored by future research. Below I discuss findings of each type of the inscriptional practices.

Constructing Practices

This study shows that constructing scientific inscriptions in an inquiry-based learning environment was more than recording numbers or plotting data points. It involved various practices such as designing an inscription, recording readings, transforming one inscription into another, and capturing visual information, which were demonstrated in different inquiry areas (Table 4.3). Additionally, when creating an inscription, students had to consider the functions of inscriptions in their inquiry, so that the inscriptions could serve specific purposes. These findings indicate that middle school students' use of inscriptions could go beyond an "operational level" as proposed by Greeno and Hall (1997, p. 366). Not only did students learn to create inscriptions accurately by following conventions, but they also realized how to create different inscriptions to serve different purposes.

As constructing practices involve more than correctly labeling and creating technical elements of an inscription, students' understandings about concepts, inquiry, and inscriptions could interact with the construction of inscriptions. It has been found in graph comprehension research that viewers' knowledge about content and graph could influence how viewers remember graphs and lead to misinterpretations (Shah & Hoeffner, 2002). Similarly, constructing inscriptions involves students' knowledge about associated concepts as well as their understandings about how to represent the conceptual knowledge in a different form. In a modeling session (Theme 6), for instance, Stefon and Charles were able to verbally describe the relationship between sun heat and thermal pollution ("because sun is the cause and it affects the turbidity and it also affects thermal pollution"), but they had difficulties representing it into a series of causal relationships in their model. This challenge then became a learning opportunity for students to improve their constructing practices and advance their conceptual understandings. In a following segment, the teacher gathered the three groups who modeled the same driving question together and the groups had a productive discussion that helped them figure out the relationships among sun, turbidity, thermal pollution, and seasons. This finding about a modeling challenge becoming a learning opportunity is similar to what Penner, Lehrer, and Schauble (1998) found in their study of how students constructed physical models of the human elbow. Penner et al. (1998) showed that design challenges students encountered during modeling tasks provided them with opportunities to extend their understanding about natural phenomena and concepts. In addition, teachers played an important role to frame such challenges as opportunities. In Penner et al. (1998), the challenge arose when the teacher asked students about the functionality of their model. Similarly, without the teacher's intervention, the three groups might have ignored the problematic relationships and constructed relatively simple models.

Furthermore, constructing practices with specific inscriptions could be distributed to another context. Theme 12 shows that students' modeling experience and practices could serve as a conceptual resource and promote students' engagement in constructing webpages, because as an inscriptional activity that students had experience with, modeling helped students make sense of webpage construction. This finding is consistent with the notion of "intertextuality" (Bloome & Egan-Robertson, 1993; Lemke, 1990) which means that "when we participate in an activity, read a text, or make sense of talk and other forms of socially meaningful action, we connect words or events up in familiar patterns" (Lemke, 1990, p. 204). As the teacher indicated the similarity between creating relationships in models and describing causes and effects in webpages, an intertextual link between the two types of inscriptions was established. However, students might not know in what ways and under what conditions their learning experience or practice could serve as a conceptual resource. Making intertextual links could be a useful teaching strategy that helps students make meanings of novel situations and events (Bloome & Egan-Robertson, 1993).

Additionally, this study finds that inscriptions and associated constructing practices were evolving to reflect students' emergent understandings about inquiry and concepts throughout the unit (Barab et al., 2001a). As students knew more about how to conduct investigations of the five water quality tests, they changed the format of their data table to accommodate different types of data. Also, they modified the relationships and variables in their models to reflect what they just learned from class discussions, group presentations, or teachers' suggestions. Creating an inscription via group collaboration and class discussions allowed students to co-construct and negotiate meanings of the inscription and associated concepts. This finding expands theories developed by previous studies with the participation of small groups of college students or scientists in a non-classroom context (Bowen et al., 1999; Kozma et al., 2000; Lynch & Woolgar, 1990). This study shows that middle school students could also use inscriptions to construct collective scientific knowledge within a learning community in inquiry-based classrooms.

Interpreting and Reasoning Practices

Different from students' demonstration of constructing practices, becoming competent in interpreting and reasoning practices might not be shown by modifications or revisions students made in their inscriptions. Theme 8 suggests that as students became more competent in interpreting and reasoning about inscriptions, they expressed more opinions or comments on the design of interpretations or on the conclusions drawn from inscriptions. They also developed more coherent arguments in their writing about data and inscriptions. According to the research on science reasoning (e.g., Dunbar & Klahr, 1988; Karmilloff-Smith, 1986; Klahr & Dunbar, 1988; Kuhn, 1989), these changes in students' interpreting and reasoning practices might indicate a progression in scientific thinking. While younger children tended to make inferences consistent with the last results generated and ignore earlier discrepant evidence, older children appeared to produce a more coherent narrative and construct a consistent theory by coordinating the succession of instances that they observed (Karmilloff-Smith, 1986; Klahr & Dunbar, 1988). This progression is similar to the development of Smita's interpreting practices described in Theme 8. As the research on scientific reasoning was mostly done in laboratories without capturing how the progression took place over time, this study could be an extension of this area of research by showing how students' inscriptional practices evolved in classroom settings. Possible explanations of the progression in students' interpreting practices might be their multiple exposures to inscriptional activities, the teachers' ongoing scaffolds, and their cognitive development.

Furthermore, this study informs research on studying a group of students as a learning community (e.g., Kelly, Chen, & Crawford, 1998; Roth & Bowen, 1995) and suggests that encouraging students as community members to internalize common concerns throughout the unit might promote the enactment of purposeful practices. In their comparative study that examined interpreting practices of graphs demonstrated by college students and scientists, Bowen, Roth, and McGinn (1999) argued that one difference between the two groups was that scientists' interpreting practices were directional and that "different concerns led scientists to draw on different resources and engage in different practices" (p. 1030). This study shows that middle school students were also capable of enacting inscriptional practices purposefully, when sufficient scaffolds were provided by the teachers and inquiry activities were well structured. Yet, the enactment of purposeful practices was a developmental process; students did not do so at the beginning of the unit. Theme 1 shows that when students engaged in inscriptional practices in WQ I, not all conclusions and interpretations generated by students would contribute to collective understandings about the overarching question and ongoing concerns. Students gradually internalized the overarching question and ongoing concerns via engaging in inscriptional practices iteratively with the teachers' reminders and scaffolds. In a sense, internalizing the overarching question and ongoing concerns of the unit was part of the development of inscriptional practices within a learning community and these concerns in turn guided students to generate meaningful conclusions (Theme 1).

Internalizing and sharing ongoing concerns of a community could be viewed as a socialization process (Vygotsky, 1978) through which community members co-construct knowledge and confirm their membership (Lave, 1993). In this study, students became socialized as they recognized ongoing concerns of the unit and demonstrated inscriptional practices to approach these concerns. This process required interactions with more competent others (Kozma et al., 2000). Teachers frequently used questioning and structuring to engage students in practices that generated meaningful predictions, explanations, and conclusions. As most studies investigated this socialization process with the participation of college students and scientists during a relatively short period time (e.g, Bowen et al., 1999; Kozma et al., 2000), this study shows how this process could take place through class discussions in middle school science classrooms over eight months.

Presenting and Critiquing Practices

This study indicates that giving and watching presentations provided students with opportunities to reveal their confusions or questions about concepts, investigations and the use of technological tools (Themes 3 and 4). Students modified and revised their models when they received timely feedback (Theme 5). However, compared with their enactment of constructing, interpreting, and reasoning practices, students in the study demonstrated relatively fewer presenting and critiquing practices. Students did not engage in many discussions that centered upon the inscription presented and the follow-up discussions were usually initiated by the teachers. In response to the teacher's question about what they learned from model presentations, Elaine said,

> I think Model-it is fun. Then you present it. Everyone presents the same thing. It's like all the same. … You need to do this; this goes up and that goes down. And you say okay. We all heard like…one presentation we learn, but every presentation is the same stuff, so we learn it over and over again. (CV102C)

Elaine enjoyed constructing models but did not appreciate the presentations because "every presentation is the same stuff." It seems that for some students, presentations were not an occasion to benefit from each others' ideas and to engage in conversations that could contribute to individual and collective knowledge. As in Krajcik et al. (1998), this study shows that engaging students in presenting and critiquing practices is a challenge for teachers in an inquiry-based classroom. The learning environment needs to provide more supports so that students could demonstrate the practices similar to those suggested in science studies, such as using various inscriptions to convince other community members and to validate their research results (Latour, 1987; Lynch & Woolgar, 1990).

Some teaching practices demonstrated by the teachers seemed useful to help students develop their presenting and critiquing practices, but these teaching practices could have been used more frequently and intensively throughout the unit. First, teachers could use a similar set of criteria for constructing, presenting, and critiquing practices to develop interrelations among practices, and encourage students to critically evaluate the quality of an inscription. Introducing students to the criteria by which their work will be evaluated could enable them to understand the characteristics of appropriate practices and assess the quality of inscriptions (Frederiksen & Collins, 1989). As students become more competent in inscriptional practices, the whole class could be involved in creating their own judgement system.

Second, similar to their development of constructing and interpreting practices, students need scaffolds and resources while engaging in presenting and critiquing practices. Teachers' questioning and structuring before and during students' presentations might be helpful for students to demonstrate more presenting and critiquing practices. Scaffolds could be provided in a written form such as guideline sheets used in the unit. The written materials could be movable and immutable scaffolds and the use of them would not be constrained by time and space.

Third, according to the science studies, inscriptions are rhetorical tools to convince other community members that the new findings are valid and reliable (Latour, 1987; Lynch & Woolgar, 1990). When presenting their inscriptions students should address the arguments or conclusions that they try to make in their inscriptions. Also, teachers are not the only audience of their presentations. Students should be aware of who the audience is and what the audience might not know, so they could decide what to present and how to present. Moreover, presenting and critiquing practices could be done in different forms and contexts, such as a written review or an online forum (Scardamalia & Bereiter, 1994). Keeping records of feedback and critiques might help students revise their inscriptions and improve their constructing practices.

A reflective assessment process developed by White and Federiksen (1998) could be adapted to promote students' presenting and critiquing practices with inscriptions. Although the reflective assessment process was designed to help students understand the inquiry process rather than evaluating the quality of inscriptions, it included several features described above, which might be useful to foster students' enactment of presenting and critiquing practices. In this reflective assessment process, students were introduced to a set of criteria for judging their research process and scaffolded to use the criteria to assess self and other students' work throughout their science investigation. Additionally, students were asked to comment on their work and research process on a scale from 1 to 5 and record their feedback and reflection. White and Federiksen (1998) found that the reflective assessment seemed to foster communication and collaboration that in turn improved learning. Thus, teachers could consider adapting the reflective assessment process to engage students in presenting and critiquing practices in an inquiry-based classroom.

In summary, this study shows that when scaffolded by teachers and the learning environment seventh graders' inscriptional practices could go beyond an operational level and become purposeful. Constructing practices could be distributed to different contexts when teachers help students use their learning experience as conceptual resources. Additionally, the development of students' reasoning and interpreting practices is consistent with the progression in scientific thinking described by the research on scientific reasoning. Repeated exposures to inscriptional activities might partially explain this progression. Engaging students in presenting and critiquing practices is a challenge for teachers in an inquiry-based classroom. Several teaching strategies might be used to promote students' presenting and critiquing practices, such as introducing a set of criteria to students by which their inscriptions are evaluated, providing ongoing scaffolds, and keeping records of the reflections and critiques. Expanding upon my discussions about students' inscriptional practices, in the next section, I will argue for an analytical viewpoint that regards learning as a historical development.

Historical Development and Learning Trajectory

One premise of this study is that the emergence and development of students' inscriptional practices are related to past classroom events. Thus, I observed and followed the use of certain inscriptions and associated practices over time in order to reveal the development of students' inscriptional practices historically. How does this study inform theories about students' learning of inscriptions by viewing learning as a historical development? In this section, I argue that this viewpoint is helpful for researchers to understand the complexity of learning processes.

This study explores the inscriptional practices that seventh graders were able to demonstrate as well as those that they had not yet developed in the unit. For example, students did not incorporate inscriptions into their reports and webpages conceptually (Theme 10). They did not recognize the interrelations among different types of inscriptional practices (Theme 2). Their understandings about chemical representations stayed at a level of defining symbols and they were not able to use these representations to conceptualize or illustrate phenomena (Theme 9). However, are these practices developmentally appropriate for seventh graders? Metz (1995) argued that with sufficient scaffolds, young learners are capable of performing science inquiry, but their investigations are less sophisticated than those of adults. What is a seventh grader supposed to accomplish in inscriptional activities?

According to AAAS (1990, 1993), during grades six through eight, students can create graphs, tables, and simple models to organize information, represent relationships between variables of a concrete situation, identify patterns and trends, make predictions about phenomena being represented, and make arguments in oral and written presentations. Additionally, they should be able to understand writing that incorporates graphs, tables, and diagrams. In terms of understandings about models and modeling, students should be able to understand that different models represent the same phenomena and that what to create in a model and how to use a model depend on its purpose. Based on their enactment of inscriptional practices, the seventh graders in this study met these expectations. Therefore, I view students' performances in those not-yet-developed practices as part of their learning trajectories instead of a lack of skills. Below I take a situated learning perspective to discuss them.

> In a theory of practice, cognition and communication in, and with, the social world are situated in the historical development of ongoing activity.…One way to think of learning is as the historical production, transformation, and change of persons (Lave & Wenger, 1991, p. 51).

According to Lave and Wenger (1991), thinking of learning as a historical development provides a useful analytical viewpoint on learning. It allows me to portray students' learning trajectories without getting into an oversimplified conclusion about students' learning of and with inscriptions. For example, in Theme 7, I presented a series of segments from the three sub-units to illustrate the historical development of students' constructing practices. Figure 5.1 indicates the timing of students' construction of data tables, graphs, digital pictures and models.

	Sep. 2000	Oct. 2000	Nov. 2000	Dec. 2000	Jan. 2001	Feb. 2001	March 2001	April 2001	May 2001	June 2001
Data table		x x	x			x			x	
Graph		x				x			x	
Digital picture			x			x			x	x
Model					x		x			
Web-page										x

Figure 5.1. Timing of students' construction of data tables, graphs, digital pictures, and models. The highlighted periods were WQ I, WQ II, and WQ III respectively.

According to Figure 5.1, if I only collected data during WQ I (from September, 2000 to December, 2000), I might have generated different assertions about students' enactment of constructing practices, because I would have not observed students' constructing practices with longitudinal graphs and digital pictures in WQ III. I wonder if my observations about the practices that students had not yet developed were such a case. For example, even though the incorporation of inscriptions was rather physical, it was an important step towards making conceptual connections among them. Some students like Cynthia and Smita indeed began to conceptually link ideas by creating hyperlinks (Theme 3). In addition, given their limited experiences in using inscriptions and science inquiry, it is not surprising that students were not able to realize the interrelations among inscriptional practices. Students might consider more in terms of what to construct and how to construct for digital pictures if they would have opportunities to create webpages in eighth grade. Therefore, although students' participation in some inscriptional practices looked peripheral, it might be a beginning of historical developments of these practices. In fact, at any given time in the unit, students showed a range of participation levels in various inscriptional practices. In February 2001, for instance, students did not need many supports from the teachers to construct data tables and bar graphs, whereas they still needed scaffolding to create meaningful digital pictures.

Learning trajectories from peripheral to full participation of some practices (e.g., constructing data tables and bar graphs) were shown (and seemed completed) within the time frame of the water quality unit, but some (e.g., constructing webpages) might not be. The development of interpreting and reasoning practices with chemical representations, for example, could begin as early as the sixth grade and continue through high school years which is out of the time frame of this study. Here I do not claim that as time goes students will demonstrate some inscriptional practices eventually. Rather, I argue that as students were able to demonstrate most of expected behaviors at the end of the unit according to benchmarks for science literacy (AAAS, 1991, 1993), thinking of learning as a historical development might explain why they did not enact some other inscriptional practices and inform researchers and educators what practices might be demonstrated next.

Students need considerable time to perform how they know and what they have learned (Lehrer & Romberg, 1996; Schauble, Klopfer, & Raghavan, 1991). Kuhn (1995, 1997) indicated an importance of collecting process-oriented data in order to examine a developmental change of scientific reasoning “in a distribution of usage of these [reasoning] strategies and a gradual evolution toward more frequent use of better strategies” (Kuhn 1997, p. 146). Similarly, this study shares an assumption that the evolution of scientific practices is from simple and procedural practices towards more sophisticated and conceptual ones. This study also argues that in order to reveal gradual changes of students’ inscriptional practices, capturing processes of using certain inscriptions and associated practices over time is crucial. However, different from Kuhn’s argument, this study does not focus on a cognitive development in a post-Piagetian sense but a development involving the appropriation of students’ learning behaviors and discourses in a social context where students’ learning interacts with teachers’ intervention and the structure of instructional activities. This study did not determine what practices are better than others. Nor did it examine the gradual evolution toward more frequent use of the better practices. Instead, this study traces the gradual changes of inscriptional practices and uses these changes to reveal what practices are conceptually complicated and sophisticated to students. The indications of these changes include the amount of teachers’ scaffolding and shifts in teacher-student discursive patterns (Roth, 1996a, 1996b).

An examination of these indications suggests that inscriptional practices might involve different levels of difficulty and complexity. Some inscriptional practices that could be enacted via group discussions at the beginning of the unit without much scaffolding, such as recording readings, capturing visual information, and creating bar graphs and data tables, seemed more likely for seventh graders to demonstrate. Others that were scaffolded heavily by the teachers and were not enacted adequately until the end of the unit might be more conceptually complicated and sophisticated to these students. These practices include incorporating several inscriptions conceptually, constructing meaningful inscriptions for given reasoning purposes, using chemical representations comprehensively, and presenting (and constructing) inscriptions to convince people.

In this section, I argue that Lave and Wenger's (1989) notion of learning as a historical development is a useful lens to understand the practices that students had not yet developed within the time frame of the water quality unit. The research on the development of science thinking also suggests tracing students' development through analyzing process-oriented data. However, this study has a different definition of "development" that leads me to use teachers' scaffolding and discursive patterns to examine the complexity and difficulty of inscriptional practices. In the next section, I take a close look at the value of using inscriptions in science learning.

The Use of Inscriptions and Science Learning

One characteristic of the inscriptions used by students is that some inscriptions used in the unit were transformed or incorporated into other inscriptions. What are the learning benefits when students use different ways to construct inscriptions? Do scientists transform one inscription into another? In this section, I discuss how scientists create inscriptions and what students might learn from transforming and incorporating inscriptions.

Latour (1987) indicated that scientific inscriptions are often transformed into other inscriptions, which are again translated, forming cascades of inscriptions. The formation of cascades of inscriptions is usually a movement from experience-near to experience-distant (Roth & Bowen, 1994) through which a phenomenon becomes a fact and the validity of evidence is enhanced (Latour, 1990). Similarly, inscriptions used by students in the unit were not always constructed by raw data. Some of them followed a cascade of inscriptions from data readings, data tables, averages, bar graphs, and finally longitudinal graphs (Theme 10). Additionally, students incorporated several inscriptions into large scale ones as suggested by previous studies (Roth & McGinn, 1998; Star, 1995). Although the incorporation did not necessarily make a large scale inscription become experience-distant, there are learning benefits for students to construct inscriptions via a series of transformations and incorporations.

First, experiencing the transformation of inscriptions might help students read experience-distant inscriptions created by others. Although this study does not show how students' constructing practices interacted with their interpreting practices, it seemed that students did not encounter major difficulties interpreting other students' models. The interrelations among types of inscriptional practices could be further explored by future research.

Secondly, by combining and superimposing several inscriptions, the meanings of inscriptions could be layered (Star, 1995) and multiplied (Lemke, 1998). For example, inserting graphs and digital pictures into webpages allowed students to provided more information about water quality tests. Graphs and pictures could also serve as evidence to validate the argument made in the same page (Rivet & Schneider, 2001). By using multiple inscriptions, an argument is established and its validity is enhanced (Lemke, 1998). Incorporating several inscriptions into one could be a way for students to create a convincing inscription as scientists do.

Thirdly, as mentioned early, one indication of a progression in scientific thinking is producing a coherent narrative by considering the succession of instances that students observed (Karmilloff-Smith, 1986; Klahr & Dunbar, 1988). Combining and superimposing several inscriptions might encourage students to construct a consistent theory by coordinating multiple inscriptions, which in turn might promote a progression in scientific thinking.

Additionally, because there are multiple interpretations of an inscription, its meaning might depend on the context of its use. For example, in their conductivity webpage, Charles and Stefon showed a stream picture and stated that “in the picture you see that there are bubbles. Bubbles not only show that there would be a change in pH, but also show that there dissolved substances in the water, that would raise the conductivity.” Thus, one picture could indicate a high pH as well as a high level of conductivity. Students might have used the same picture in different test pages (i.e., the conductivity webpage and pH webpage). How to use a picture and how to write about its caption could be determined by the context in which the picture is used (Roth & McGinn, 1998). In doing so, students might recognize the relations between stream features and test results, and construct referential links among concepts, observations, and inscriptions.

Finally, Lemke (1998) argued that as figures, graphs, tables, and captions are incorporated into scientific text, “scientific text is not primarily linear, it is not meant to be read according to a unique implied sequence and represents a primitive form of *hypertext*" (original emphasis, p. 95). Interpreting, constructing, and reasoning about multiple inscriptions require non-linear ways of thinking and reading science, and allow students to represent their ideas via hyperlinks. Through transformation and incorporation, inscriptions could become changeable knowledge productions that demonstrate students' emergent understandings about concepts and inscriptional practices.

In this section and the previous two sections, I focus on the learning aspect of inscriptional practices. Yet, many of students' inscriptional practices might have not been demonstrated without supports provided by the teachers and the learning environment. In the next two sections, I discuss the role of the teachers and the features of the learning environment that might promote the development of competent inscriptional practices.

Teachers: A Cultural Mediator between Two Communities

At the end of the water quality unit, the use of some inscriptions (e.g., data tables and graphs) was embedded in students' investigation and became an integral part of inquiry as students were capable of using these inscriptions to record data, analyze data, and present findings without teachers' prompts (Theme 7). During interviews, students voluntarily used data tables and graphs to organize information and present findings. These findings suggest that in this inquiry-based learning environment, some inscriptions and associated practices were recognized and internalized by students. Using these inscriptions became part of classroom culture (Kelly & Chen, 1999; Kelly, Chen, & Crawford, 1998; Roth, 1996b) that matched with those in the community of scientists as proposed by National Research Council (1996). What was the teachers' role in creating such a learning community? A discussion of the teachers' role in this learning environment might explain the positive trend related to students' development of competent inscriptional practices.

Research on teachers' conceptions about the nature of science has indicated that teachers' understandings, interests, attitudes, and classroom activities influence student learning to a large extent (Akerson, Abd-El-Khalick, & Lederman, 2000; Lederman, 1992; Pomeroy, 1993). Teachers are interpreters of developed curricula (Lederman, 1992) and mediators between a learning community and the community of scientists (Kelly & Green, 1998). As the water quality curriculum was developed and enacted by the teachers participating in the study, they socialized these seventh graders to the norms and expectations of the scientific community through their teaching practices such as embedding inscriptional activities in investigations, privileging the use of inscriptions, engaging students in authentic practices, and supporting students' inquiry process with inscriptions. In the quote below, Andrea indicated the differences between her students and scientists in their understandings about concepts and inquiry processes and explained what they did in order to help students do what scientists do.

> I'd like to think that we're mirroring what scientists do here in class, but, of course, our students are novices, and so they don't have the rich understanding of things. They, you know when they approach the idea of designing an experiment, they're clueless. …That's why we take them through that slowly so that over the course of two years, they should feel pretty confident in terms of what they're doing or the same thing that scientists do, of course, not as a sophisticated level. (Teacher's interview #2)

In the theoretical framework, I indicated that the cultural negotiation process (Bruner, 1990) between a local group and the community of scientists should be seriously considered, because the norms developed by a learning community in educational settings could match as well as clash with those in the community of professional scientists. The differences in tasks, understandings, and value systems between the two communities should be considered so that students could benefit from learning activities that mirror scientists' practices. The teacher's quote above indicated that the teachers (as curriculum designers) recognized the differences between students and scientists and scaffolded students to experience what scientists do based on their understandings about students' learning trajectories and about the discipline of science.

Additionally, by adapting water quality tests from a field manual written by professional scientists (Stapp & Mitchell, 1995), teachers brought in the concerns that scientists have in the field of water quality (e.g., human impact, sources, causes, and effects of water pollution) to the classes and promoted students to enact inscriptional practices purposely. Becoming a member in a community involves sharing similar views and concerns with other community members (Lave, 1993). These concerns are part of enculturation into a field of practice (Bowen, Roth, & McGinn, 1999). As shown in the results, these concerns led students to draw meaningful conclusions from available inscriptions (Theme 1). By recognizing these concerns and constructing knowledge to contribute to understandings about them, students confirmed their membership in a learning community that was aligned with the professional community of scientists.

Moreover, students did not "invent" scientific inscriptions in the unit. The teachers introduced general rules for constructing inscriptions and provided students with opportunities to apply these rules and construct inscriptions in different contexts and inquiry areas. In doing so, students experienced two sides of science: Ready-made-science and science-in-the-making (Latour, 1987) as I discussed in the theoretical framework.

Therefore, although this study focuses on students' inscriptional practices rather than teaching practices, the findings suggest that the teachers' understandings about the discipline of science and the differences between the two communities might explain the success of creating a culture that encouraged the development of competent inscriptional practices. Future research on teachers' conceptions about the discipline of science and their pedagogical practices would advance understandings of how teachers' understandings about scientific practices interact with the construction of a culture of inquiry.

Designing a Learning Environment for Developing Competent Inscriptional Practices

> The educational goal of representing work should not be simply to create images, but to understand our relationship to those images and to the inscription practices that create them (Roth & McGinn, 1998, p. 52).

Based on the studies of college students and scientists, science education researchers (Bowen et al., 1999; Kozma et al., 2000; Roth & McGinn, 1998) called for educators to design a learning environment in which students develop competent and authentic inscriptional practices. These authentic practices share similar characteristics of those demonstrated in the professional scientific community, such as constructing inscriptions to generate patterns in data, interpreting inscriptions created by others, using inscriptions to make predictions and explanations, and identifying and analyzing visual features of an inscriptions. In their study of college students and professional scientists, Bowen et al. (1999) proposed a question for future research: "What kind of features do such learning environments need to have so that students' competencies [in inscriptional practices] are developed?" (p. 1040). As the seventh graders in this study demonstrated these authentic inscriptional practices with different levels of participation (Themes 1, 7, 8 and 11), this study provides insights into this question.

The use of inscriptions should not be assigned as isolated tasks. Rather, to help students understand the relationships among inscriptions, concepts, and inquiry, the use of inscriptions should be embedded in the inquiry process. In doing so, students have a need to learn (Blumenfeld, Marx, Patrick, Krajcik, & Soloway, 1997), realize the purposes of using inscriptions, and construct the meanings of inscriptions based on the context (Greeno & Hall, 1997). Additionally, inscriptions are traditionally viewed as tools to present findings and analyzing data (Brasell & Rowe, 1993; McKenzie & Padilla, 1984; Preece & Janvier, 1992). According to the analysis of classroom videos, however, the seventh graders in this study demonstrated inscriptional practices in various inquiry areas, including making predictions, developing questions and planning and carrying out investigations (Table 4.3). Constructing, interpreting, and reasoning about inscriptions in different inquiry areas provided students with opportunities to decide how and what inscriptions should be used based on the characteristics of the inscriptions and the purposes of reasoning. The inscriptional practices demonstrated by students were similar to those proposed by the literature (e.g., Bowen et al., 1999; Kozma et al., 2000; Roth & McGinn, 1998). Different inquiry areas could provide meaningful contexts for students to engage in authentic inscriptional practices.

Additionally, students' initial enactment of inscriptional practices requires co-participation of more competent others (Themes 7 and 8). As shown in the results, teachers' scaffolds were crucial to facilitate students' engagement in inscriptional practices. This finding is supported by other studies conducted in a guided-inquiry environment (e.g., Krajcik et al., 1998; Tabak, 1999; White & Frederiksen, 1998; Wisnudel-Spitulnik, 1999). This study further indicates that when and how much scaffolding should be faded might be a challenging decision for teachers to make (see the example of digital pictures in Theme 9). During the water quality unit, students became competent in constructing data table as teachers' scaffolds gradually faded out during WQ II and WQ III, but they still needed supports in order to construct meaningful digital pictures.

Scaffolds were not necessarily in a form of discursive interactions between teachers and students. They could be provided by curriculum materials (e.g., Hoffman & Krajcik, 1999) or learning technologies (e.g., Fretz, Wu, Zhang, Krajcik, & Soloway, 2001). In this study, guideline sheets prepared by teachers played a role of scaffolding because they provided a series of questions or guidelines that structured a difficult inscriptional activity and allowed students to participate in the activity without the presence of teachers (see Abby and Mason's segment in Theme 8). As mentioned previously, students demonstrated relatively fewer presenting and critiquing practices compared to their enactment of constructing and interpreting practices. Providing a set of criteria or guidelines to evaluate inscriptions might have helped students present their inscriptions and give feedback to other students' presentations.

Two features of the curriculum design, sequencing inscription-related activities and engaging students in using inscriptions in an iterated matter, seem to promote competent inscriptional practices (Theme 11). Sequencing and iterating instructional tasks are not new ideas in curriculum development (Krajcik et al., 1998). Using sequencing as a type of scaffolding allows students to focus on completing one sub-task at a time and makes a complex task feasible (Krajcik, Czerniak, & Berger, 1999). Also, it is unlikely that students could internalize the sequence and ongoing concerns of a task by only one exposure, so engaging in inscriptional activities in an iterated matter could help develop thematic continuity of content and practice (Tabak, 1999). However, sequencing a task is different from a step-by-step activity in which teachers gave the instruction about how to carry out the activity and every student performs the same activity (Krajcik, Czerniak, & Berger, 1999). The four steps of data analysis suggested by the teachers in this study (see details in Theme 11) were procedural as well as conceptual. Each step required students to use social, conceptual, and material resources to accomplish it (White & Frederiksen, 1998). Students not only learned how to interpret inscriptions, but also what to interpret from the inscriptions by intentionally abstracted certain information from the inscriptions. Also, iterating tasks is not simply repeating what students have done before. In each sub-unit, for example, students were assigned tasks with different levels of complexity. Iterating inscriptional activities maintained continuity of practice and helped students demonstrate more sophisticated practices.

In summary, the inquiry-based learning environment in this study had several features that might promote students' development of competent inscriptional practices. First, the use of inscriptions should be embedded in different inquiry areas that provide meaningful contexts for students to engage in authentic inscriptional practices. Second, students need to interact with more competent others in their initial enactment of inscriptional practices. Third, ongoing scaffolding should be provided in different forms and should be considered to work in tandem with all the scaffolds in the classroom system. Finally, the design of the curriculum should maintain continuity of practice, allows students to internalize the ongoing concerns, and engage students in inscriptional activities iteratively. Also, sequencing inscriptional tasks could keep students focus on each sub-task at a time and make inscriptional tasks feasible.

Conclusion

Expanding upon early research on students' learning of inscriptions, this study shows that seventh graders could demonstrate competent, purposeful inscriptional practices when they were scaffolded by the teachers and the curriculum in a learning environment where the inscriptional activities were sequenced, iterated, and embedded in scientific inquiry. Using inscriptions in science classrooms might have positive impact on students' understandings about concepts as well as scientific inquiry. The historical development of students' inscriptional practices documented in this study could inform theories about social practices, learning communities, scientific reasoning, and science inquiry. The findings about the use of resources and the curriculum features provide insights into the design of a learning environment in which students have opportunities to develop competent and authentic inscriptional practices.

In the last two sections, I indicate the implications for teaching that could be drawn from this study, and provide possible directions for future research on students' learning of inscriptions.

Implications for Teaching

Through exploring seventh graders' use of inscriptions, this study suggests some features and teaching practices in a learning environment that could promote the development of competent inscriptional practices. In this section, I summarize educational implications for teaching.

<u>Exploiting the potential use of inscriptions.</u> In the water quality unit, maps, chemical representations, and the pH scale were usually used to introduce concepts and develop background knowledge for science investigations. They might have been used in other inquiry areas, such as collaborating and presenting findings. Additionally, digital pictures would be helpful for data analysis as they show details of stream features that could explain test results. Graphs could be used to support arguments when students present findings in webpages.

<u>Sharing the driving question for models.</u> As shown in Theme 6, when three groups shared the same driving question, it provided opportunities for large group discussions allowing students to exchange ideas and co-construct their models together. It might be beneficial to engage students in in-depth discussions about the content of model and improve the quality of models.

<u>Guiding students to conceptually incorporate different inscriptions.</u> Teachers could model how to make references to inscriptions in written text. They could also remind students to make coherent arguments throughout the same inscription and verbally relate results to data tables and graphs in science reports.

<u>Helping students realize the interrelations among types of inscriptional practices.</u> For example, when constructing digital pictures, students might make annotations, record

the reasons of taking pictures, and mark the locations where they take pictures on their stream drawings. The annotations and records might later help students use these pictures as evidence and demonstrate meaningful reasoning practices.

Providing timely feedback and opportunities for students to revise their inscriptions. Students might not record or remember the feedback they receive and reflect them on their inscriptions unless the feedback is timely. They need opportunities to modify their inscription during or right after the feedback is given.

Using inscription-related experiences as resources. Resources could be material, social and conceptual. Inscriptions and associated experiences could be a helpful resource for students to construct new inscriptions. Teachers might encourage students to apply their inscriptional experiences in new situations.

Future Directions

This study presents an eight-month investigation of middle school students' inscriptional practices in a water quality unit. A number of claims are made to suggest that students are able to demonstrate competent inscriptional practices when sufficient scaffolds from teachers and the environment are provided and that using inscriptions provides students with opportunities to construct understandings about concepts and science inquiry. This study also raises some questions and issues that require future research. These questions and issues could come from the limitations of the study and could be the questions mentioned in my previous discussions but not yet investigated thoroughly by this study. Future research that addresses these questions and issues would help educators and researchers better understand the complex learning processes with inscriptions.

As indicated in Chapter 3, there are limitations of the study that derive from the theoretical framework as well as the methods. These limitations include de-emphasizing students' cognitive skills and individual differences among students, conducting the study in classes with atypical class sizes, and underplaying the importance of the scaffolds and learning supports provided by technological tools. These limitations raise several questions for future research: How do students' cognitive skills contribute to their enactment of inscriptional practices? What is the relationship between students' cognitive skills and their participation in inscriptional practices? Who (e.g., low or high academic achievers) would benefit from inscriptional activities the most? Can the findings of this study be generalized to the classes with larger class sizes and/or with teachers who have less experience in teaching inquiry-based classes? How do scaffolds provided by learning technologies support students' demonstration of inscriptional practices?

There are also questions and issues emerging from the study that require future research. First, in my discussion of inscriptional practices, I indicated that as students developed ways of knowing and doing science via appropriating different notation systems, engaging in inscriptional practices might have epistemological impact on science learning. Yet, this study does not include data to indicate what exactly this epistemological impact would be. Do students know more about the dynamic and ongoing nature of science after a comprehensive use of inscriptions? Do students' views about the role of inscriptions in knowledge construction change after a comprehensive use of inscriptions? Possible interactions between inscriptional practices and students' epistemological understanding about science could be explored by future research.

Next, although this study indicates interrelationships among different types of inscriptional practices, it is still unclear whether the development of one type of inscriptional practices (e.g., interpreting practices) would improve or foster another type of inscriptional practices (e.g., constructing practices) and vice versa. Further research about interrelationships among types of practices is needed.

A third issue that should be addressed in future research is the teaching aspect of inscriptional practices. Similar to others (Collins, Brown, & Newman, 1989; Krajcik et al., 1998; Perkins, 1996; Wisnudel-Spitulnik, 1999), this study finds that teaching practices could shape students' learning performances and their enactment of inscriptional practices. More research is needed to better understand how teaching practices and teachers' pedagogical content knowledge might interact with students' enactment of inscriptional practices and with the construction of a learning community where the members share a culture similar to those in a professional community of scientists.

Moreover, the social distribution of knowledge, intelligence, and reasoning has been characterized as an important dimension of learning and understanding scientific knowledge (e.g., Dunbar, 2000; Roth, 1996a; Salomon, 1993). In my discussion of students' constructing practices, I indicated that by using modeling and associated experience as conceptual resources, students distributed their constructing practices to different contexts with different inscriptions involved. However, my findings are limited to students' constructing practices. A number of questions in terms of the distribution of inscriptional practices remain: How do students distribute their interpreting, reasoning, presenting, and critiquing practices? How do students distribute their practices through different participation structures (e.g., group discussions and class discussions)? The latter question is particularly relevant to the design of curriculum and instructional activities.

There are important questions and learning issues about the use of inscriptions that are not addressed in this study. This study does not investigate the metacognitive dimension of students' inscriptional activities. My discussion about students' critiquing practices and the reflective assessment process (White & Frederiksen, 1998) indeed implies a possible relationship between metacognition and inscriptional practices. Is there any metacognitive strategy involved in critiquing practices or other type of inscriptional practices? Does metacognition promote students' enactment of inscriptional practices? It is possible that metacognition fosters students' enactment of inscriptional practices as well as improves the quality of inscriptions created by students. Another issue that could be further explored is about the quality of the inscriptions created by students. The findings show that students' presenting practices seemed irrelevant to the quality of their model, but this study does not take a close look at a possible relationship between different types of practices and the quality of inscriptions. Future research that investigates this relationship might deepen the understandings of how to promote students to construct sophisticated inscriptions that reflect on their practices.

APPENDICES

APPENDIX A

Class Observation Fieldnotes

---

* School: G
* Teacher: Andrea
* Unit: Water Quality
* Date: 10/2/2000
* Tape No.: 005
* Video: Classroom
* Period: A

Summary: Today's class involves a lot of discussions about scientific processes and how to practice these processes. Andra gives students several minutes to quick review their procedures done last Thursday. Then the class begins to discuss. Students volunteer their ideas about what procedures should be included in the experiment. Andrea generates a list on the board. The topic then moves to writing conclusion and analyzing data. Some students suggest graphing the data, but the discussion doesn't go further about how to do it. Andrea has them to create a data table. Students discuss in pairs about what their tables may look like. It seems that BS and SG don't quite understand the task or don't know how to start a table. Andrea then has students draw their data table on the board. Four groups of students draw their tables. Three of them are similar, and only CH's table is for each substance. Andrea tells them there is no wrong or right. The class discusses the tables. Before the class end, Andrea assigns the homework which will be due on Wednesday.

8:03 Kids come in
Table 1: 4 girls (CH, ST)
Table 2: 4 girls
Table 3: 4 boys (CF , SP)

8:07 Review last Thursday's class
Last week, we talk about procedures. Find that from your notebook.
okay, last week, Thursday
We start to do procedure for experiment.
Review Thursday class.
What is procedure?
S: Step by step order.
S: Generate something for procedure.
Go through to your list, talk with the person next to you.

8:10 Share ideas and discuss procedures
let's share.
[B]
Procedure
Clean containers
Distilled water→ control
Put in substances→ the same amount of substances, the same of water
+ mix
Prediction
Test → three times 7.6, 7.3, 7.5→get average

Record
Rinse of probe with distilled water before putting in another substances.
Repeat for each substance
Clean up. Graph data.

[B] Analyze→ conclusions→ more questions.

Discuss how much they should put into the water. Do the amount influence pH?
Just change one thing. We try to keep everything the same. That's good science. Tomorrow we will create three amounts of the same
Do we need to let it settle?
Do you think everything will mix the same?
It will mix differently. For example, if we put sand, (draw a picture on the board)
We have to expand the "testing." Rinse. Couple times.
[NOTE: how will students do with outliners?]
Math and science connection: outliner.
Should we record only average? No, we record everything. Raw data.
Something before test.
Make hypothesis. Basic or acidic?
We will do test and go back what pH means.
For example, these substances have similar pH. What makes them similar?
After all these test, something we should do.
S: Graph the data.
Andrea uses a sport example. We need to "analyze" data.

[NOTE: the teacher not only introduces these terms about scientific processes to students, but also guides students to discuss them in depth. Also, students' ideas count in this class. So far Andrea never formally rejects students' ideas.]

8:31 Data Table
We want to record. What should we record in it? It's quantitative data from emate.
We should create data table. We want to organize them.
Think about data table. Create one together.

[NOTE: This segment should be transcribed later. How did Andrea introduce the idea of data table? Did all students know what data table means? What social meanings are generated after the tables are created? Analyze: purpose, creator, and user.]

8:37 Create tables
Andrea has students come up to the board.

Data table discussion.

Homework due on Wed:
Question, Procedure, Data table for pH experiment.

APPENDIX B

Student Interview Protocol

The following information is provided during interviews:

Temperature and Conductivity

Predictions:

Temperature difference:
I predict that there will be thermal pollution in summer, because thermal pollution is caused by the amount of sunshine. Summer has more sunshine that makes the stream water hotter. The more sunshine, the higher the temperature differences. In winner water gets cooler, so there will be no thermal pollution.

Conductivity:
I observe that during winter, people use a lot of salt to melt the ice on the road and the salt goes into the stream. I think when salt dissolves in the stream, it increases the conductivity. In summer, no people use salt, so the conductivity will be the lowest. Therefore, I predict that the colder the season, the higher the conductivity.

Data:
Water data were collected from September 1999 to July 2000. Two locations, A and B, in the stream were selected to collect temperature data. These two locations were a mile apart. In September, the water temperature in location A was 22.25 ºC and the temperature in location B was 22.60 ºC. The conductivity reading was 420 mg/L. After a month (October 1999), the water temperature in location A was 18.20 ºC and the temperature in location B was 18.60 ºC. Conductivity in October was 486 mg/L. In November, the conductivity increased to 462 mg/L. The water temperature in location B decreased to 14.52 ºC and the temperature in location A was 14.00 ºC. In January 2000, the water temperature in location A was 11.50 ºC and the temperature in location B was 12 ºC. The conductivity reading was 494 mg/L, which was higher than the reading in November. In March 2000, the conductivity was 450 mg/L. The water temperature in location A was 15.10 ºC and in location B was 15.34 ºC. After two months (May 2000), the water temperature in location A was 20.1 ºC and the temperature in location B was 20.38. The conductivity was 384 mg/L. In July, the water temperature in location A was 23.7 ºC and the temperature in location B was 24 ºC. The conductivity was 390 mg/L.

Standards:
The water quality is excellent when temperature difference ranges from 0 ºC to 2 ºC. The water quality is good when temperature difference ranges from 3 ºC to 5 ºC. The water quality is fair when temperature difference ranges from 6 ºC to 10 ºC. The water quality is poor when temperature difference is higher than 10 ºC.

If the conductivity is lower than 100 mg/L, the water quality is excellent. If the conductivity ranges from 100 to 250 mg/L, the water quality is good. If the conductivity ranges from 250 to 400 mg/L, the water quality is fair. If the conductivity is higher than 400 mg/L, the water quality is poor.

Based on the following information provided, students are asked to answer the questions below:

1. What would you do to answer a question of: How does the stream quality change over a year? (Students may sketch or write down their ideas.)

2. What will you do next in order to generate conclusions and finish the report? (Students may be reminded that their report has to answer the question 1.)

3. How do you do with the data?

4. How would you use the information from predictions?

5. Why do you choose xxxx (xxxx is students' previous answer about data analysis) for your data analysis?

6. What do you think scientists would do in order to analyze these data?

7. How will you show the data to your classmates? Why?

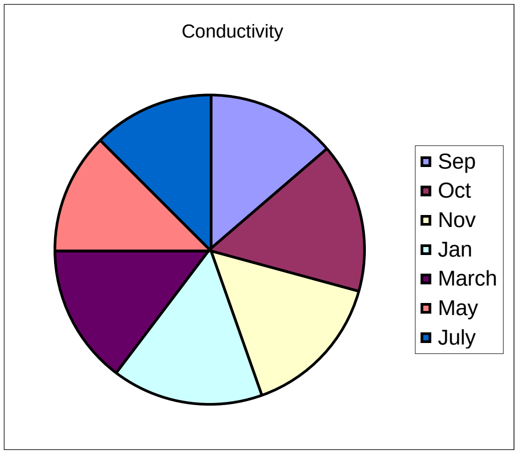
8. How will you communicate your conclusions to your classmates?

The following questions are asked with 6 graphs shown on the next page:

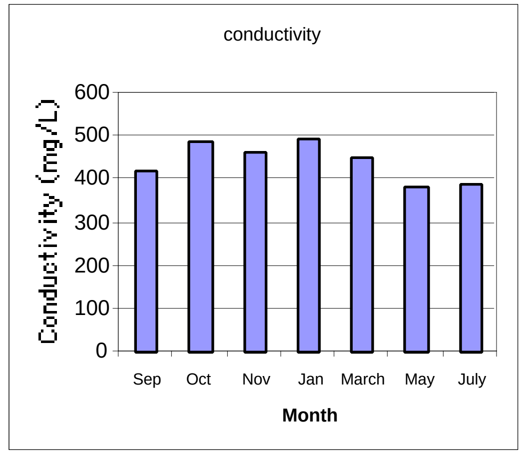
9. Take a look at these graphs. In your opinion, which one is the best graph to represent the data? Why?

10. In what situation will you use bar (or line or pie) graphs?

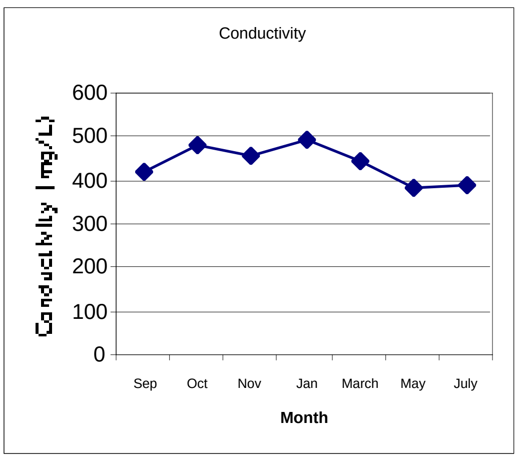
11. Based on the graph you chose, what conclusion could you make about the water quality over a year?


Conductivity
Sep
Oct
Nov
Jan
March
May
July

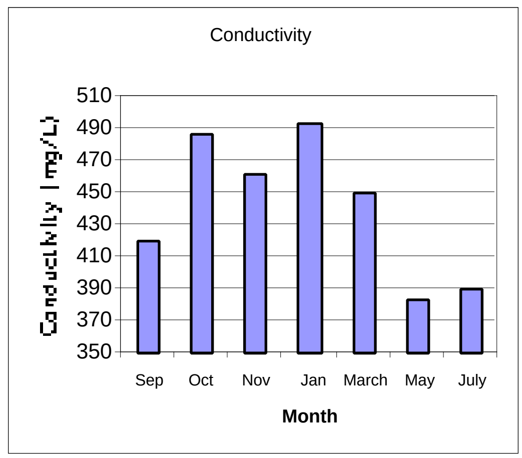
A


conductivity
Conductivity (mg/L)
600
500
400
300
200
100
0
Sep
Oct
Nov
Jan
March
May
July
Month

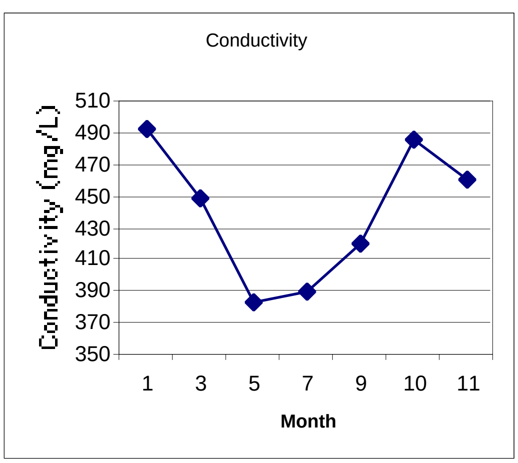
B


Conductivity
Conductivity (mg/L)
600
500
400
300
200
100
0
Sep
Oct
Nov
Jan
March
May
July
Month

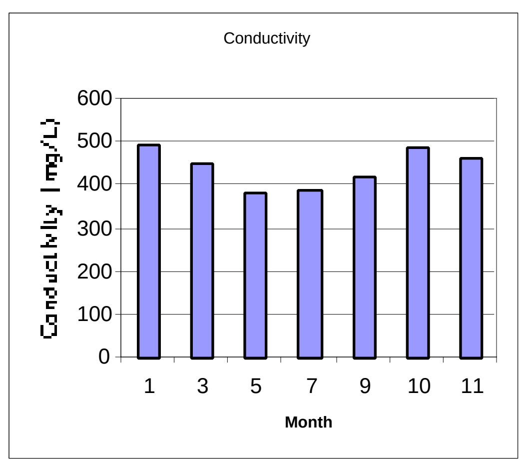
C


Conductivity
Conductivity (mg/L)
510
490
470
450
430
410
390
370
350
Sep
Oct
Nov
Jan
March
May
July
Month

D


Conductivity
Conductivity (mg/L)
510
490
470
450
430
410
390
370
350
1
3
5
7
9
10
11
Month

E


Conductivity
Conductivity (mg/L)
600
500
400
300
200
100
0
1
3
5
7
9
10
11
Month

F

APPENDIX C

Classroom Video Transcript

* School: G
* Teacher: Celia
* Unit: Water Quality
* Date: 11/2/2000
* Tape No.: 038
* Video: Classroom
* Period: C

Summary: Today the class goes out to the stream (stream drawing). The plan was changed; yesterday Celia told them they would have a lab today. Tomorrow weather may not be good, so they go out today. Celia passes out the handout and collects their turbidity paragraph. Students are excited about going out. Nathan/Olisa and Denny/Ally are assigned to the portions 3 and 5. They work well and engage some discussions about features and test results.

================ Transcript ================
----------Episode 1: Recitation, setting up the task—stream drawing
11:11:03
T passes out the sheets.
T: tonight remember you have DO. That's the last thing for the background information.
Ss are talking.
T: are you ready to listen? I really need your cooperation.

T: what you need to do is you're gonna go out to the stream and you're gonna take an xxx and draw or a sketch of your section of the stream. You're gonna go 10 feet on either end of the stream. So you can get some trees and markers that would tell you that's your part of the stream. Now you're gonna do that in your com book. When you come in, on the weekend remember, we said we still do that on the weekend, is on a sheet of blank paper like this, you're to draw your section of the stream. And you're gonna size it to one inch equal to one foot, all right. This is 8 and half by 11 [T uses a stack of guiding sheets to indicate the size of a page]. So if you imagine you have ten foot section, it should fit nicely this way, okay. now if you end up being assign to something that's a little bit bigger, then you can add another sheet of paper to the side area and just fold it over. I think we'll be okay.

T: now, when you get out to the section that I assign to you, you're gonna measure it with this meter stick, so that you can have how far everything is in your section of the stream, so you could draw it appropriately.

T: you'll also, as it says here, you need to pick location A, B and C that you'll be testing each time, okay, through the seasons, to collect these chemical data. all right, point A, B and C. okay. It will be your section throughout the year, okay, your section throughout the year, so that you could compare what the results are. And they could be different than any of the other classes that they pick points, testing points. Some of them would be the same, because of certain characteristics where you're gonna be drawn on and take data on that point. All right.

T: on the weekend as well, this sheet tells you this very explicitly, is that you'll not only draw that picture. You'll also come up with a couple of short paragraphs, that explain why you pick point A, B and C, okay, so that you can jot your memory and then when you collect data, you can see if any of those certain ideas that you have about that location are correct or not. Okay?

T: as I said before, we're taking the opportunity to do that today because clouds are supposed to move in and who knows what kind of weather moves in.

11:16:58

T assigns groups.

------------Episode 2: Field, creating stream drawing
11:26:26
Assign sections to target students.
Ally/Denny, Elaine/Allan, Olisa/Nathan are assigned to sections next to each other.
11:29:33
Ally talks to Allan and Elaine: are we supposed to draw right now?
Ally measures the length of their section.
Ally talking to Allan and Elaine: how long is yours? Ours is 16 feet.
Ally: ours is like 16 feet with curve.
T comes by: that's fine.
Ally: each section is like this big [point to the stream] or that big [show T her drawing]?
T: it will be in inch, right. So you may do what you have, two sheets of paper and then fold it over.
Ally: can I do that?
T: sure.
Ally: can I write like how big of that little thing?
T: yes.
Ally: is that all right?
T: yes, you can. Anything that's gonna mark for you.

11:32:06
Nathan: we have 18 or 19 feet, then we should have 18 or 19 inches of paper.
Olisa: wow, this is so cool.
Nathan and Olisa begin their drawing.
Elaine puts sticks into the stream.

11:34:48
Nathan: ours is like 18 or 19 feet.
T: so you'll have two sheets of paper like this and fold it over like the one I show you. You're going to sketch this and then on either side this way [left and right]. And then what you're going to do is pick your three testing points.
Nathan: should we draw like from the top or from the side?
T: top view, okay?

11:36:55
Elaine throws leaves into the stream.
Nathan: you're polluting our water.
Allan: we see where the current is moving.

------------Episode 3: Field, choosing 3 locations for tests
11:38:00
Ally and Denny are picking their locations.
Ally: right here. The fall there. [no explanation about why they pick the locations].

Olisa: Turbidity is pretty good. Not a lot of xxxx.
T: pick those points that you can test.
Olisa: are we gonna come up here one more time?
T: yes, you're gonna take pictures and make predictions.
11:39:44
Nathan: there will be one.
Olisa: okay.
Nathan: Ms. Gleason, are we gonna to pick a section or a little point?
T: individual point that you're gonna be testing.
Nathan: so I'm gonna put X.
T: yes, just put X on the spot.

11:41:00
Olisa: the waterfall is kinda of muddy.
Nathan: we should make one like maybe on the top of waterfall or on the bottom?
Olisa: or like in the middle.
Olisa goes to point to the middle.
Nathan: let's make that little point.

[Nathan and Olisa discuss the physical features of each point before they pick it.]

11:43:10
Ally and Denny show T where they pick.
They consider current, shallow, oil on top.
They pick 4 points.
T: it seems that you got reasons for each one of them.

=========
Note:
1. Ss in class II really focused on the scale of the stream.
2. Celia did not spend much time explaining what they should draw. It would be interesting to see what students chose to include in their stream drawing.
3. What did they capture in their drawings?
4. Did they talk about the criteria of picking the locations?
5. How did students make connections between features and concepts?

APPENDIX D

NUD*IST® Report of Constructing Digital Pictures

```
Q.S.R. NUD*IST Power version, revision 4.0.
Licensee: Hsin-Kai Wu.

PROJECT: Inscription010602, User Hsin-Kai Wu, 2:29 pm, Jan 16, 2002.

*****************************************************************************************
(I 26)                  //Index Searches/Digital pix-construct
*** Definition:
Search for (INTERSECT (3 7) (4 1)). No restriction

Margin coding keys for selected nodes:
A: (5 1) /Teacher Practice/Frame inscription task        G: (5 2 6) ~Scaffold inscripti
B: (5 2 1) ~affold inscription practice/Constructing scaf   H: (6 1) /Inquiry Process/Ask
C: (5 2 2) ~affold inscription practice/Interpreting scaf   I: (6 2) /Inquiry Process/Desi
D: (5 2 3) ~/Scaffold inscription practice/Reasoning scaf   J: (6 3) /Inquiry Process/Coll
E: (5 2 4) ~Scaffold inscription practice/Critiquing scaf   K: (6 4) /Inquiry Process/Anal
F: (5 2 5) ~/Scaffold inscription practice/Other scaffold   L: (6 5) /Inquiry Process/Carr

++++++++++++++++++++++++++++++++++++++++
+++ ON-LINE DOCUMENT: CVT041A-DigitalPix
+++ Retrieval for this document: 52 units out of 99, = 53%
++ Text units 34-85:
----------Episode 2: Field, digital pictures                                 34    D
                                                                             35    D
9:30:44 stream                                                               36    D
ST is absent today.  CF and SP are videotaped.                               37    D
9:35:50                                                                      38    D
T:  you don't necessarily agree on every test.                               39    D
9:36:51                                                                      40    D
T asks CH about soap and pH.                                                 41    D
9:38:59                                                                      42    D
R: why are you taking picture here?                                          43    D
CH: because when we were describing it, it might be hard to describe how          D
there is kinda like a sandy bank there, how there is like soap bubbles            D
down there.  It's hard to draw them on the picture, so we're gonna take           D
some pictures, I think, so we can explain more about what we mean.           44    D
R: will this bank affect any test result?                                    45    D
CH: yeah.  They will affect the turbidity because sand can fall into it           D
[the stream].                                                                46    D
R: is that your point B?                                                     47    D
CH: no.  yeah, yeah, our point A is right with it.  so I'm thinking maybe         D
it's gonna have a higher turbidity level at A.                               48    D
                                                                             49    D
9:40:22                                                                      50    D
CF and SP are making predictions.                                            51    D
SP: take a picture for C.                                                    52    D
CF takes pictures for point C.                                               53    D
                                                                             54    D
9:43:20                                                                      55    D
Sally stops by and asks CH how to make predictions for temperature.          56    D
CH says she doesn't know.                                                    57    D
                                                                             58    D
9:44:46                                                                      59    D
CH: I don't understand how to predict conductivity.                          60    D
T: well, you're gonna have to decide, you can't see anything, right?              D
Although we can maybe see some evidence, uh [T takes a look at SP's               D
notebook].                                                                   61    D
CH: will the soap affect conductivity?                                       62    D
```

APPENDIX E

Coding Scheme II

	Inscriptional Practice		Inscription		Teacher Scaffold
PR.01	Tool or resource use	IN.01	Procedures to construct an inscription	TC.01	Model the practice
PR.02	Inquiry process, context	IN.02	Inquiry process	TC.02	Demonstrate
PR.03	Concepts	IN.03	Concept required	TC.03	Question
PR.04	Field experiences, prior experiences, lab, observations	IN.04	Data required for construction	TC.04	Elaborate ideas
PR.05	Indications of the quality of practice	IN.05	Nature, function, characteristic	TC.05	Give examples
PR.06	Background info for interpretation	IN.06	Structure, content, components	TC.06	Sequence task
PR.07	Explanations, meanings, reasons to make sense of data	IN.07	Referential links among inscription, concepts, and phenomena		
PR.08	Meanings for terminology	IN.08	Indications of the quality of inscriptions		
		IN.09	Relevant inscriptions		
		IN.10	Potential readers		
		IN.11	Outliers		**Other (OT.00)**
		IN.12	Identify features (patterns) of inscription to interpret	OT.1	Regular learning or instructional sequence
		IN.13	Describe data represented	OT.2	Breakdowns
		IN.14	Construct explanations, meanings, reasons to make sense of an inscription	OT.3	Change over time

APPENDIX F

Episode Description of NUD*IST® Report

I.5 Data Table/constructing

EPISODE DESCRIPTION		
Tape number: CVT005A-pHDataTable	Sub-unit: WQ1	Episode number: 2
Class activity: Recitation/discussion	Participants: T and class I	
Inscription: data table	Practice: Constructing	T's practice: Instruction, scaffolds
Tool used: board, notebooks		Content accuracy:
Description:		

Episode 1: the class reviews the procedures of pH lab.

Episode 2: (IN.04) (IN.05) (IN.06) Then T indicates they are going to record the data. "What are we going to record it?" Carla says "graphic notebook, " which is not an answer T looks for. T rephrases the question "in what will we record it in our graphic notebook?" Again, students' responses are varied, "number," "pencil," "quantitative." (PR.01) T confirms their answer by saying "it's quantitative data with our emate. We could also include qualitative data, right?" (IN.01) CH volunteers the idea of "like a table of it" and wants to know if they can do it on computer. (IN.05) T gives her a positive answer and then asks the class "why do we wanna do that?" Annie says "organize." T confirms the answer and further gives instruction of how she wants them to create a "data table." (IN.01) T wants students to discuss in groups and create a data table in their graphic notebook. (IN.08) They need to "think about everything that has to go in there." (PR.05) "We're gonna create one together." "Then we'll share and we'll see uh... hopefully between all of you will get an idea what kind of data table."

When groups discuss, Carla comes up with an idea of using pH scale to indicate pH values of different substances. (IN.05) (IN.09) T thinks her idea is valuable, but that is better to "do that afterward," so she "can make 0 to 14 you were talking about, and the stuff all on the line." When Carla shows T another representation, (TC.04) T provides detailed and specific scaffold. The scaffold indicates why they need a table, how the table should be looked like by considering the data they are going to collect. (IN.04) (IN.06) (PR.04) "Carla, I think that's a great idea after we get the data. That's one way, remember we said graphing, somehow we need to represent our data. That will be one excellent suggestion. Okay. But first we need to collect our data. We need to have spaces to put...We [higher the voice to the class] need to have spaces to put 3 times, right?" (IN.06) T further points out that they need to consider having a space for averages. (IN.08) (PR.05) This time, T explicitly asks students "Come up with some kinds of table, talk with each other. If you're not sure, the two of you could start to talk as a table."

Episode 3: Students present their data tables.

Analytical notes:

(PR.01) This episode occurred when students designed their investigation and planed procedures for their pH lab. (PR.03) Although it was a pH lab, this episode did not involve discussions of pH concept.

(OT.02) There were several breakdowns in this episode. When T asked what they were going to "record their data," students' responses indicate that they did not quite understand T's question. These misunderstandings might be caused by several reasons. First, students have not fully realized the process of "recording" data. They could not foresee the investigation they were going to conduct, so it was difficult for them to figure out "what they are going to record their data" besides using their graphic notebook. Second, students confused "what will be used to record data" with "what to record," so they came up with ideas of data types such as number and quantitative. Third, as novices to conduct inquiry, students did not conceptually connect the recording procedure with use of inscriptions, although using inscriptions indeed is not always necessary for data recording. Later when T asked students to come up with something that make data easier to read, many of them mentioned about inscriptions. Thus, it seems that students realized that inscriptions could be used to representing data visually, but in terms of using inscriptions to record data, they needed practices to realize that inscriptions can be used in many different contexts and inquiry areas. (TC.04) T's scaffold indicated that she realized students' difficulties, so she describes the investigation briefly.

(TC.00) T's initial instruction for data tables seems not explicit or detailed enough for students to create inscriptions that can be used for recording data. So Carla used pH scale as her data table. Carla might also misunderstand what a table is. (IN.06) T's scaffold included important information about a table: having spaces for three trials and averages. Again, it is difficult for students to foresee what data they were going to record by considering the procedures. Students need to consider the procedures when creating their data table.

[CVT005A-Students' pH Data Tables]

Austin:

	PH Level				
Names of substances	1st	2nd	3rd	average	predictions

Carla and Annie:
Data Table

Substance	pH	
		x1
Prediction		x2
		x3

Smita and Cynthia:

Substance	Prediction and observations	pH level Test 1	2	3	Average

Marie and Ellen:

Substance	Prediction	pH level time # 1	pH level time # 2	pH level time # 3	Results Average

APPENDIX G

Temporary Themes

Temporary themes followed by types of inscriptional practices

Constructing Practices:
(1) Constructing practices included planning and designing inscriptions, recording readings, transforming one inscription into another, incorporating and combing several inscriptions, and capturing visual information.

(2) Constructing practices were demonstrated in various inquiry areas, including making predictions, designing investigations, analyzing data, and presenting findings.

(3) Constructing practices were supported by teachers' scaffolds, peer interactions, and various resources including textbooks, science reports, curriculum materials (e.g., guideline sheets), and the inscriptions students constructed early in the unit.

Interpreting Practices:
(1) Interpreting practices included examining the consistency of data, identifying patterns, searching for reasons to explain patterns and data, comparing findings to predictions and standards, and providing meanings to components of an inscription.

(2) Interpreting practices were mainly demonstrated when students analyzed data. Each step of data analysis led students to use different inscriptions and demonstrate different interpreting practices.

Reasoning Practices:
(1) Reasoning practices included using inscriptions to make predictions, support arguments, illustrate ideas, conceptualize a phenomenon, gain new understandings, and draw conclusions.

(2) Reasoning practices were demonstrated in various inquiry areas, including developing background knowledge, making predictions, analyzing data, and presenting findings.

(3) Reasoning practices were relevant to other inscriptional practices. The inscriptions students constructed allowed and constrained certain arguments, conclusions, and predictions to be made. Some interpreting practices were required before students engaged in reasoning practices.

Presenting Practices:
(1) Presenting practices included describing and providing meanings to the components of an inscription, explaining the relationships among the components, elaborating on the ideas based on critiques or feedback they received, and clarifying confusions or questions in a follow-up discussion.

(2) Teachers' scaffolds and instruction indicated their expectations about what to present and how to present that in turn might shape students' presenting practices.

Critiquing Practices:
(1) Critiquing practices included asking for clarifications and explanations, indicating missing components, suggesting a change of components and categories, and asking for an answer and a conclusion.

(2) Teachers' scaffolds and instruction indicated whether and how students in the audience should participate in a presentation that in turn might shape students' critiquing practices.

(3) During WQ II, students did not revise the models that they created in WQ I. Students modified their models if they had opportunities to construct their models during and right after their presentation.

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