Exploring Middle School Students' Use of Inscriptions in Project-Based Science Classrooms

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ABSTRACT: This study explores seventh graders' use of inscriptions in a teacher-designed project-based science unit. To investigate students' learning practices during the 8-month water quality unit, we collected multiple sources of data (e.g., classroom video recordings, student artifacts, and teacher interviews) and employed analytical methods that drew from a naturalistic approach. The findings showed that throughout the unit, provided with the teachers' scaffold and social, conceptual, and material resources, the seventh graders were able to use various inscriptions (e.g., digital pictures, Web pages, and models) to demonstrate meaningful inscriptional practices such as creating and using inscriptions to make arguments, to represent conceptual understandings, and to engage in thoughtful discussions. Inscriptions and associated practices provided students with experiences and understandings about certain ways to organize, transform, and link data or scientific ideas. However, when constructing inscriptions, students did not consider how the inscriptions could serve certain reasoning purposes. In addition, more scaffolds were needed to help students use multiple inscriptions to make a coherent argument. © 2006 Wiley Periodicals, Inc. *Sci Ed* **90:**852–873, 2006

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INTRODUCTION

Creating, reading, and reasoning with scientific inscriptions such as models, graphs, diagrams, data tables, symbols, and maps are among the fundamental elements of scientific learning underlying the science education standards (National Research Council [NRC], 1996) and valued as important learning practices for the development of scientific literacy (American Association for the Advancement of Science [AAAS], 1989, 1993). According to the AAAS, during grades six through eight, students should be able to 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. These learning practices mirror scientists' use of inscriptions documented in science and technology studies (Latour, 1987; Lynch & Woolgar, 1990). According to Latour (1999), inscription refers to various "types of transformations through which an entity becomes materialized into a sign, an archive, a document, a piece of paper, a trace" (p. 306). Science and technology studies have showed that inscriptions are central to the practice of science and that scientists produce, share, and use a variety of inscriptions to conduct scientific investigations. Together the AAAS recommendations and findings of science studies suggest the importance of engaging students in activities that involve constructing, interpreting, presenting, and reasoning with scientific inscriptions. These various ways of using inscriptions are viewed as "inscriptional practices" in this study.

However, many students encounter difficulties when learning and using scientific inscriptions (Krajcik, 1991; Leinhardt, Zaslavsky, & Stein, 1990). Students cannot selectively create or use certain inscriptions to explain phenomena (Kozma & Russell, 1997), do not use inscriptions as tools to expand their experience (Kozma, 2000a), and lack resources to interpret and create inscriptions meaningfully (Bowen, Roth, & McGinn, 1999). Thus, there is a need to understand how the design of a learning environment (e.g., classroom activities, learning materials, and teaching practices) supports students' enactment of meaningful inscriptional practices. The study reported in this article was designed to respond to the need by exploring middle school students' use of inscriptions during an eight-month project-based science unit that emphasized water quality and related concepts (the water quality unit).

In this teacher-designed water quality unit, two teachers guided their seventh graders to conduct scientific inquiry and to investigate the driving question of "what is the water quality of the stream behind their school." Throughout the unit, students collected water quality data, analyzed the data, generated conclusions, and created artifacts to represent their understandings. The purpose of this study is to examine students' use of inscriptions in such a project-based learning environment. The central questions for the study are (1) what are the characteristics of students' inscriptional practices?, (2) in what ways do the inscriptional practices interact with students' understandings about concepts and inquiry processes?, and (3) what are the resources provided by the teacher and the learning environment supporting students' enactment of inscriptional practices?

We use a naturalistic approach (Guba & Lincoln, 1994; Moschkovich & Brenner, 2000) to portray the emergence and evolution of inscriptional practices within the learning community. This approach has been used by other studies to examine students' learning practices in real-life settings (Barab, Hay, Barnett, & Squire, 2001; Roth & Bowen, 1994). Through examining the inscriptional practices demonstrated by seventh graders, this study aims at providing insight 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.

THEORETICAL BACKGROUND

This study takes a social practice perspective to exploring students' use of inscriptions in a project-based science classroom. Central to this perspective is the idea of learning through and engaging in social practice (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). It suggests that when students learn inscriptions they learn to do activities about and with inscriptions. Therefore, rather than examining students' graphing skills and mental structures, this study focuses on their learning practices in inscriptional activities that involve creating, interpreting, and critiquing inscriptions.

According to Wenger (1998), practice is more than just doing and does not exist in isolation: "it is an action of doing in a social and historical context that gives structure and meaning to what we do" (p. 47). Practice in a context involves explicit instruction, subtle cues, underlying assumptions, and embodied understandings that are shared with and co-constructed by members in a community (Lave & Wenger, 1991). To capture the complex nature of practice, the foci of our analyses are on content and patterns of classroom discourse, teaching and learning sequences involved in inscriptional activities, and resources students used to carry out their practices.

The prominent role language plays in learning practices has been recognized by researchers in science education (Kelly & Chen, 1999; Lemke, 1990). Class members create particular ways of talking, thinking, and interacting that shape and are shaped by the communicative processes of class discourse. These discourse processes are rule-driven that allow and exclude what and how scientific knowledge is practiced and constructed through class interactions (Wu, 2003). Classroom discourse therefore is an important source of data on students' inscriptional practices. A detailed analysis of the history, content, and discursive pattern of classroom discourse can reveal the meanings and purposes of students' practices.

In addition to class discourse, the regular teaching and learning sequences of inscriptional activities are one of the primary ways that inscriptional practices get enacted. Analyses of regular teaching and learning sequences could provide insight into a question of how students' inscriptional practices evolve over time. Moreover, by identifying regular sequences, the occurrence of trouble and repair become salient (Jordan & Henderson, 1995). Troubles are interruptions of regular instructional and learning sequences. Troubles typically happen when the usual roles taken by class members change, when teachers introduce new ideas and skills, or when students do not have sufficient skills or knowledge to engage in desirable practices. Troubles could also indicate insufficient resources or a lack of common knowledge among members. Analyses of the regular sequences and the occurrence of trouble could help identifying students' difficulties in demonstrating certain inscriptional practices.

Students could demonstrate expert-like behaviors when sufficient social and material resources are available to support learning processes (Kozma, 2000a). Resources could be "any piece of information, object, tool, or machine" (Roth, 1996, p. 191) that support participants to enact a practice. In addition to materials and technological tools, resources include those of a conceptual nature and those of a social nature. For example, understandings of the context become a resource as they allow students and scientists to interpret graphs (Preece & Janvier, 1992). Resources afford students to accomplish tasks and to demonstrate inscriptional practices (Gibson, 1977). The focus on resources is particularly important for understanding how features in a learning environment promote students to develop competent inscriptional practices.

Taken together, the constructs described above (i.e., practice, discourse, regular learning sequence, and resource) constitute a framework that guides our analyses of students' inscriptional practices.

TYPES OF INSCRIPTIONAL PRACTICES IN SCIENCE

In this study, we identified four types of inscriptional practices demonstrated by scientists and used them as an initial model of our analysis. First, scientists use tools or instruments to *construct* and generate inscriptions for various purposes, such as organizing data and highlighting information (Latour, 1987). These instruments 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. If constructing inscriptions is viewed as transforming a phenomenon or a conceptual entity into another form, then interpreting could be viewed as a reverse process of construction. Interpreting is a process of generating meanings out of an inscription and reconstructing the phenomenon or concept that is represented by the inscription. Yet, the constructor and the reader of an inscription are not always the same person. This increases the difficulty interpreting an inscription. Also, some inscriptions, such as chemical formula, convey substantial conceptual knowledge so interpreting them requires understandings about concepts. Therefore, students' interpreting practices and their conceptual knowledge mutually influence or coevolve with one another (Kozma, 2000b).

A third type of inscriptional practice is *reasoning*. Scientists demonstrate various ways to reason about and with inscriptions (Kozma, Chin, Russell, & Marx, 2000). 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) or social (e.g., supports from peers or teachers).

After constructing inscriptions, scientists use particular criteria, instruments, 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.

METHODS

Guided by the framework described previously, this study is a long-term, classroom-based investigation designed to examine students' interactions and practices in a project-based science (PBS) context. A naturalistic approach is taken to study the dynamic and ongoing learning process in two PBS classrooms.

The Learning Environment

Two seventh-grade science classes (27 students: 16 girls and 11 boys) at an independent school participated in this study. Among the participants, 25 students were white and two were Asian American. The school located in a Midwestern university city offered grades 6–12 and enrolled approximately 75 students per grade. Although it was not a school for gifted students, it had an admission process that generally admitted students from the upper two-thirds of standardized test norms.

The science teachers at the middle school had been working with university researchers to develop and implement interdisciplinary, integrated, project-based science curricula (Novak & Gleason, 2000). The teachers regularly met before the first class period for planning curriculum, creating materials, sharing handouts, and discussing students' progress. The two teachers participated in this study were Ms. Adams and Ms. Clement.[1] Ms. Adams had 10 years of teaching experience, a bachelor's of science (BS) with a major in broad field science and a master's of art (MA) in adolescent development. Ms. Clement had 28 years of teaching experiences, a BS degree with a major in biology, and a MA degree in special education. Both teachers had secondary science teaching credentials.

The goal of the science program was to promote students to develop in-depth and integrated understandings of fundamental science concepts and process skills within a context of inquiry, including using a variety of scientific inscriptions throughout the program. During each school year, the students explored several science units that incorporated fundamental science concepts across several science disciplines. The instructional units were built around five features of project-based science (Krajcik, Blumenfeld, Marx, & Soloway, 1994): (1) driving question, (2) artifacts, (3) long-term scientific investigation, (4) collaboration, and (5) learning technologies. Each unit began with a driving question that provided students with a real-life context. Students worked collaboratively with their group members and conducted a long-term investigation of the driving question and related subquestions. Teachers provided substantial supports as students engaged in inquiry through activities such as asking questions, collecting data, analyzing data, creating graphs, presenting ideas, and generating conclusions (Krajcik et al., 1998). Students developed a series of artifacts such as concept maps, science reports, models, and their learning performances were evaluated by multiple ways. Additionally, students were provided with a variety of learning technologies to carry out their scientific investigations. This instructional approach was consistent with the National Science Education Standards (NRC, 1996).

The Water Quality unit, the focus of this study, was the first time that most of the seventh graders were exposed to a project-based instructional approach. Before the unit, the students were not familiar with the PBS features, including an emphasis on asking questions and the use of technological tools. The Water Quality unit was taught in three subunits during the school year (see Table 1). The students engaged in three rounds of data collection throughout the unit to investigate changes in water quality over a year. We refer to these three subunits 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). The unit began with a driving question about the health of the stream behind the school and integrated a variety of inscriptions (e.g., stream drawings, digital pictures, graphs, data tables, and models) into students' investigations of stream quality. The teachers used mini-lectures, class discussions, experiments, and group activities to introduce key ideas in science, including fundamental concepts and the process of inquiry. During each subunit (i.e., WQ I, II, and III), students explored the stream quality by conducting various water quality tests including pH, conductivity, turbidity, dissolved oxygen, and temperature change. They then analyzed the data, reported their analyses, generated conclusions to answer their driving question, and created artifacts to represent their understandings.

Students used a variety of learning technologies (e.g., portable technology, computer, digital camera, and computer-based modeling tool) throughout the project. The portable technology used by the students was "emate" produced by Apple® which 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). In addition, five Olympus® D-360L cameras were used to capture pictures of the stream. With six groups in the class,

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

TABLE 1
Overview of the Water Quality Unit

	Concept	Inquiry Process	Inscription
WQ I			
Weeks 1–5	pH, neutralization, thermal pollution	Design experiments, make predictions, and share data	pH scale, data tables, chemical equations
Weeks 6–7	Conductivity, turbidity, dissolved oxygen	Design experiments, and collect data from the stream	Stream drawings, digital pictures
Weeks 7–11	Topography, watershed	Analyze data, share data, make conclusion, and construct models	Data tables, graphs, map, computer-based model
WQ II			
Weeks 12–13	pH, dissolved oxygen, conductivity,	Make predictions, collect data from the stream, analyze data, and make conclusion,	Data tables, graphs
Weeks 14–15	Water quality	Construct, revise, and present models	Computer-based model
WQ III			
Weeks 16–17	pH, dissolved oxygen, conductivity,	Make predictions, collect data from the stream, analyze data, and make conclusion,	Data tables, graphs, digital pictures
Week 18	Water quality	Make conclusion, and create Web pages	Web pages, digital pictures, graphs

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 had access to the files and saved them to their group's computer through the school network. Students used these pictures to support their longitudinal analysis and results in their Web pages. The computer-based modeling tool used by the students was Model-It (Fretz et al., 2002; Jackson, Stratford, Krajcik, & Soloway, 1994) that supported students to build dynamic models of scientific phenomena, and to run simulations with their models to verify and analyze the results.

Data Collection

We collected multiple sources of data throughout the water quality unit. Every class period during the unit was videotaped, and field notes were taken to capture classroom activities. The classroom video recordings illustrated how the teacher supported students in their inscriptional practices and provided data of students' use of inscriptions during the class. Students' artifacts including science reports, computer-based models, digital pictures, Web pages, and notebooks were collected. These artifacts presented various inscriptions created and used by students. The teachers' feedback and comments to students on the artifacts indicated how certain ways to represent data and reported analyses were valued and emphasized by the teacher. The teachers were also interviewed to understand the rationale behind the curriculum design and their perceptions about the use of scientific inscriptions in the unit. The interviews were transcribed and later analyzed.

Data Analysis

To answer the research questions, we followed analytic steps suggested by Erickson (1986) and Jordan and Henderson (1995). We first reviewed the field notes, identified episodes on the videotapes that involved inscription activities, and transcribed these episodes verbatim into text files. Episodes were defined as "smaller units of coherent interaction within events" (Jordan & Henderson, 1995, p. 57). The episode transcripts and interview transcripts were then imported into a database for coding. The database was organized using the NUD*IST analysis software (Qualitative Solutions, Melbourne, Australia).

The codes used to analyze the transcripts were generated based upon our theoretical framework and emerged from a review of the data corpus. We identified four types of inscriptional practices, i.e., constructing, interpreting, reasoning, and critiquing, from the literature. Another type of practice, presenting, emerged from the data management process. We used a set of analytic tools suggested by Strauss and Corbin (1998) to facilitate the coding process and developed a coding scheme that included types of inscriptions, inscriptional practices, inquiry areas (Krajcik et al., 1998), and teacher scaffolds. We defined scaffold as assistance that allowed students to accomplish tasks they could not do alone (Palinscar & Brown, 1984; Wood, Bruner, & Ross, 1976). Once these transcripts were coded, we extracted episodes that were identified by one or more codes (such as episodes containing constructing practice [inscription practice code] and asking questions [inquiry area code]) and created reports.

We then read through these reports and identified coding categories for the second level of coding. These categories included tools and resources used to support practices, criteria indicated by the class members about the quality of practices or inscriptions, characteristics of an inscription created by the class members, and formats of an inscription. We reviewed the reports, abstracted information around these categories, and generated descriptions and analytical notes to generate themes. Themes were recurrent activities that emerged from the descriptions and notes. We searched for confirming and disconfirming evidence from different sources of data to triangulate our interpretations and to increase the credibility (Erickson, 1986).

FINDINGS

In this section, we describe how students used inscriptions when they engaged in inquiry activities. Each subsection opens with a general description of the finding and is followed by examples and segments drawn from the data. These examples provide evidence of students' inscriptional practices and illustrate the findings in detail.

Interrelationships Among Inscriptional Practices

In the unit, there were 10 types of inscriptions used: data tables, models, chemical representations, maps, tables, pH scales, digital pictures, graphs, stream drawings, and Web pages. Among them, six of them (i.e., data tables, models, digital pictures, graphs, stream drawings, and Web pages) were constructed by students and involved in two or more inscriptional practices. For example, each student group was assigned to a portion of the stream to conduct their water quality investigation. They identified three locations within the portion for data collection and created a hand-drawing map (stream drawing) to record visual features of the three locations. Later the drawings were used to make predictions and to explain the results of their investigation. Thus, making predictions, creating a drawing, and using the drawing to explain results were three drawing-related learning activities. In order to make the drawing useful for their investigation, students had to capture visual features of the three locations (e.g., grass, bubbles, and waterfalls) because these features could provide useful information for interpreting their test results, such that a location with waterfalls might have higher amount of dissolved oxygen. Thus, the enactment of constructing practices with stream drawings (e.g., what features should be captured in a drawing and how detailed a drawing should be) could influence students' engagement in reasoning practices (e.g., what predictions and explanations could be made from the drawings). Below we present students' reasoning practices with digital pictures to further illustrate the point.

In the water quality unit, digital pictures were constructed to make predictions and to serve as evidence that supported arguments students made in their Web pages. This was the first time students used digital pictures as evidence. When engaging in this type of reasoning practice, student groups formulated an argument and then searched for an appropriate photo to support it. In the evidence-searching process, they usually modified or changed their argument based on the availability of the evidence. The following segment shows an example in which Cynthia and Smita chose digital pictures to support an argument about dead grass increasing the conductivity level.

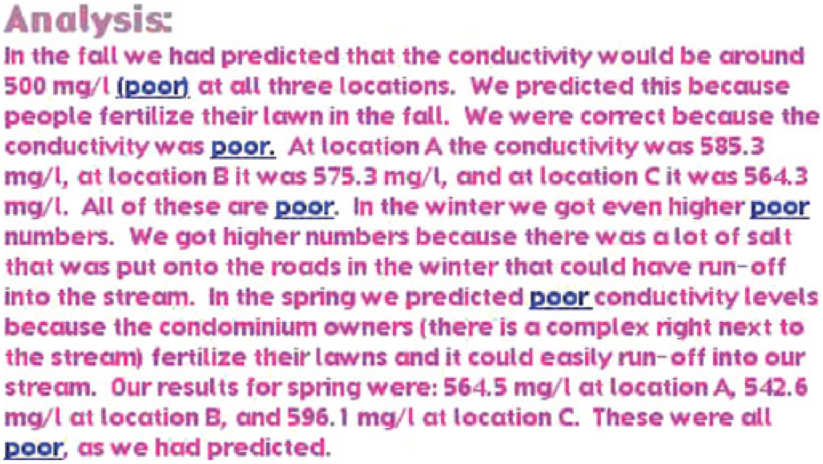
Segment 1: Reasoning practices with digital pictures

(CV122A) Cynthia and Smita are looking for digital pictures that could be used in their conductivity Web page.
Smita: We're going to use the litter and we're going to say that is dissolved substances.
Cynthia: okay.
Smita: I know where the picture is. I have a picture.
Smita opens a folder, 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.
Ms. Adams (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 the teacher station] that says winter stuff on that.
Smita: Okay, sure.
T: It's in the digital thing [folder]. That says winter [folder name].
Smita: Okay.
Smita and Cynthia resize the picture.
Smita: Make it smaller.

30 Smita and Cynthia split the cell into two. They then find a dead grass picture
31 from picture folders in the teacher's station and insert two pictures into their
32 Web page.

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, another target student pair, did not find pictures they needed and went out to take more pictures (CV120A). It seems that students did not think about how they would use these pictures when they took them. When they were asked to use photos to explain their results, they either had to go out to take more pictures or select a picture that did not exactly capture what they wanted to illustrate. Among the available pictures, Smita chose a grass picture (lines 6,7) to explain an increase in conductivity during the winter. To better support the statement that "all of this grass will die," the teacher suggested that they insert a picture of dead grass (lines 18–21). They took up the teacher's suggestion and used two pictures to show the seasonal changes of grass. 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 caption was made to match the pictures that were available. It was not consistent with the arguments made in the data analysis shown on the same Web page (Figure 1).

In their conductivity analysis (Figure 1), 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 arguments made in their analysis, Cynthia and Smita should have used pictures of salt on the roads, run-off, or fertilizers. The lack of such documentation could be attributed to the different focuses of attention students had when they engaged in constructing and reasoning practices with digital pictures. When the digital pictures were taken early in the unit, they were not taken to support students arguments. Students just took pictures for the locations where they collected data. During WQ II, when Stefon and Charles were asked how they decided what pictures to take in the stream, Stefon answered (CV087A), "we want to take pictures for each one of our locations." 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),



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 1. The analysis paragraph shown in Cynthia and Smita's conductivity Web page. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

it was not surprising that they could not find appropriate pictures to explain their results. As shown in Segment 1, Cynthia and Smita looked for available evidence to support any argument relevant to the conductivity test, even though the arguments were different from those written in their analysis.

This case suggests that the enactment of constructing practices interacted with the enactment of reasoning practices when the same inscriptions were involved. However, as first-time users of digital cameras, students did not recognize or foresee the potential interrelation among inscriptional practices so some digital pictures were unable to serve reasoning purposes that they had to accomplish later. More scaffolding might be needed to help students recognize the interrelations among different inscriptional practices so that they could construct useful inscriptions for the enactment of other inscriptional practices.

Inscriptional Practices and Understandings About Concepts and Inquiry Processes

Although students did not realize interrelations among inscriptional practices, engaging in inscriptional practices provided students with opportunities to have thoughtful discussions about inquiry processes and scientific concepts. Below we present two examples.

In WQ I, creating data tables was part of designing an 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 and brought up their understandings about pH as they created a table for their pH experiment.

Segment 2: Constructing practices with data tables

(CV006C, EP 1) Students in Class II plan procedures for their pH experiment. Ms. Clement (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.
Ally sketches a table on her notebook.
Alan: Okay [looking at Ally's notebook].
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 at her table. The girl answers her question, "It's number."]
Ally: Okay, so we can have like trial 1, trial 2 [Drawing 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, basic, 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

25 line. Put a check if it's...
26 Ally: You won't know what they are until you fill it out.
27 Alan: Yeah. But after we're doing the graph, we...
28 Ally: You put substances down, and you put that [trial 1] down, you put that [trial
29 2] down, you put that [trial 3] down, write average, and then basic or acidic,
30 and put that down.
31 Alan: Okay, so we're doing... we figure out what they are and in the end.
32 Ally: And the trial pH level whatever it is. Is it acid middle? Or whatever is put
33 here.

Ally first had a question about data format (lines 9–14). She was then confused about creating a table without any data (line 25), and Alan's suggestion about having a column about neutral, basic, and acidic (line 23) did not make sense to her. With the scaffolding provided by the teacher and Alan, Ally was able to conceptually go through the experiment (lines 27–29) and took up Alan's suggestion although she was not certain about the pH range of acid (lines 31, 32).

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 and the pH range of acid. This shows that inscriptional practices involved not only the structure of an inscription and the data represented by it, but also the inquiry process and relevant concepts.

The second example also provides evidence of how inscriptional practices supported discussions about science concepts. In Segment 3, Stefon and Charles engaged in a discussion of whether they should make a relationship between two variables, "sun" and "turbidity." 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.

Segment 3: Model construction I
1 (PV169, Build Mode, 9:25 AM) Charles and Stefon's model is to answer the
2 question of "what are the effects and causes of thermal pollution?" They create a
3 relationship between turbidity and thermal pollution in the build mode and start
4 discussing whether they should connect turbidity to the sun variable (Figure 2).
5 Stefon: Actually, you got to say the sun. You got to connect it to the sun.
6 Stefon: Should we connect to these two [turbidity and sun]? [The cursor is
7 moving between turbidity and sun.]
8 Stefon: The sun heats up the stream.
9 Charles: The stream is turbid.
10 Stefon: So why don't just connect this [sun] to that [turbidity]? Everything will be
11 fine.
12 Charles: So sun goes to turbidity?
13 Stefon: Because sun is the cause and it affects the turbidity and it also affects
14 thermal pollution.
15 Stefon: It causes the heat. It puts the heat into the turbidity.
16 Students create a causal relationship between sun and turbidity.
17 Stefon: Oh, wait, that's wrong. [Reading the textual description on the top of the
18 relationship editor (see Figure 3)] As the sun heat increases, turbidity increases.
19 Charles: Yah.
20 Stefon: That's wrong. Cancel.

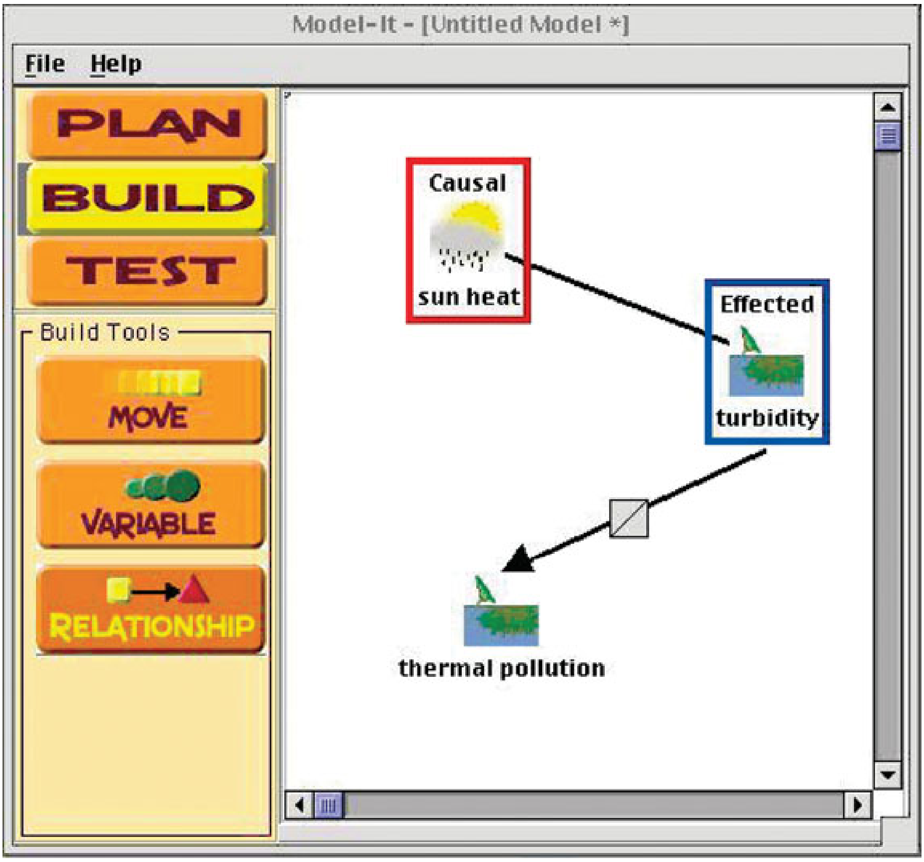
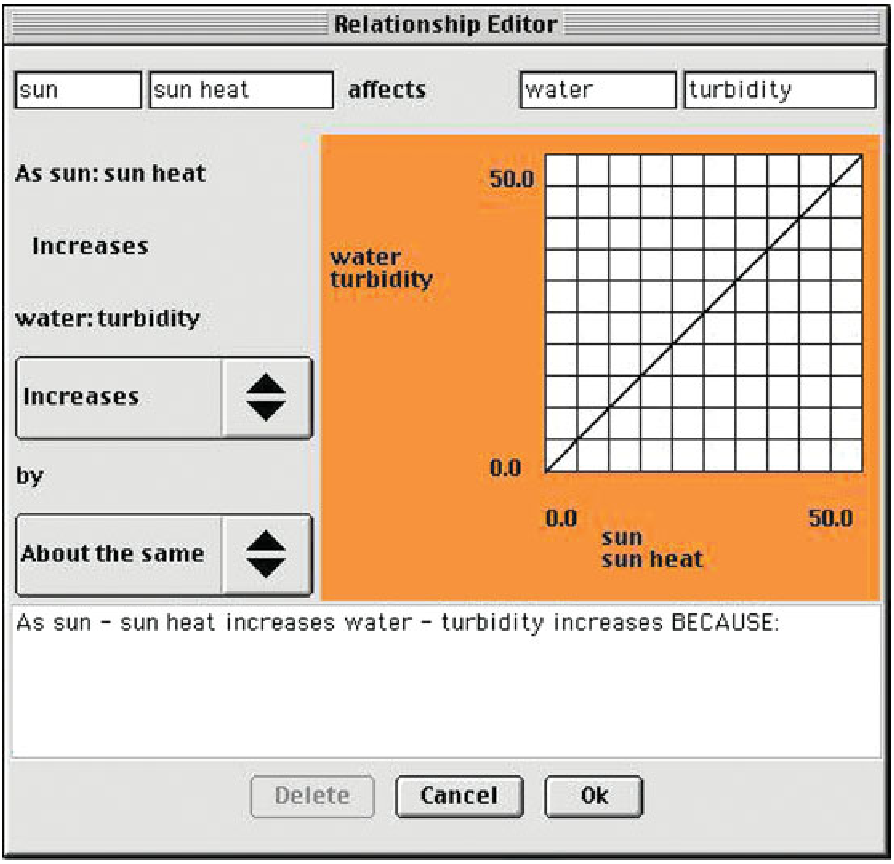


Figure 2. Charles and Stefon's water quality model. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Stefon and Charles understood that sun heat (heat energy from the sun) affects thermal pollution when the stream is turbid (lines 8–14), but a simple causal relationship between sun and turbidity did not represent what they meant. The textual description provided by Model-It helped students realize that the relationship between heat from the sun and turbidity was not causal. This realization led Stefon to cancel the relationship (lines 17–20). Line 20 signaled a trouble. Stefon and Charles were not the only pair who had difficulties representing their understandings about heat from the sun, turbidity, and thermal pollution. As shown in Segment 4 that occurred in the same class period, all three groups that modeled the same question about thermal pollution had difficulty. Ms. Adams (T) used this common confusion as a learning opportunity and gathered the three groups to discuss the relationships among heat from the sun, thermal pollution, and turbidity. Through a group discussion, students shared ideas (lines 34–52) and clarified their understanding.

Segment 4: Model construction II
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 heat from the sun, turbidity, and thermal
24 pollution. She gathers them together to discuss a solution. Ms. Adams first asks
25 students "what can the weather and the sun do?" Students volunteer their ideas
26 that sun could directly warm up the stream, warm up the particles in the stream,



sun | sun heat affects water | turbidity

As sun: sun heat

Increases

water: turbidity

Increases

by

About the same

As sun - sun heat increases water - turbidity increases BECAUSE:

Figure 3. The relationship editor of heat from the sun and turbidity that provided a textual description, a line graph, and a BECAUSE statement. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

and hit sidewalks and pavement.

T: Let's hold this idea that it hits the sidewalks or parking lots or rooftops. Okay now this is the question that I posted to them yesterday. We have some days with sunshine in February, right?

Stefon and Charles: Yap.

T: And if we have sunny days in February and sunny days in July. How might those compare in terms of their effects on thermal pollution?

Carla: Not really, I mean if there's whole stream.

Several students are talking at the same time.

Charles: It [water temperature] wouldn't change, would it?

T: Well, I don't know.

Charles: If the stream is really cold, the water would be very cold, too. It wouldn't be that much difference, 'cause in July, the water will be warm, but it heats it up more, too.

T: Okay.

Annie: If it's winter, water would be colder. And if the sun heats it up, it probably heats it up as much as it does in the summer.

Charles: But the stream is already hot, it's not going to be heated up.

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.
51 Charles: There're seasons. You need a season variable. That will connect to your
52 sun variable that will connect to your turbidity variable.

Students' responses to Ms. Adams's question (lines 25–27) indicate that they had some understandings about how heat from the sun might directly or indirectly warm up the stream and cause thermal pollution. They also realized that the heat from the sun does not always cause thermal pollution (lines 34–36). Ms. Adams's questions about the weather in different seasons (lines 32, 33) became crucial for students to rethink about the relationship between heat from the sun and thermal pollution. Her questions led a productive discussion among students (lines 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 heat from the sun and turbidity.

The two segments show that through constructing models students' confusion about certain concepts was revealed. Models had affordances for transforming students' conceptual knowledge into a series of causal relationships and representing their emergent understandings of a specific topic. The segments also indicate the importance of teacher scaffolding and peer interactions to support students in accomplishing inscriptional tasks.

Together Segments 2–4 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 and inquiry processes.

Inscriptional Practices and Characteristics of Inscriptions

The decision of how inscriptions were used in the unit was made by the design of inquiry activities as well as the characteristics of inscriptions. Analyses of classroom activity data and students' artifacts indicated that different inscriptions were used for different purposes in different inscriptional practices. For example, Segments 3 and 4 show that models allowed students to externalize their conceptual understandings through building causal relationships among variables. Below we present an example of digital pictures. Although students had difficulties using digital pictures to make a coherent argument, the visual nature of these pictures supported students in developing links among stream features, concepts, and test results.

In WQ I, students took pictures of their stream section to make predictions. When viewing the pictures, students identified stream features shown in pictures, discussed whether these features would impact the stream quality, and predicted test results based on 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.

Segment 5: Making predictions with digital pictures
1 (CV043C) Ms. Clement reminds students that the pictures they took are prompts,
2 which help them make predictions in their part of the stream. She then shows
3 them where picture folders are. Students work in pairs and use graphic converter
4 to view their pictures. Denny and Ally open a picture file of one testing location.

5 They first predict turbidity results of the stream section.
6 Denny: Excellent? [Looking at the screen.]
7 Ally: But there’s stuff here [pointing to the screen].
8 Denny: It’s like. . . [Moving toward the screen to take a close look at it.]
9 Ally: Can I see another one and then we can compare to that one?
10 Denny: Okay. [He opens another picture file.]
11 Ally: I think turbidity will be fine. What else? DO?
12 Denny: Well, it’s [the water is] moving [He is not looking at the picture. The
13 comment is made based on what he observed yesterday], so I guess it’s pretty
14 good.
15 Ally: So will it [D.O.] be excellent?
16 Denny: I think it’s good, ‘cause there’s no plant there. So it’s good.
17 Ally opens a picture of the second testing location.
18 Ally: I think it looks pretty bad, isn’t it?
19 Denny: Well, you can’t see the bottom.
20 Ally: Look at all that stuff. It looks weird. I think the turbidity is bad. I say it’s
21 really poor.
22 Denny: I think it’s not that terrible. Fair, maybe.
23 Ally: DO?
24 Denny: I think there’s something in there.
25 Ally: You’re right. DO is good.

In this segment, Ally and Denny made predictions by viewing digital pictures they took the day before. Based on what they saw from the pictures (lines 7, 16) and what they observed (lines 12–14), they made predictions for the tests. Ally and Denny knew that certain features in the stream indicated whether 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 12) and whether there were plants in water (line 16). When predicting turbidity, Ally and Denny focused on whether there was something in the water (line 20).

This segment shows that students were able to use digital pictures to show features of the stream and to make predictions based on the visual information represented by the 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 in the water suggest that they understood that turbidity was determined by the amount of suspended substances in the stream. They also realized that moving water would contain more dissolved oxygen.

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 lines 7 and 8, Ally saw something in the stream, but they were not certain about what they saw 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 blurred due to the low resolution so they had to decide whether they should ignore these features or try to search for other pictures to confirm their observations. Additionally, some stream features that supported students in making certain predictions might not be captured by digital pictures. For example, pictures could not clearly show the depth of the stream and the speed of current so Denny’s comment on water movement (line 12) was made by his observation instead of what he saw from digital pictures.

Therefore, by providing rich visual information, digital pictures could help students make predictions and construct links among concepts, observations, and features of the stream represented in the pictures. Yet, digital pictures should not be the only source for making predictions because they have certain limitations. Students should combine other sources such as observations on physical features of the stream when making predictions.

Inscriptional Practices and Use of Resources

In this PBS unit, students' inscriptional practices were supported by various social, material, and conceptual resources. Social resources included teachers' scaffolds and peer interactions. The segments presented earlier suggest that teachers' scaffolds such as questioning, modeling, elaboration, and explaining served as crucial supports for students' enactment of inscriptional practices. For example, in Segment 1 (Reasoning practices with digital pictures), the teacher helped Cynthia and Smita demonstrate reasoning practices with digital pictures. By incorporating pictures in their Web page, Cynthia and Smita made a convincing argument about seasonal changes and conductivity, although the argument differed from the one they made in their analysis on the same Web page. When students constructed models and encountered difficulty in making a relationship between heat from the sun and turbidity, the teacher gathered students and created an interactional space (Heras, 1993) for students to share and co-construct understandings. Additionally, students benefited from interacting with peers by exchanging information, sharing and clarifying ideas, and giving and receiving feedback. The big group discussion in Segment 4 (Model construction II) 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 in supporting students engagement in inscriptional practices. For example, the textual description provided by Model-It helped students realize that the relationship between heat from the sun and turbidity was not a simple causal relationship.

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. For example, students' modeling experience became a conceptual resource when they created Web pages. The following segment took place in WQ III when Ms. Adams (T) demonstrated how to use Netscape Composer® to create Web pages. To engage students in writing background information for each test page, Ms. Adams indicated the similarity between constructing a model and writing the background (lines 7–23).

Segment 6: Constructing practices with Web pages
1 (CV104A) During the Web page demonstration, Ms. Adams (T) indicates that each
2 of students' test Web pages should include "background" about the test.
3 T: Background would be, I think that there will be a lot of thermal pollution,
4 maybe ten degrees difference, because what kind of background will you put in
5 there?
6 No student answers the question.
7 T: Think about Model-It. What is the whole purpose of Model-It? Show what?
8 Students: Relationships.
9 T: Relationships, okay. So, if you think we're going to have high temperature
10 differences, what do we need to talk about temperature?
11 Stefon: Thermal pollution.
12 T: If you think there's going to be thermal pollution, okay, that's the effect. Then

13 what's the background you want to say? Think about relationships. Think about
14 working backwards.
15 Cynthia: There's like turbidity in the water.
16 T: So that's one of the reasons or the causes, right? So in Model-It, think of the
17 things you put in Model-It, causes and effects. Remember all of your models
18 were supposed to show the causes of something and the effects of something.
19 These reasons are going to say why, what are the causes, so as the result the effect
20 is what you're predicting, right? Go and look at your fall and your winter
21 predictions and take a look at my feedback.

To help students understand what information should be included and how the information should be organized in the background, Ms. Adams reminded students of their modeling experiences (lines 7, 8). One salient characteristic of modeling was to create causal relationships between variables. Stefon and other students' responses indicated their recognition of this feature (lines 8, 10, 12). Ms. Adams then reinforced the idea of incorporating causes and effects in their background as students did in their models (lines 16–18). She also suggested including other resources such as predictions they made in previous subunits and her feedback that would be helpful for students in writing their background (lines 20, 21).

In Segment 6, the teacher regarded modeling 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, Ms. Adams indicated the similarity between creating a model and writing background information for a Web page so that students could realize the expectation of the task and engage in constructing practices with Web pages with minimal difficulties. Students' modeling experience and practices became a conceptual resource that helped them engage in constructing a new inscription, Web page. The following background was written by Stefon and Charles on their Web page about temperature change.

> Tempature [Temperature] change is the amount of change in degrees celsius [sic] from one point of a stream to the end. This test helps us see if there is thermal pollution in the water. Thermal polution [sic] can be caused by rain, chemicals, turbidity and factories. Sidewalks, if hot, can heat up rain water and when it enetrs [sic] 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 discussing 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, that is, as one variable (a cause) increases/decreases, another variable (an effect) increases/decreases (see Figure 3), they described the process of how a specific cause affected temperature change.

The examples discussed above and the segments presented previously 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, 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 ideas that could be applied to a different context.

DISCUSSION AND CONCLUSIONS

This study was designed to explore students' use of inscriptions in a project-based learning environment and to identify the resources provided by the learning environment that supported students' enactment of inscriptional practices. The findings show that when the seventh graders were scaffolded by the teachers and provided with social, conceptual, and material resources, they were able to use various inscriptions to demonstrate meaningful inscriptional practices such as creating and using inscriptions to make arguments, to represent conceptual understandings, and to engage in thoughtful discussions. This study expands previous work reported in the literature (Bowen et al., 1999; Kozma, 2000b; Lynch & Woolgar, 1990) by showing that middle school students could also use inscriptions to construct scientific knowledge within a project-based learning environment.

Characteristics of Inscriptional Practices

This study indicates that constructing scientific inscriptions in a project-based learning environment was more than recording numbers or plotting data points. It occurred with different inquiry activities such as making predictions and interpreting test results and involved various practices such as using tools to capture visual information, incorporating several inscriptions into one, and creating relationships among variables to create a model. Additionally, the findings show that when creating an inscription, students had to consider the functions of inscriptions in their inquiry so that the inscriptions could serve specific reasoning purposes. This suggests that middle school students' use of inscriptions can go beyond an "operational level" as proposed by Greeno and Hall (1997, p. 366). In this study, not only did students learn to create inscriptions by following conventions, but they also learned to realize how to create different inscriptions to serve different purposes.

Additionally, 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 Segment 3, for instance, Stefon and Charles 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 difficulty representing it as a series of causal relationships in their model. This challenge became a learning opportunity for students to improve their constructing practices and to advance their conceptual understandings. The teacher gathered the three groups who modeled the same driving question together and fostered a productive discussion that helped the students determine the relationships among sun, turbidity, thermal pollution, and seasons. Additionally, teachers played an important role in framing such challenges as opportunities. Without the teacher's intervention, the three groups might have ignored the problematic relationship and constructed relatively simple models.

Furthermore, constructing practices with specific inscriptions can be distributed to another context. Segment 6 shows that students' experience and practices on modeling could serve as a conceptual resource and promote students' engagement in constructing Web pages. As an inscriptional activity that students had experience with, modeling helped students make sense of Web page 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 Web pages, 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).

The findings also suggest that inscriptional practices might involve different levels of difficulty and complexity. Some inscriptional practices that could be enacted via group collaboration without much scaffolding, such as using digital cameras to capture visual information, creating a simple model, and inserting pictures into Web pages, seemed more likely for seventh graders to demonstrate. Others that were scaffolded heavily by the teacher 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 into Web pages to make a coherent argument and constructing meaningful digital pictures for given reasoning purpose.

The Use of Inscriptions and Science Learning

This study suggests that using inscriptions and engaging in inscriptional practices could have positive impact on students' understandings about concepts. Segments 2–4 show that using inscriptions provoked discussions about relevant concepts. As an object of practices, an inscription makes the content of conversations and the entity it inscribes (e.g., relationships among the sun, turbidity, and thermal pollution) concrete and visible. Students could attach information to an inscription and modify its format and content to reflect upon their emergent understandings (Forman & Ansell, 2002). 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., digital pictures, models, and Web pages) as different notation systems could promote ways of knowing and doing science. That is, engaging in inscriptional practices might affect students' understanding about how scientific knowledge is constructed and 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.

The seventh graders in this study used some ready-made inscriptions (graphs and digital pictures) create a new one (Web pages). What might students learn from incorporating inscriptions into a new one? 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 with multiple inscriptions require nonlinear ways of thinking and reading science, and allow students to represent their ideas via hyperlinks. Segments 2–4 show that inscriptions could become changeable knowledge productions that demonstrate students' emergent understandings about concepts and inscriptional practices.

Implications for Teaching

Through exploring seventh graders' use of inscriptions, this study suggests some teaching practices and features in a learning environment that could promote the development of competent inscriptional practices. First, exploiting the potential use of inscriptions might provide students with more opportunities for science learning. In this study, some inscriptions were only used in one or two practices. These inscriptions indeed have capabilities for students to engage in more inscriptional practices.

Next, sharing the driving question for models may be beneficial to engage students in in-depth discussions about the content of model and improve the quality of models. It supports students to have large group discussions, to exchange ideas, and to co-construct their models together.

Third, it is difficult for seventh graders to make a coherent argument by using evidence from different sources (Klahr, Fay, & Dunbar, 1993). Teachers could model how to make references and verbally relate inscriptions to written text, encourage students to identify the argument they try to make, and remind them to make coherent arguments throughout the same inscription (e.g., science reports and Web pages).

Finally, to help students create meaningful inscriptions for reasoning purposes, when students take digital pictures, teachers might require students to make annotations, record the reasons for 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.

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