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Proliferation of Inscriptions and Transformations Among Preservice Science Teachers Engaged in Authentic Science

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Abstract: Inscriptions are central to the practice of science. Previous studies showed, however, that preservice teachers even those with undergraduate degrees in science, generally do not spontaneously produce inscriptions that economically summarize large amounts of data. This study was designed to investigate the production of inscription while a group of 15 graduate-level preservice science teachers engaged in a 15-week course of scientific observation and guided inquiry of two organisms. The course emphasized the production of inscriptions as a way of convincingly supporting claims when the students presented their results. With continuing emphasis on inscriptional representations, we observed a significant increase in the number and type of representations made as the course unfolded. The number of concrete, text-based inscriptions decreased as the number of graphs, tables and other sorts of complex inscriptions increased. As the students moved from purely observational activities to guided inquiry, they made many more transformations of their data into complex and abstract forms, such as graphs and concept

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maps. The participants' competencies to cross-reference ultimate transformations to initial research questions improved slightly. Our study has implications for the traditional methods by which preservice science teachers are taught in their science classes. J Res Sci Teach 44: 538–564, 2007
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Science began when natural philosophers started using illustrations, diagrams, graphs, and other non-textual forms to represent the objects of inquiry; these forms are constitutive of what we know to be science (Cunningham, 1988; Edgerton, 1985). Psychologically oriented researchers use the term "representation" to denote illustrations, diagrams, graphs, and other non-textual forms, but they also use the term to denote ideas in the mind. To avoid the confusion and to clearly focus anthropological studies of what scientists *actually do*, social scientists have introduced the term "inscription" to denote all non-textual materials that appear in scientific work (Latour & Woolgar, 1979). As an inspection of the leading and most cited journals in the history and sociology of science reveals, *inscription* is the accepted standard concept for theorizing non-textual materials in science, mathematics, and technology.

Inscriptions now are recognized to constitute one of the most important aspects of science, because they are so central to the way in which facts are established for what they are (Latour, 1993). In other words, the idea behind constructing an inscription is to provide a terse but compelling argument in favor of the fact, claim, or assertion that is the topic of thought at hand. Studying inscriptions, anthropologists of science focus on the practices that draw on these artifacts as resources for action; it is only after all other explanations of inscription use have been exhausted that researchers have been asked to look for hidden factors of the mind (Latour, 1987). One review of the educational literature, therefore, calls for an increased emphasis on inscriptional practices, because students learn what science is and how to make scientific arguments by watching others *use* inscriptions (Roth & McGinn, 1998). Clearly, the process skills of science extend beyond laboratory prowess and logical thought. As established by Latour and Woolgar (1979), and by many subsequent researchers, a scientist must be able to communicate the outcome of his craft and the very content of his mind to others. So, in helping students to understand scientific process skills, it is not enough to merely have them enter data into preformed tables or construct a graph from sets of numbers given to them. The suggestion is that, by exposing students to the entire set of processes that lead to thinking in terms of a table or graph, the nature and purpose of the inscription may become clearer to the student (Greeno & Hall, 1997). They may also become more adept at fashioning and understanding inscriptions (Wu & Krajcik, 2006). Although there is an increasing push for teaching inscription practices (Lehrer, Strom, & Confrey, 2002; Popkewitz, 2004; Sandoval & Millwood, 2005), there is evidence that even university science students have difficulties interpreting them (Bowen & Roth, 2002), including those enrolled in science teacher preparation programs (Roth et al., 1998). The *National Science Education Standards* explicitly list competencies that we may count among the inscription-related practices (National Research Council [NRC], 1996). Thus, the NRC (2000, p. 19) lists as key areas of competencies: (a) the use of data to construct a reasonable explanation; (b) the competence to communicate investigations and explanations; (c) the use of mathematics in all aspects of scientific inquiry; (d) the use of technology and mathematics to improve investigations and communications; and (e) competent communication and defense of scientific arguments.

The NRC descriptions focus our attention on the inscriptional practices in science. One would expect to find them embodied within a well-prepared science teacher, like supporting beams in a building (Bowen & Roth, 2005). It seems reasonable to assume that a person who has completed multiple university-level science courses would be able to construct and read a graph, argue the merits of an experimental outcome, and communicate their thoughts within the scientific community or to a group of students. Some studies have presented startling evidence that this is not the case. Several studies of university students showed that they do not competently act in ways that the *Standards* expects even middle and high school students to act (Bowen, Roth, & McGinn, 1999). Despite having at least a bachelor's degree, and for many a master's degree, university students were outperformed by a group of eighth graders when it came to their ability to design and use inscriptions when confronted with the task of explaining, defending, and communicating conclusions based on scientific data (Roth et al., 1998). The authors suggested that science teacher education programs must reexamine the ways by which science teachers are taught to teach science. Specifically, there is a plea for these students to have opportunities to be engaged in some actual scientific practices, such as inquiry with data collection, presentation, and interpretation tasks, in an effort to develop and hone their inscriptional practices.

There are suggestions that future science teachers will be better able to construct and use representations of scientific knowledge and pass these skills to their students if these tasks are incorporated within a more authentic, science-like experience that is characteristic of classroom inquiry (Roth et al., 1998). This assertion is certainly compelling and needs to be widely examined within the context of actual science teacher preparation programs. If teachers of science are expected to pass along skills, such as how to read and construct a graph, to their students, and if we know that they are now lacking in abilities such as these—even in the production of inscriptions—it is critical to examine alternatives to the status quo, which continues to produce science teachers who do not use inscriptions in the manner called for in the *Standards*.

Although the concept of inscription has been prominent for over two decades in anthropology, sociology, and history of science, there have been only a few studies in science education that have adopted this decidedly anthropological perspective of doing science. To our knowledge, there has not yet been a study investigating whether future teachers would develop inscriptional practices if they were learning science in a context of open investigation, a learning context generally referred to as *authentic science* (Roth, 1995). This study was designed to determine whether the production of inscriptions by preservice teachers would increase while they completed investigations that they had designed; we were also interested in finding out about the quality of the inscriptions and any changes therein while the preservice teachers completed several research projects. Finally, we examined the complexity of the students' transformations of inscriptions, from simple to complex, and sought to determine whether the ultimate (final) transformed inscriptions were detailed enough to stand alone in terms of being able to effectively communicate the students' conclusions.

Background

Inscriptions are powerful resources in communication among professional scientists (Latour, 1987; Lynch & Woolgar, 1990); in the hard sciences, inscriptions constitute the essential form of data presentation. Inscriptions are so central to science that there is not an article without them, and it is not out of the ordinary for a meeting to grind to a halt as an inscription is prepared or retrieved (Henderson, 1991). With these facts in mind, and with the idea that inscriptions are intended to represent nature in an abstract way, some educators proposed that inscriptions might hold promise in science education, especially if approached in terms of practices that can be taught, because they are observable by teacher and peers alike (Roth & McGinn, 1998). Roth and McGinn stressed that inscriptions should be authentic and derived from authentic scientific practices (inquiry). In the classroom, inscriptions may take many forms. These include lists, photos, computer files, maps, diagrams, concept maps, and other examples of representations produced during scientific activity or science talk. It is therefore not surprising that increasing numbers of science and mathematics educators focus on the production and use of inscriptions (Kozma, Chin, Russel, & Marx, 2000; Meira, 1995).

Not all inscriptions are created equal; those that summarize more information from more situations are treated as more powerful and convincing (Latour, 1987). Equations are generally more powerful than graphs, which in turn are given greater value than tables, diagrams, drawings, and photographs (Bastide, 1990). At the same time, photographs and drawings are more easily related to the things that they denote—that is, they are closer to experience—whereas graphs and equations have little in common with the natural phenomena they stand for, and therefore are more distant from experience (Pozzer & Roth, 2003).

Inscriptions are characterized by their permanence, mobility, and combinability with other inscriptions to form more abstract (or at least more summarized) representations of scientific data. Furthermore, inscriptions are subject to easy reproduction and are readily changed in size. Changing from inscription to inscription is known as transformation (Janvier, 1987) and leads to a cascading effect as inscriptions with greater locality and lower complexity are summarized into inscriptions of less local and more general nature (Latour, 1987). For example, a set of notes, questions, and tally marks in tables may be transformed into a graph, or a series of observations and questions may be organized into a concept map. By combining inquiry and inscription, students are given the opportunity to deal with actual ‘‘science-making,’’ as they represent their data and ideas within an authentic context (Roth, 1995).

The collaborative construction of inscriptions may allow students and teachers to share in and negotiate the construction of knowledge; it may also provide students with a better understanding of the collaborative construction of knowledge in the domain of science (Roth & Roychoudhury, 1992). In a study of middle school science students, for example, Wu and Krajcik (2006) noted that production of inscriptions, such as graphs and tables, by the students fostered many opportunities for discussion, consideration of the inquiry process, and review of content. Such opportunities help students move beyond narrow content knowledge and allow them to see the social aspect of scientific knowledge construction as they begin to talk about, write out, and negotiate meaning within their learning community (Crawford, Kelly, & Brown, 2000; Kelly & Green, 1997; Klaasen & Lijnse, 1996).

Method

In this study, preservice science teachers conducted their own research and produced their own inscriptions. The purpose of our study was to track these activities, and to determine whether any changes occurred in production and use over time.

Research Participants

A group of 15 preservice science teachers (10 women, 5 men), who were enrolled in a graduate program in science education at a major southeastern state university, were the primary participants. One of the present authors, a science education doctoral student, also participated in the course. In addition to completing the coursework related to this study, he acted as a *participant observer* in the class. This methodology fit well with our goal of conducting a study of the natural workings of an established classroom. Participant observation is a widely utilized qualitative research methodology in which a researcher actively participates in the group being studied rather than just observing as an outsider. The insider perspective provides researchers with valuable information that can be held against other pieces of information during data interpretation (Denzin, 1988; Jorgensen, 1989).

The participants were seeking certification to teach science, mostly biology, at the secondary level most had degrees in biology. Their academic transcripts provide evidence that they had taken many science courses, including biology, chemistry, zoology, physiology, physics, geology, and microbiology. Despite heavy emphasis on science content, all participants lacked experiences with real scientific research. Pursuant to that, they were directed to enroll in a course entitled ‘‘Knowing and Teaching Science: Just Do It’’ (*Just Do It*), originally designed to allow students to design and conduct open-ended experiments.

Instructional Setting

The *Just Do It* course, designed by a botany / genetics professor (the fifth author) and a science educator (the second author), spanned an entire semester. The scientist and the science education doctoral student co-taught the course. The first and third authors did not participate in the instruction of this cohort of students. However, the first author did introduce the heavy emphasis on inscriptions in *Just Do It* with a previous cohort of students. The course was scheduled twice each week for approximately 3 hours per session. The participants were the sole occupants of the lab during the term and had free access to the facility. This was thought to foster a more authentic element to the students’ work. Many routinely visited and worked in the lab outside of normal class hours, including weekends. Students had access to basic lab equipment as well as computer programs capable of generating graphical inscriptions and statistical analyses, and to a digital camera. Other details on the organization and outcomes of *Just Do It* are available (Lunsford, Melear, & Hickok, 2005; Melear, Goodlaxson, Warne, & Hickok, 2000).

The participants researched two organisms. The first organism, a cultivar, of the fern *Ceratopterius richardii*, is known as *C-Fern* (the name is copyrighted, but for simplicity, we omit the copyright sign). This plant may complete its life-cycle within 90 days under ideal conditions. It is easily cultured and requires minimal magnification to observe even the most minuscule details of its life-cycle. *C-Fern* gametophytes include both male and hermaphroditic plants. Various genetic strains of the plant are commercially available (Hickok, Warne, Baxter, & Melear, 1998). The other organism, *Nasonia vitripennis*, is a solitary wasp often known by the common name *jewel wasp*. Like others of the order Hymenoptera, jewel wasps display a complete metamorphosis. Females parasitize various species of flies (order Diptera) by depositing about 15 fertilized ova within dipteran pupal cases. The eggs hatch and the larvae feed on the fly tissues (Darling & Werenn, 1990; King, 1993). At the outset of the course, students were given small amounts of one organism or the other. The organisms were initially called alpha and beta unknowns. Minimal care instructions were provided. Students were further told to consider their resources unlimited unless told otherwise.

On their own, the participants formed six collaborative laboratory groups. Although there was interaction among all class members, the initial groups remained intact throughout the research study. On a typical class day, the participants carried out observation and experimentation on the two research organisms. Their work was largely independent of input from the course instructors, who acted as facilitators. There were no formal training sessions about how to set up experiments before the fact. Instead, the instructors mentored individual students or groups on an as-needed basis, typical for authentic learning environments. For example, if a group tried to carry out an experiment that lacked a control, the instructor(s) asked guiding questions or explicitly pointed out the need for a control. Within the context of an on-going project, the instructors assisted students with mastery of laboratory techniques (such as the procedure to sterilize *C-Fern* spores) or use of the digital camera. The students designed and set up studies concerning the organisms and made inscriptions relating to the same. Informal discussion of the students' ongoing work, within and among cooperative work groups, was frequent. Also, students presented formal summaries of their work. In both cases, the inscriptions students made were a primary focal point in terms of guiding discussion. Examples of the types of research carried out by the participants include documenting life-cycles of the organisms and introducing variables in the life-cycles to determine any effects on development. The students completed many projects involving the research organisms. Over the course of the semester, three laboratory phases were identified and are named and described in what follows for purposes of clarity.

Laboratory phase 1: observation. This phase took place during approximately the first one-third of the course. Students occupied themselves mostly with observational activities concerning the organisms. Some groups were assigned to work with the alpha unknown, others with the beta. Participants were told not to be concerned if they did not complete an experiment during this phase. However, students largely directed their own work in terms of the observations they chose to pursue.

Laboratory phase 2: first guided inquiry. About 4–5 weeks after the start of the course, students were required to shift from simple observation of their initial organism into experimentation with the same. They were specifically told to generate a research question, hypothesis, and methodology. There was attention to sample size, replication, control, and other standard concerns of the research scientist.

*Laboratory phase 3: second guided inquiry.*Two procedural changes occurred in class during about the ninth week of the semester. The students swapped organisms. Those who had been working with *C-Fern* began work with jewel wasps, and vice-versa. Students also had the ultimate goal of producing an inquiry lesson, based on their own lab work with the new organism that was suitable for high school students. They were free to consult with other class members who had previously worked with their ''new'' research organism during the first two lab phases.

Laboratory Inscription Notebooks: Primary Data Source

Students in *Just Do It* were required to maintain a notebook of inscriptions they made during each of the three course lab phases, and in other course activities. To initiate this activity, students were given a summary of the purpose of laboratory inscriptions, and inscription uses by professional scientists. A discussion of the production and purpose of transformation cascades was included along with a rubric that provided guidelines. The completed laboratory notebooks accounted for a total of 10% of the students' course grade. Formative assessment about the lab notebooks was informally provided to the students throughout the course. At the midterm point of the semester, all students were required to submit their notebooks for formative assessment. Students were provided with informal suggestions on ways to improve their inscriptional practices, and were given written feedback. The completed notebooks were submitted for summative evaluation at the end of the semester. Criteria included numbers of inscriptions produced, numbers of episodes of transformation, and attention to detail in making inscriptions. These assessment criteria did not vary by lab phase or activity.

Participants were encouraged to incorporate technology-generated inscriptions (such as digital photographs, computer-generated graphs, etc.) into their notebooks, but they were not required to do so. A hand-drawn graph, for example, would not have automatically been considered to be secondary in value to a computer-generated graph. Many students glued or taped technologically produced inscriptions into their lab notebooks.

Analyses

To facilitate analyst triangulation (Patton, 1990) the notebooks were examined by two authors (the first and the fourth). The fourth author's notebook was excluded from the analysis. This left 14 laboratory inscription notebooks, one from each of the remaining participants, to be analyzed. Inscriptions were coded (Denzin & Lincoln, 2000; Patton, 1990). Blank grids, listing the various types of inscriptions, with category-based headings, were prepared. The coders categorized each inscription in each notebook by entering corresponding page numbers from individual lab notebooks where the examples of each type of inscription could be found. The coding occurred only once, at the end of the course, with both coders individually analyzing all notebooks. The coders resolved differences about how to code prior to the actual coding and followed patterns established by previous researchers (Pozzer & Roth, 2003; Roth, Bowen, & McGinn, 1999). No disagreements were found between the individual coders once the categorization was complete. The various categories of inscriptions are described in what follows.

Written inscriptions. When participants recorded information from their lab work in a text-based, narrative, and concrete format, the inscription was placed into this category.

Lists. An inscription primarily characterized by a numeric, bulleted, or otherwise sequenced arrangement was called a list. Lists, while being very similar to written inscriptions, represent a more organized or planned pattern of representation.

Diagrams. Any hand-drawn representation of an organism, a piece of lab equipment, or other entity relating to the students' lab work was included in this group.

Photographs. Images recorded with the digital camera comprise this category. Although these inscriptions are arguably similar in intent and purpose to diagrams, they were considered independently as an indicator of students' use of the digital camera during their work. Furthermore, an argument could be made that diagrams represent a slightly more experience-distant or abstract representation than do photographs.

Data tables. Inscriptions in which students exhibited a tabular presentation of data, in the form of tallies, counts, or totals, were placed here. Data tables are often used in the presentation of scientific information and may be found in most professional journals.

Transformation cascades. Inscriptions are characterized by a tendency for their being altered from simple and concrete to abstract and symbolic. As part of our data-coding process, we looked for such patterns in the students' laboratory inscription notebook. Any instance in which a student incorporated or summarized a previously recorded and more basic inscription into a new and more conceptual one was registered as a transformation cascade episode. A data table may be part of a transformation cascade if it met these criteria. If this was the case, the complex data table was counted as a transformation, not as a simple data table. It is important to note that such transformations were not "double counted" in Table 1. In other words, the complex data table in

Table 1

Categorization of inscription types ($n = 2172$) produced by all participants ($n = 14$) per lab phase and by chi-square-test expected frequencies (in parentheses)

Phase	Written	List	Diagram	Photo	Table	Transformation	Row Total
Observation	126	45	115	106	45	23	= 460
	(100)	(60)	(57)	(109)	(66)	(68)	
First inquiry	144	105	51	196	151	145	= 792
	(172)	(103)	(98)	(188)	(113)	(117)	
Second inquiry	203	132	104	213	114	154	= 920
	(200)	(119)	(114)	(218)	(131)	(136)	
Column total	473	282	270	515	310	322	

this example was scored only as a transformed inscription. Furthermore, four or five inscriptions can each lead to a more complex one, in series. For example, if a student wrote a narrative plan to count the male jewel wasps observed, then recorded her count by way of tally marks, then placed the totals into a data table, and finally created a graph, such a complex series would be recognized. Other examples of transformations recognized in our analysis included statistical treatments of data, concept maps, any type of graph, pie charts, and life-cycle composite inscriptions made in diagrammatic or photographic formats. Chi-square analysis, comparing written inscriptions against all other types, was also performed.

As part of the coding of the raw data, ultimate inscriptions made by the participants were identified. Operationally, these ultimate inscriptions were those in which the students made some final transformation and presentation of their data, according to the criteria just described. In each lab phase, any ultimate inscription was identified by type. The transformation pathway leading to the ultimate inscription was delineated by observing the nature and sequence of the students' laboratory notebook entries. In only one case was a portion of a transformation pathway inferred (Table 2, Tabitha's inscription number 3-2). This case involved omission of a table from one student's notebook, without which the inscription that followed could not have been constructed. In all other cases, students supported individual inscriptional entries by means of titles, references to previous page numbers, or statements that tied the individual inscription to previously recorded ones. The nature of the conclusion or use of the final inscription in the pathway by the student was identified, along with the number of steps in the transformation. The assumption is that more lengthy transformation pathways represent a more advanced level of inscriptional skills.

From among the six cooperative student groups, representing 14 students, two groups were randomly selected. One student in each group was randomly selected as well. The laboratory inscription notebooks belonging to those two students were utilized as a source for the illustrations presented.

Findings

Previous research provided evidence that preservice teachers make little use of complex inscriptions when asked to analyze data that they were provided with on written tests (Roth et al., 1998); a follow-up study by the same researchers showed considerable variation in the competencies with which preservice teachers with science degrees prepared inscriptions to present the results of research studies that they designed on their own (Bowen & Roth, 2005). The present study was designed to investigate inscription production and changes therein while the participants in a specially designed hands-on course that focused on inscriptions and inscription use—*Just Do It*—engaged in their own investigations. Our examination of the students' laboratory inscription notebooks, in the context of the various laboratory phases and classroom activities, shows several trends. These trends primarily occur in time; in other words, time and participation in inscription practice may account for them. Other trends are likely more situational in nature. They may depend more on context than time. The trends identified are discussed in what follows in four subsections. We present the results in the form of four assertions, in which we ascertain that, upon mediation through participation in *Just Do It*: (a) the number of inscriptions that participants produced per investigation increased with time; (b) written, text-based data were supplanted by various forms of inscriptions; (c) transformation cascades became more common and complex; and (d) ultimate inscriptions were more complete.

Table 2
All Ultimate inscriptions and transformation pathways per lab phase

Participant	Lab Phase	Inscription #	Type of Inscription	Pathway (Use, Comment, # of Steps)
Allison	1	1	Descriptive statistics	Photo + written → measurements of 12 random samples → statistics (presented range, mean and mode of measurements; student said "unsure of accuracy" 3 steps)
	2	1	Bar graph	Question → hypothesis → 6 tables of measurements of 10 samples → line graph of all measurements → line graph comparing days 14 and 28 → bar graph of control days 14 and 28 → bar graph of days 28 for 3 treatments → bar graph of days 14 and 28 for 3 treatments (student says "hypothesis is supported by data but more trials are needed"; 8 steps)
	3	1	Bar graph	Diagram → photo → photos with operational definitions → 10 tables of counts → table of totals → cleaned table of all counts → bar graph → cleaned bar graph → bar graph of # of organisms (shows # of organisms over time produced in 16 treatments; 9 steps)
	3	2	3 pie charts	Table of totals from 3-2 above → 3 pie charts (tracks percent of female offspring in 3 samples; 6 steps)
Ben	1		No transformations	
	2	1	Bar graph	Written + 17 photos → 5 diagrams → 2 pie charts → bar graph → bar graph (compares growth of organism with 2 treatments and control; 5 steps)
	3	1	Concept map	Nineteen lists of observations → concept map (presents observations on both sexes of organisms; 2 steps)
		2	2 Bar graphs	Written → 10 lists of counts → 2 bar graphs → 2 comparative bar graphs → 2 bar graphs → 2 bar graphs (student says hypothesis not supported; 6 steps)
David	1	1	4 bar graphs	Written → list → 5 lists → 3 tables → composite table → 4 bar graphs (shows # of organisms over several days; 6 steps)
		2	Diagram	All of 1-1 + 7 photos → diagram (shows life cycle of organism and remaining questions; 7 steps)
	2	1	Written/photo composite	1-2 → Diagram + 3 photos → table → written → 25 photos → concept map with new observations and questions → 33 photos → written/photo composite (shows summary of life-cycle with timeline and photos; 8 steps)
		2	Bar graph	Four lists of counts → totals → cleaned written → 2 lists of counts → composite table → composite table with statistics → cleaned table → bar graph (shows percent of surviving organisms over 4 days; 8 steps)
	3	1	Bar graph	Written → concept map → 4 expanded concept maps → cleaned concept map with possible results and conclusions → diagram + table + 5 photos → 3 tables of counts + concept map → 2 composite tables → 2 composite tables with notes → cleaned table → bar graph (shows # of organisms in 4 treatments over 14 days; 10 steps)

Debby	1		No transformations	
	2	1	List	Question + photo → 9 lists of observations + 5 photos → concept map → 4 photos → list (shows life-cycle sequence, student says "we accomplished our goal but had no manipulation of variables in the experiment. . .to determine success or failure"; 5 steps)
	3	1	Bar graph	Two written → concept map → diagram → concept map → cleaned concept map with possible results and conclusions → 2 written + photo → 6 tables → bar graph (shows # of organisms in 4 treatments over 3–4 days; 8 steps)
Jesse	1		No transformations	
	2	1	Bar graph	Two written → 7 written + 8 photos → bar graph and pie chart combination → bar graph (compares percent of male and female growth data; 4 steps)
	3	1	Composite table	Written → 12 tables of counts → composite table → 2 bar graphs → 2 bar graphs → composite table → cleaned composite table (says "data do not support hypothesis but show 2 distinct types of organisms exist"; 7 steps)
Joan	1	1	Scatterplot	One table of measurements → scatterplot (shows growth of organism over time; 2 steps)
	2	1	Line graph	Written + diagram → 6 tables of measurements → line graph → composite line graph; (shows averages of 5 data points from 11 samples, student says "these averages are not very meaningful but now that we know there are in fact 2 types we shouldn't expect to see narrowing"; 4 steps)
		2	Line graphs with slope	Two diagrams + photo → written → concept map → 3 tables of counts → 2 tables of means → composite table → composite graph → best line graph with slope → smooth curve → 2 line graphs with slop (says "data show no differences in growth between 2 treatments"; 10 steps)
	3	1	Photo series	Four written + 9 photos → photo series (says "experiment verifies organism has multiple stages of development" and provides description; 2 steps)
		2	2 scatterplots	Two written → 2 tallies → 2 scatterplots (student says "more male organisms were found on older pupae and more females on fresh," offers hypothesis to explain; 3 steps)
		3	4 *t*-tests	Question → 2 tables of counts → composite table → table of means → 3 line graphs → 4 statistical treatments → 4 *t*-tests (student says because of *p*-value,"on day 1 there is no significant difference between experimental and control samples, but there is a very significant difference on day 3"; 7 steps)
		4	Written/photo composite	Two lists → 4 photos → written/photo composite; (presents life cycle of organism; 3 steps)
Judy	1	1	3 bar graphs	Written → 2 lists → 2 written counts → concept map → table → 3 bar graphs (show # of organisms in various samples over 3 days; 6 steps)
		2	2 bar graphs	Table from 1-1 → 2 bar graphs (shows sizes of 3 randomly selected males and females; 6 steps)
		3	Concept map	Six photos → concept map (student says the figure lists details of "what we believe to be true" about the organism's life-cycle; 2 steps)

(*Continued*)

Table 2
(Continued)

Participant	Lab Phase	Inscription #	Type of Inscription	Pathway (Use, Comment, # of Steps)
	2	1	Line graph	One written measurement → 1 table → 6 photos → line graph (shows size versus # of organisms; 4 steps)
		2	Bar/best line graph	Eleven lists of measurements → 3 tables of measurements → 2 bar graphs → bar/best line graph (student says graph shows "distribution of body lengths of all insects"; 4 steps)
	3	1	Bar graph	Written → 6 written measurements → table → bar graph; (shows # of organisms in each treatment and control over 3 trials; 4 steps)
		2	Photo series	Written → 8 photos → 4 diagrams from published sources → photo series (shows examples of stages of mitosis in organism; 4 steps)
		3	Photo series	Written → 1 diagram from published source → photos series (shows examples of stages of meiosis in organism; 3 steps)
Katelyn	1	1	Scatterplot	Three tables of measurements → scatterplot (shows growth of organism over time; 2 steps)
	2	1	Ratio	Written → 5 lists of measurement → tally → ratio (presents raw ratio of 2 growth patterns of organisms; 4 steps)
		2	Bestline graph	Written → 3 tables of tallies → totals → 2 line graphs with slope → best line graph; (student says "our data supported the hypothesis. . .as the number of individuals per plate increased so did the number of type II organisms"; 5 steps)
	3	1	Photo series	Two written + 6 photos → photo series (shows life-cycle of organism; 2 steps)
		2	3 scatterplots	Two photos → 2 tables of counts → composite table → 3 scatterplots (shows # of male and female organisms observed in 2 treatments; 4 steps)
		3	2 line graphs	Tally + 3 lists → 4 statistical treatments → 4 *t*-tests → 2 line graphs (compares mean # of offspring in treatment and control over time; 4 steps)
Mary	1	1	Concept map	Two lists → flow chart → 11 photos → concept map (presents possible life-cycle of organism and remaining questions; 4 steps)
		2	2 bar graphs	Written → 8 photos with measurements → bar graphs of 3 organisms' size → 2 bar graphs (shows average sizes of 3 organisms; 4 steps)
	2	1	Concept map	List → 7 lists of observations → 2 summary tables → concept map (student says this is a "new theory of life-cycle" of the organism; 4 steps)
		2	Bar/smooth graph	Two tables of measurements → 2 bar graphs → bar graph with smooth curve (student says the graph shows "distribution of body lengths of all insects"; 3 steps)
		3	Composite table	Two tables from 2-2 → composite table; (presents a summary of observations over 9 days; 2 steps)
	3	1	Concept map	List → 6 lists of observations → 4 diagrams + 7 photos + 4 diagrams from published sources → 9 photos + 7 diagrams from published source + 16 photos → concept map (student says this is a "theory of life-cycle" of organism; 5 steps)

Pam	1		No transformations	
	2	1	Concept map	Three lists → concept map (student says this is a summary of "experiments and observations to date"; 2 steps)
		2	Bar/smooth graph	Eleven lists of measurement → 3 tables → 2 bar graph → bar graph with smooth curve (student says this shows "distribution of body lengths of all" organisms; 4 steps)
	3	1	Written/photo combination	Seven diagrams → 2 diagrams from published sources → 19 photos → written/photo combination (presents summary of stages of mitosis and meiosis and comments on spore maturity and release; 4 steps)
Seth	1		No transformations	
	2	1	Descriptive statistics	Two written → tally → table → descriptive statistics (presents means of measurements to conclude "there are 2 distinct sizes of adults & pupae"; 4 steps)
	3	1	3 bar graphs	List and table → 7 tables of counts → table of means → table of results → 7 tables of counts → 2 summary tables + 5 operational definitions with photos → 1 bar graph → 3 bar graphs; (shows final results of offspring from cross in 17 samples; 8 steps)
Steve	1	1	Table	Diagram → 2 tables of measurements → tallies → table (says data demonstrates the organisms "are separate types, the small ones are not just slow growths of the other"; 4 steps)
	2	1	Composite scatterplot	Written → 9 tables of measurement → 4 composite tables → table of means → 4 scatterplots → composite scatterplot (shows differences in growth patterns among 4 treatments; 6 steps)
		2	Bar graph	Table of means from 2-1 + table of controls → complex table → table of means → bar graph (compares treatments and controls, student says "more nutrition does not make little [organisms] grow more"; 7 steps)
	3	1	Bar graph	Question → written operational definitions → 13 tables of counts → 4 cleaned tables → table of totals → bar graph (student says "no yield from any sample"; 6 steps)
		2	Bar graph	Allison's 3-2 → bar graph (compares organisms produced with various treatments; 2 steps)
Tabitha	1		No transformations	
	2	1	Bar graph	Written → written question → hypothesis → operational definitions → table describing experiment → 22 lists of counts → 4 tables of totals → 7 summary tables → bar graph (compares # of organisms among 4 treatments and control; 9 steps)
		2	Table	2-1 → table (shows live and dead organisms among 4 treatments and control with timeline; 2 steps)
	3	1	Composite diagram	Sixteen diagrams + 9 photos + observations shared from another work group → diagram (student says this shows life-cycle of organism "we have deciphered from our observations"; 2 steps)
		2	Line graph	Concept map of plan → concept map of procedure → table of measurements [missing from notebook, found in partner's notebook] → line graph (shows # of organisms observed over time among 4 treatments and control; 4 steps)

(*Continued*)

Table 2
(Continued)

Participant	Lab Phase	Inscription #	Type of Inscription	Pathway (Use, Comment, # of Steps)
Terri	1		No transformations	
	2	1	Composite diagram	Five diagrams → composite diagram (shows life-cycle of organism with written notes; 2 steps)
		2	Line graph with slope	2 written → 12 tables of measurements → line graph with slope (shows growth of organism over time; 3 steps)
		3	Line graph with slope	Question → written counts → totals → composite table → line graph → line graph with slope (student says "density of populations does show an effect on # of type II versus type I. When type II are separated from type I they start to [change]"; 6 steps)
	3	1	Best line graph	Written → table of counts → 4 statistical treatments → 4 *t*-tests → 2 line graphs → combination scatterplot → combination scatterplot → best line graph (compares # of offspring among treatment and control; 8 steps)
		2	3 scatterplots	Written → 3 lists → table of totals + 2 photos → 2 composite tables → 3 scatterplots (compares # of male and female organisms from two treatments; 5 steps)
		3	Photo series	Five photos + written observations → photo series (shows life-cycle of organism to clarify best times for counting organisms; 2 steps)
Vivian	1		No transformations	
	2	1	Composite diagram	Written → 4 tables + 6 diagrams → concept map → 5 tables + 6 diagrams → composite diagram; (shows life-cycle of organism with remaining questions; 5 steps)
		2	4 bar graphs	Written + 9 tables from 2-1 → 5 cleaned tables → 4 bar graphs (shows # of organisms observed over time; 4 steps)
	3	1	2 pie charts	Written → concept map → concept map → 2 diagrams → list + 2 diagrams → 2 tables → 2 bar graphs → diagram + table → composite table → 2 bar graphs → 4 bar graphs → 2 pie charts (compares percent of male and hermaphroditic organisms over 2 days; 12 steps)

Assertion 1: Number of Inscriptions That Participants Produced per Investigation Increased With Time

During the course of their enrollment in *Just Do It*, the participants collectively generated more than 2000 permanent scientific inscriptions over 15 weeks of the semester (Table 1). This number, and all subsequent numbers referring to inscriptions, is conservative because it includes only those inscriptions recorded in the participants' laboratory inscription notebooks. Additional inscriptions were frequently made in other media. Some were produced spontaneously and as needed on pieces of paper while the students collaborated on some idea or procedure. Others were produced using the classroom chalkboard as medium as part of student–student and student–teacher interactions. Still others were offered during formal student presentations on poster board, handouts, or computerized projections. These inscriptions did not survive as *permanent* artifacts, and, although important to student–student and student–instructor interactions—and therefore to learning and development—are not included in the analysis.

Consistent with other research on inscription use (Greeno & Hall, 1997), the participants in *Just Do It* produced an increasing number of inscriptions: 460 to 792 and 920 over the three laboratory phases. This increase was observed even though the second lab phase (the first guided-inquiry session) was actually shorter by 1 week than the first lab phase. By the third lab phase, the number of inscriptions produced had doubled compared with the first (Table 1). Although the third lab phase was 1 week longer than the first, it included a substantial amount of class time being devoted to student presentations of their results and inquiry lessons; therefore, students did not produce (or produced only few) permanent inscriptions during this time.

A common theme among students who have completed *Just Do It* is that the minimum requirement for total number of inscriptions (as listed in the rubric) is often initially intimidating, but quickly becomes a non-issue as the course progresses. This was clearly the case with the current group of participants. Every student in class exceeded the minimum number of inscriptions by more than 56%. Some students more than tripled the minimum requirement. Furthermore, 11 of the students had at least half of the minimum number of required inscriptions before they began the second laboratory phase. So, it does not appear that there was any significant and artificially imposed pressure to record representations in the notebooks merely for the sake of reaching some minimum number for purposes of getting a good grade. Our results, showing increasing production of inscriptions, are also consistent with another study, where inscription production was studied in the course of open inquiry (Roth & Bowen, 1994).

Across this and previously reported studies, and as predicted, there appears to be mounting support for the contention that framing research and producing inscriptions in an authentic context (such as student-directed or -guided observation and inquiry) can lead to increased generation of inscriptions. Like the eighth graders in the Roth and Bowen study, participants in the current study increased the numbers of inscriptions they produced as they continued to be engaged in science activities over time. The passage of time, of course, also includes more opportunities to practice construction of inscriptions and to experience peer and teacher feedback on the same.

Table 1 provides the distribution of inscriptions produced across six categories identified as salient in other studies (Roth et al., 1999). A chi-square test ($p < 0.0001$) shows that the equidistribution model has to be rejected. That is, the distribution of inscriptions across the six categories was not constant over time. A comparison of actual frequencies with expected frequencies on the chi-square test shows some substantial deviations; particularly notable is the production of diagrams during the first two phases, as well as the production of tables and the use of transformations.

Assertion 2: Written, Text-Based Data Were Supplanted by Various Forms of Inscriptions

Science is characterized by its production of inscriptions; historically, science became what it is because scientists began to move from predominantly verbal descriptions and discussions typical of natural philosophy to the production of diagrams, ordered tables, and graphs (Edgerton, 1985). Previous research has shown that the production of verbal representations on data analysis tasks that—from a scientific perspective—clearly asked for transformation or statistical treatment, predominated among preservice science teachers despite their science degrees (Roth et al., 1998). An important part of science education, therefore, has to be the provision of opportunities for students to move from textual, narrative modes of representing phenomena to other inscription types characteristic of science.

To test whether there was a change in inscription production from verbal to other modes, we collapsed Table 1 to oppose the written mode to all others. A chi-square test showed that the equidistribution model had to be rejected ($p < 0.001$). During the observation and first experimentation phases, there were substantially more verbal inscriptions (126, 144) than expected by the equidistribution model (100, 172); only during the second experiment was the equidistribution expected number of inscriptions produced. That is, with time, there was a shift from text-based inscriptions to other types. In other words, the practice making inscriptions (time) and the shift from mere observation into inquiry while inscribing (context) seemed to make a difference in the participants' inscriptional abilities. As predicted, and as set forth as a goal in science reform recommendations (NRC, 1996; 2000), participants became more adept with regard to production of science-like inscriptions (i.e., they made fewer written and more abstract representations of their work).

Central to scientists' production and use of inscription is the transformation into more complex (generalizable) forms. A chi-square comparison of the transformations against all other inscriptions produced shows that the equidistribution model has to be rejected ($p < 0.00001$): The number of transformations was much less than expected during the first phase of this study (23 vs. 68, respectively) and was much higher than expected during the second and third phase of this study (145 and 154 [actual] vs. 117 and 136 [expected], respectively). In Figure 1, we present the breakdown of the different and more complex inscriptions used. Graphs accounted for the largest single transformation, although the frequency decreased over time.

Narrative, text-based inscriptions are clearly not ''wrong'' in science. In fact, they are often used effectively to communicate research questions, hypotheses, and other information. However, during the observation phase, this category accounted for more than 27% of the inscriptions; this number decreased to 18% to 22% for the two experimental phases, respectively. Our analysis of the notebooks revealed that there were numerous instances during the earliest weeks of the course

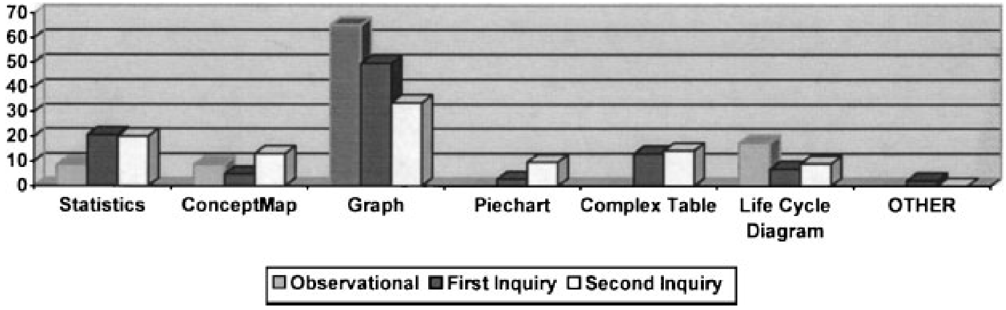

Figure 1. Percentages of various transformation types.

in which students elected to make purely written representations of their work when, perhaps, some other format would have been selected by a more practiced scientist. An example of such a purely written inscription is shown in Figure 2a. In this inscription, Tabitha details observations made while cutting open ‘‘pellets’’ containing jewel wasp larvae. By lab phase 2, Tabitha began to incorporate such supplementation in her written inscriptions, as evidenced in Figure 2b. Eventually, she opted for tabular presentation of data in a more systematically organized format. Figure 2c provides an example.

The same type of trend, away from heavy reliance on written inscriptions, was observed in Ben’s inscription notebook. During lab phase 1, for example, he made the following written entry in his notebook concerning *C-Fern* cultures:

> The second plate viewed was dry. Branches again were present. These fibrous branches appeared to have newly formed bulges/buds on the fibers. It could not be determined if the branches were independent of the particles or attached. Fibers appear to be a contaminant (a fungus). Dark spots in the middle of each particle. (from Ben’s notebook)

Later entries covering the same subject (*C-Fern* growth patterns on Petri dishes) took a diagrammatic, rather than purely narrative form. An example is shown in Figure 3a. Ben also began to systematically organize observations in the form of a table, as shown in Figure 3b.

We noticed an increase in the number of digital camera images made by the students during the early weeks of the course (Table 1). This increase was probably due to the novelty of the medium as more and more students became familiar with the camera’s use. Many more digital images than diagrams were produced during lab phase 2. The numbers of digital images remained high during the third lab phase, but dropped slightly as students began to again make diagrams in lieu of digital images. It does not appear that familiarity with the camera or with any other technology used to generate or record inscriptions had a significant role in the overall trend away from text-based inscriptions toward other forms. One of the most significant changes to account for the increase in non-written inscriptions is the implementation and development of the students’ inquiry projects. It is of note that the earliest inscriptions, from lab phase 1, were made during a purely observational (non-experimental) context. Because the students’ laboratory work was framed with more of an empirical purpose (scientific inquiry as opposed to mere observation), they likely had more opportunities and motivation to move into more complex and abstract forms of inscriptional representation.

Assertion 3: Transformation Cascades Became More Common and Complex

We noted that students used significantly more transformations in the later stages of the program than in the earlier phases. Like five of their peers, neither Ben nor Tabitha made any transformations of their inscriptions during the first lab phase. Of the seven remaining students who did transform inscriptions during these early weeks, most made only one or two very simple transformation. Table 2 presents ultimate inscriptions and transformation pathways from all 14 notebooks. Katelyn’s inscription number 1-1 was a scatterplot, derived in two steps. She measured the width of *C-Fern* gametophytes growing in 11 Petri dishes over the course of 8 days and combined the measurements to form the scatterplot.

By the second lab phase, each student had recorded at least one transformation cascade within the pages of their laboratory notebooks. More than half of the students produced at least two. Katelyn’s most complex one, in terms of the number of steps of transformation involved, was inscription 2-2 (see Table 2). The significance of this inscription, when compared to her inscription

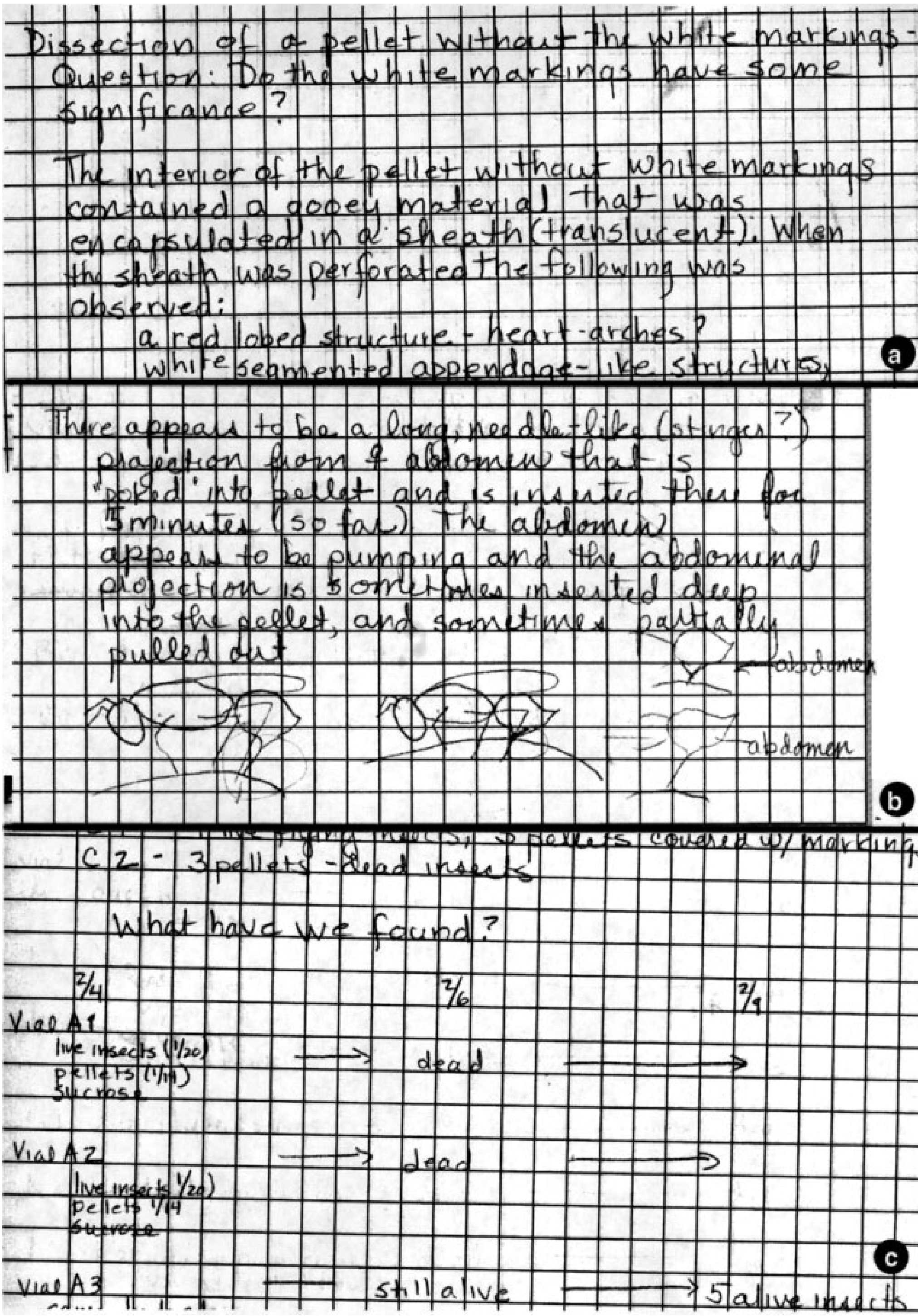

Figure 2. Excerpts from examples of Tabitha's inscriptions. (a) Written inscription. (b) Written inscriptions supplemented with diagrams. (c) Table.

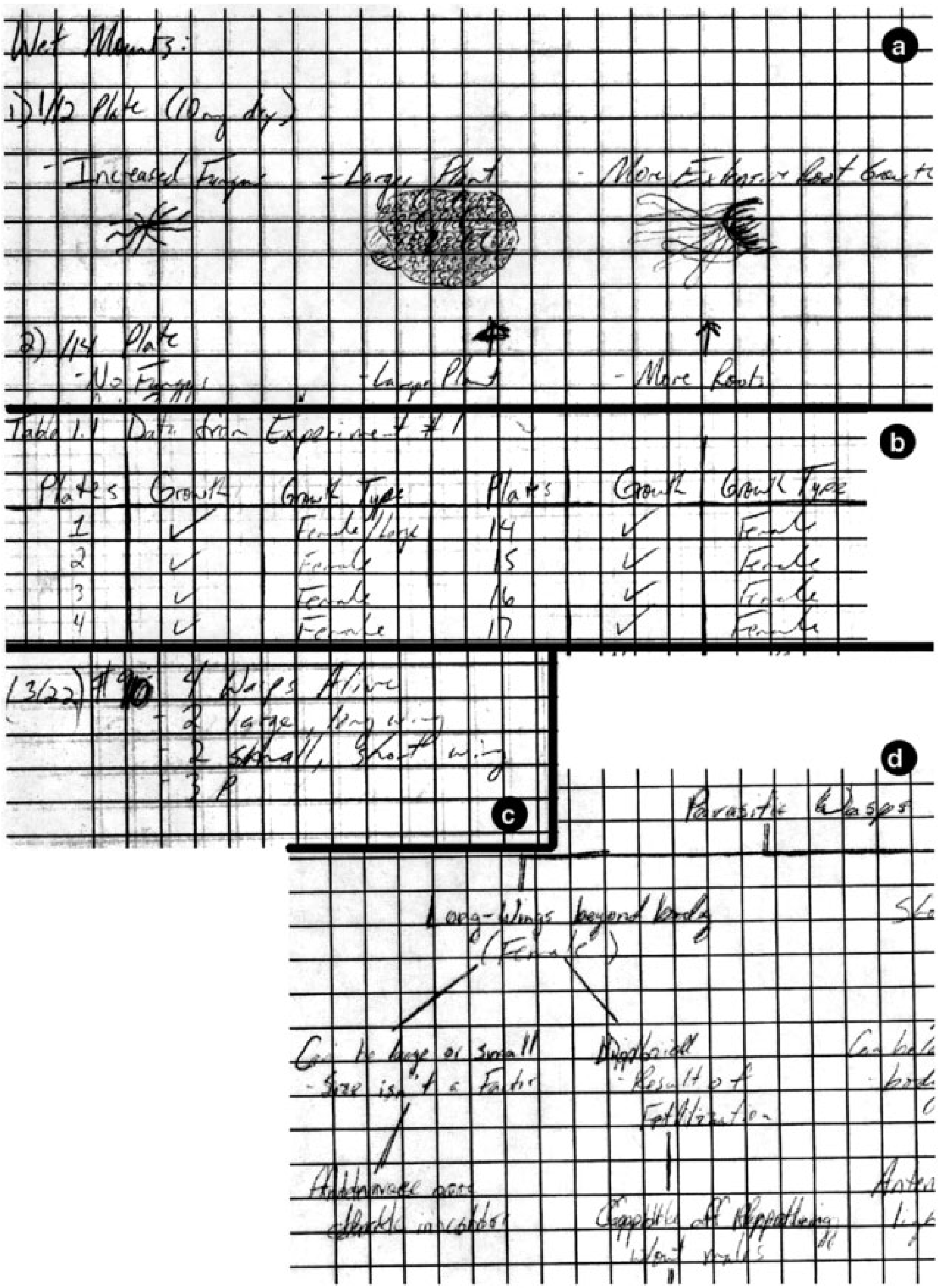

Figure 3. Excerpts from examples of Ben's inscriptions. (a) Microscopic observations. (b) Table of C-Fern growth data. (c) Transformation cascade (step 1: observation of wasps). (d) Ultimate transformation concept map of male and female characteristics.

number 1-1, was in the complexity. Inscription 2-2 involved more stages than the simple two she used in inscription number 1-1. Using computer technology, she generated the best-fit line on a scatterplot in five steps. Unlike her inscription number 1-1, the transformation now in question involved more detailed mathematical processes. From tallies of *C-Fern* gametophyte types, totals and line graphs were generated to produce the ultimate inscription. Curiously, Katelyn calculated the slope of the two penultimate line graphs but did not utilize this calculation to derive the ultimate inscription. From a teacher's perspective, it may have been of interest to put Katelyn into a situation where she was forced to account for the fact that she did not include the slope values in the final report. Such a situation might be precipitated through a teacher question or in a whole-class discussion where another student challenged her on this point. As a group, students could then have evaluated the potential benefits and power of this particular inscription in support of the claims she made.

For purposes of illustration, we show examples of transformation cascades from Ben and Tabitha's laboratory inscription notebook. One student was selected to illustrate the simplest cascade, the other was used for the most complex. Ben's simplest transformation (Table 2, inscription number 3-1) was essentially a two-step process in which a series of 19 lists of observations (e.g., see Figure 3c) concerning male and female jewel wasps (identified initially by Ben as ''long wing'' and ''short wing'') were made. These observations were transformed into a concept map (Figure 3d), detailing characteristics that could be used to identify male and female jewel wasps.

Tabitha's inscription number 2-1 (Table 2) was a product of her most complex transformation cascade, which involved nine steps. She began the process with four written inscriptions. These are reproduced in typewritten form in what follows. Her first written inscription was entitled ''What We Know'':

> Insects lay eggs in the pellets.
>
> How do we know? Observed behavior.
>
> Pellets w/ insects had white markings on them. These white-marked pellets eventually ''hatched.''
>
> 1. What are the pellets?
>
> Fly b/c we observed flies in the tubes that contained no flying parasitic wasps.

Immediately following this initial inscription, Tabitha listed a series of potential research questions (and titled the inscription ''Questions'') based on her ''what we know'' inscription just shown. The questions are reproduced as follows:

> If flying insects parasitize pupa—would they parasitize the flies [larvae]?
>
> If live flies are in vessels w/ flying insects, who would prey on whom?
>
> How long is the flying insect and fly life-cycle?
>
> How does [sic] light, food, and temperature affect pellets and insects?

Tabitha and her lab partner eventually settled on the question of food, noting their hypothesis in step 3 of the transformation: ''Our hypothesis is as follows—presence of sucrose solution in vials w/ live insects will prolong insect life.'' Tabitha clarified her hypothesis by operationally defining (step 4) sucrose as a solution containing "3.0 grams of sucrose and 30 ml of distilled water." Tabitha's experimental set-up, in which she delineates symbols used to identify the vials, as well as the various treatments and controls, was summarized in a table (Figure 4a). Next, Tabitha and her lab partner made a series of counts of adult insects in the various vials over the course of several days. Twenty-two such lists were found. An example is shown in Figure 4b. Using these data, and computer-assisted technology, Tabitha totaled the counts into a series of four tables (e.g., Figure 4c). These data were combined into a penultimate summary table that Tabitha entitled "The Total Number of Live Insects in Vials. . .Over an 18-Day Observation Period." This summary table is shown in Figure 4d. No data were entered for treatment conditions involving sucrose, water, and control for three days on the example shown. Here, as in other situations, it might have been of interest to precipitate a whole-group discussion about the role the omitted data play in the power of the ultimate claims that can be made based on her study. Finally, step 9 of the transformation, the ultimate bar graph, was generated using the summarized data (Figure 4e). Units of time on the x-axis of this graph were not included, although, in a whole-class situation, another student or the teacher might have challenged her on this point.

Again, it seems that the trend toward more complex transformations may best be attributed to the fact that the students were actively engaged in inquiry-based activities during their second and third lab phases as opposed to the simpler observations of organisms that characterized lab phase 1. Time and practice, along with viewing other students' transformations and coaching from instructors, also probably made an impact. It is also of note that the students seemed more open to the idea of alternative types of transformations as evidenced in Table 2 and Figure 2. Graphs are arguably the most commonly encountered type of transformation seen in professional scientific publications (Roth et al., 1999). They remained the participants' most common ultimate inscription throughout all three laboratory phases. However, as described previously, students began to make more of other sorts of transformations, such as concept maps, statistical treatments, and complex tables, during the inquiry activities of the second and third lab phases.

Assertion 4: Ultimate Inscriptions Were More Complete

The mark of a good and effective ultimate inscription (such as a graph) is its ability to communicate information. In other words, a well-prepared ultimate inscription should be complete enough that, together with the surrounding text, it provides sufficient information for the reader to access the critical steps leading to its manufacture. The loop will be closed, with the text and inscription leaving little to the observer's imagination (Bastide, 1990)—although the analysis of biology textbooks revealed that textual forms play an important part in providing interpretive resources and constraints (Pozzer & Roth, 2003). Our data show a moderate improvement in the participants' collective transformations with regard to this criterion. Because no true experimentation was completed during the first lab phase, there were no hypotheses or research questions stated to loop back to the few ultimate inscriptions made. The transformations made during this first lab phase were mostly descriptive in nature, as opposed to being interpretative in nature, if they served any explicit purpose. For example, Katelyn's inscription 1-1 (Table 2) did not begin with any overtly stated purpose. The scatterplot does provide a summary of data, but the reader is left to imagine if there was any special treatment of the organisms. Katelyn does not list the name of the organism involved or how the growth was measured (length, width, roots, aerial, etc.).

By the second lab phase, students were actively engaged in traditional inquiry-based experimentation with their organisms. One might expect that the ultimate inscriptions from this lab phase would be more complete, with a closed loop between the initial and ultimate step of the transformation. Of the 27 ultimate inscriptions made during this phase, 10 began with some

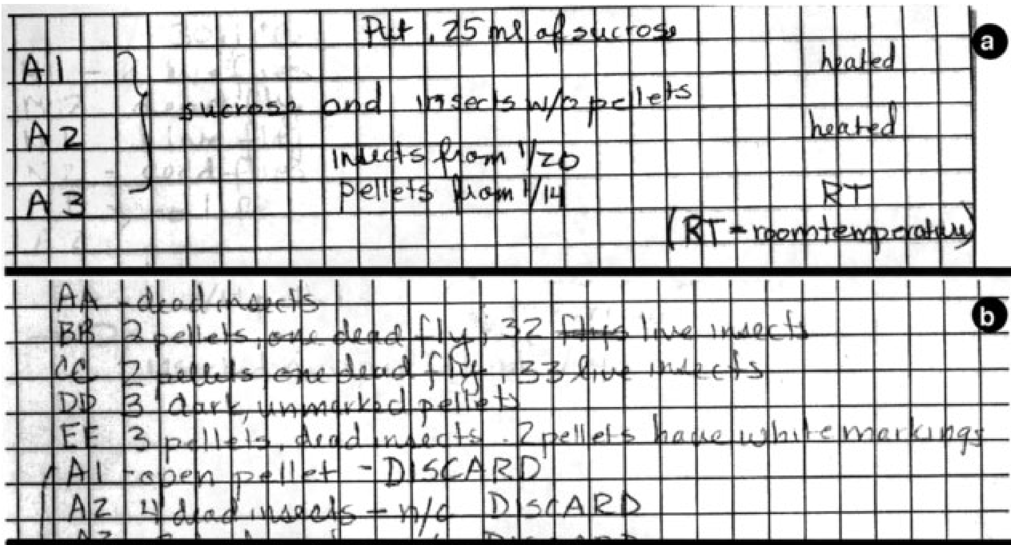

Table 2: The Number of Live Insects in Trial 3 Sucrose Experiment

c

Date	2/9/2004	2/11/2004	2/12/2004	2/16/2004	2/18/2004	2/20/2004	2/23/2004	2/25/2004	2/27/2004
Vials									
S 1 (sucrose)	20	17	17	14	14	10	10	3	3
S 2 (sucrose)	6	6	6	3	2	2	2	2	1

Table 4 and Figure 1: The Total Number of Live Insects in Vials S, NS, SU, W and CO Over an Eighteen Day Ob

d

Vials / Date	2/9/2004	2/11/2004	2/12/2004	2/16/2004	2/18/2004	2/20/2004	2/23/2004	2/25/2004
S (sucrose) series	49	44	43	37	33	29	18	6
NS (no sucrose)	53	0	0	0	0	0	0	0
SU (sucrose)				49	32	30	29	15
W (water)				53	22	5	0	0
CO (control)				92	36	2	0	0

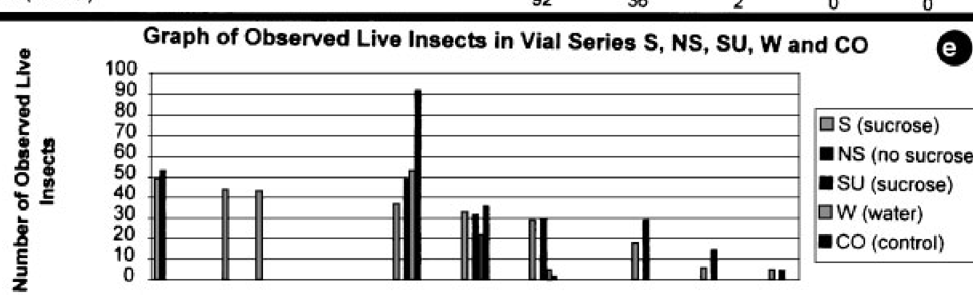

Figure 4. Excerpts from Tabitha's transformation cascade (see text for steps 1–4). (a) Step 5: The plan. (b) Step 6: The data. (c) Step 7: Table of totals. (d) Step 8: Penultimate summary table. (e) Step 9: Ultimate bar graph.

explicit written statement involving a research question, a purpose, or a hypothesis. Tabitha's transformation pathway toward inscription number 2-1 (Table 2) was detailed in the preceding section. Her ultimate inscription (Figure 4e) clearly shows numbers of live insects among sucrose-rich and control environments and allows the observer to see trends. A table produced by Tabitha (inscription number 2-2, Table 2) extended the transformation to summarize the entire experiment. Ben did provide a written statement of the purpose of an experiment that led to his inscription 2-1 (Table 2). The bar graph generated included details of treatment and control. Similarly, both of Katelyn's ultimate inscriptions from the second lab phase were easily linked to an explicitly stated purpose, question, or hypothesis. In her inscription 2-2 (Table 2), Katelyn specifically mentions that her hypothesis was supported by the data.

As far as lab phase 3 is concerned, the pattern is much the same. Twenty-eight ultimate inscriptions were identified. Thirteen of these cascades were initiated with an explicitly stated purpose, hypothesis, or question. Of these, six explicitly looped back to join the hypothesis or question with the ultimate inscription in the cascade, thereby exhibiting trends similar to those reported in a previous study of preservice teachers (Bowen & Roth, 2005). Ben's concept map (number 3-1, Table 2) provided a useful summary of the characteristics of *C-Fern* gametophytes, but was not derived from any formally stated plan of action. He not only stated a hypothesis in his inscription 3-2 (Table 2), but linked the ultimate inscription, a bar graph, back to it by stating that his hypothesis was not supported. Katelyn did not list any questions or a hypothesis, which might have functioned as springboards into the third lab phase. Two of her transformations from Table 2 (3-2 and 3-3) demarcate the results from various experimental treatments. The same trend was observed for Tabitha during lab phase 3. Only one of her transformations (Table 2, inscription 3-2) began with a clearly stated purpose. The line graph she produced was probably sufficient for the observer to follow her line of thinking in the presentation of her results. As a group, students increased their use of inscriptions that were capable of standing alone in terms of communicating and summarizing their results. This improvement was only moderate.

Discussion

This study was designed to investigate the production of inscriptions during a course in which students designed their own investigations, which they were asked to present and defend in their peer community. Previous research with eighth grade students studying ecology suggested that such a context leads to an increased use of inscriptions, especially to an increased use of more generalizable inscriptions (Roth, 1996). At the same time, preservice teachers did not appear to be prepared to use inscriptions to analyze data, where patterns could not be discerned by simply looking at the data pairs (Roth et al., 1998). The earlier suggestions from the eighth grade study were borne out in the present study: preservice teachers substantially increased the total number of inscriptions they produced in each of the phases (Table 1). The passage of time, practice with constructing inscriptional representations, and the contextual shift from simple observation to inquiry (as predicted by Roth et al., 1998) seemed to account for these trends. With time and shift in goal or context, there was also a shift from text-based to other inscriptions, and there was a significant increase in the use of transformation to more complex forms of inscriptions. In this way, our study is consistent with reform recommendations that suggest increasing attention to data analysis and use of inscriptions (AAAS, 1993; NRC 1996, 2000). The present study further shows that inquiry activities may be one of the contexts in which this shift toward more scientific practices can be achieved.

Although change has been remarkably slow, a number of national reform recommendations in science education have found their way into preservice teacher preparation programs. It is of note that the state guidelines, under which the university where this study took place operates, require that potential teachers of science demonstrate adequacy in "open-ended experiments most appropriate for their major" for purposes of certification. It has already been well established that the traditional methods of instruction such groups are exposed to leave tremendous deficits in their abilities to do inquiry and to efficiently represent, interpret, and use scientific data (Bowen et al., 1999). It is for this very reason that the *Just Do It* course was designed. It has the additional function of providing students with a model of inquiry-based teaching. Furthermore, it is of long-term duration. In our study, as predicted by previous authors, we have shown that these facets help lead preservice teachers toward competence in not only producing inscriptions but transforming them.

One of the key resources available to the *Just Do It* students is mentoring from, and access to, a professional university scientist. We consider the presence of scientists and the scaffolding students receive in a *just-in-time* and *as-needed* manner to be an important element of our program, as the students come to experience how to use inscriptions to present *their own results* just when they need to present them. The presence of the scientists in the context of the open nature of the inquiry confers a degree of authenticity to the experimentation, which appears to be an important element in learning *to do* science rather than to regurgitate phrases (Roth, 1995). Students in the present study routinely presented their claims and conclusions and increasingly supported them with inscriptions rather than with text-based data, both in formal and informal situations (within-group discussions). The scientist-instructor required all participants to substantiate every conclusion or claim they made by using their own evidence, often in the form of their self-generated inscriptions, which is an important element of how science is practiced.

There were other important elements that helped to recreate some of the overall authenticity of the participants' experiences and foster development of competence with inscriptions. One of these was use of contemporary technology in the form of computer programs capable of producing graphical and mathematical inscriptions. Another was the digital camera, which provided opportunities to generate photographs. These resources are not only typical of the modern scientists' domain but are advocated by reformists (NRC, 1996, 2000). Access to laboratory equipment and facilities is also important. One cannot work like a scientist in the absence of the proper tools of the profession.

In a perfect world, with hindsight, one may readily speculate about potential ways to foster even greater development of representational practices among preservice science teachers. As noted, students improved in their competencies to make convincing ultimate inscriptions that summarized all essential parts leading to their construction. From an instructor's perspective, we would like to achieve more and more completeness in ultimate inscriptions. A further examination of the transformations made by this group of participants, focusing on completeness and the claims made by the participants (compared with what the inscriptions actually communicate), may prove useful in achieving this goal. In science, the peer-review process assists in the production of articles that better withstand criticism. We hope that future implementations of the *Just Do It* program will incorporate an increased number of opportunities for students to defend what they have produced in a peer-review situation—which may have the additional benefit of being less threatening than instructor feedback.

A greater emphasis on using their own inscriptions in front of an audience might help students to close some of the gaps in the processes that led to the construction of their transformed inscriptions. One potential way to overcome this may be to require more extensive evaluation of such inscriptions. For example, students may be required to submit such an ultimate inscription to a panel of peers and professionals with the question, "What does this mean?" in an effort to determine if the inscription has been carefully enough prepared to effectively communicate the intended message. A more ambitious plan may be to require preservice science teachers, engaged in inquiry and production of inscriptions, to actually submit their work to a professional journal. Time constraints may prohibit this from being completed in a semester, but perhaps it should be looked at in terms of a program goal. A greater emphasis on mathematization of inscriptions (Roth & Bowen, 1994) in evaluation of the participants' lab notebooks may also help students to become more adept with the process of making and using graphs, equations, and the like.

Conclusions

At the time of this writing, the *Just Do It* experience for preservice science teachers continues into its 10th year. The emphases on long-term, authentic, inquiry-based lab experiences, along with inscriptional representation and use of evidence by participants to substantiate their conclusions, have remained in place. In the process of revising the course, we introduced a scoring rubric that initially was for grading purposes (Lunsford, Melear, & Hickok, 2005). It turned out that the criteria also constituted a resource for students to increase the number of transformation items. Since the introduction of the rubric, students from several cohorts have repeatedly remarked that the task of maintaining a lab notebook seemed more purpose-driven and formalized.

Some science educators have asked us why we use the notion of competence in experimental design as measured by *inscription* to plan curricula, teach, and analyze data. The present study has amply shown the benefits of such an approach. Because inscriptions are public, peers and teachers can model, observe, evaluate, and critique their use without having to resort to explanations based on mental representations. Specifically, representation becomes a public rather than a private practice and, as such, can be appropriated, researched, documented, and theorized. It is also an approach consistent with the contention that there are no other meanings to an inscription—even to words—than their situated use (Wittgenstein, 1958).

The results of this study support the contention that inquiry courses in which students have to defend the experiments and experimental results support the generation of inscriptions, especially those that are more complex and therefore generalizable. However, our experiences show that this may not be sufficient. Contextual factors such as a scoring rubric may encourage students to produce more of those inscriptions that scientists preferentially use. We therefore strongly encourage programs aimed at effectively educating preservice science teachers in the ways of the profession to reexamine their methods and goals, but encourage the exploration of the explicit contextual factors that appear to be supporting the growth of competencies. Future research therefore should answer questions such as "Does a peer review process before ultimate submission of laboratory reports increase the quality of inscriptions?" "How does a peer review process assist producers and consumers of inscriptions in better understanding their production and use?"

Laboratory experiences offered for preservice teachers must shift if we expect to produce classroom teachers who are competent with scientific processes and communication. Such experiences may not shift or may shift only slowly in undergraduate science classes. Our study shows that well planned classes can contribute to developing science teachers' competencies related to the production and use of inscriptions. Science teacher education programs with this and similar aims may require multiple experiences, spanning multiple semesters, in which potential teachers of science are routinely expected to engage in authentic scientific activity and use of inscriptions to document and communicate. This, we contend, may help future teachers of science achieve a competence in teaching science in a more authentic and inquiry oriented way, and in dealing with scientific data in their classrooms. Additional research should be undertaken to determine whether science teachers who are taught with the techniques described in our research will indeed incorporate them into their classroom instruction or assessment practices.

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