Learning from Inquiry-Based Laboratories in Nonmajor Biology: An Interpretive Study of the Relationships among Inquiry Experience, Epistemologies, and Conceptual Growth

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Abstract: The use of inquiry-based laboratory in college science classes is on the rise. This study investigated how five nonmajor biology students learned from an inquiry-based laboratory experience. Using interpretive data analysis, the five students’ conceptual ecologies, learning beliefs, and science epistemologies were explored. Findings indicated that students with constructivist learning beliefs tended to add more meaningful conceptual understandings during inquiry labs than students with positivist learning beliefs. All students improved their understanding of experiment in biology. Implications for the teaching of biology labs are discussed. © 2003 Wiley Periodicals, Inc. J Res Sci Teach 40: 986–1024, 2003

Interest in using inquiry-based teaching strategies has increased in recent years as science teachers have become more critical about the efficacy of cookbook-type laboratory activities and indeed the purposes, practices, and learning outcomes of laboratory in general (Wellington, 1998). It is gradually being recognized that whereas cookbook labs can teach some laboratory techniques and skills (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000) or serve as visual aids for concepts already studied (Millar, 1998), they are largely ineffective as a tool for teaching science concepts. As stated by one teacher-researcher, “In the same way as any scientist, students will see what their prior theories lead them to expect. More significantly, they will not make the meaning that we as teachers expect them to make of experimental evidence until they have already grasped the theoretical framework that allows them to ‘see’ the evidence” (Hart et al., 2000, p. 659). Therefore, cookbook laboratories may work well as illustrations of concepts already studied and understood but it is unlikely they will lead to new conceptual learning.

Many definitions of inquiry-based labs and inquiry pedagogical models may be adapted to fit the local context (Keys & Bryan, 2000). The authors of this report consider inquiry to be any combination of the following activities described as inquiry by the National Science Education Standards (National Research Council, 1996): observing objects and events, posing questions,
designing investigations, proposing explanations, collecting data, analyzing data, and comparing proposed explanations with new data. As inquiry-based labs gain popularity, one important question facing science education researchers is whether inquiry-based labs have the potential to teach science concepts. Do the problem-solving components of inquiry promote conceptual growth in science? The purposes of this study were to explore, using interpretive research methodology, potential change in the conceptual ecologies of college students enrolled in an inquiry-based laboratory for nonscience majors and to relate this change to the students’ learning beliefs and science epistemologies.

This study is significant in that it is one of the first to explore in depth relationships between inquiry and conceptual learning. Previous studies have indicated that prior knowledge plays a large role in determining the character of new learning that occurs during a science experience (Driver, Leach, Mortimer, & Scott, 1994; Jones, Carter, & Rua, 2000). We now recognize that not only prior knowledge about science concepts but also ideas about what science is, and how humans come to know in science, may affect learning outcomes (Edmonson & Novak, 1993; Tsai, 1998). In this study, we explored possible relationships among three theoretical constructs in the context of an inquiry-based learning experience: (a) conceptual ecologies—the conceptual knowledge structures students have before and develop further during instruction; (b) learning beliefs—beliefs students have about what science learning is and how they learn science; and (c) science epistemologies—beliefs students have about how what scientists do, and the nature of knowledge production in the scientific enterprise. Thus, we framed the following research questions: (a) What is the development in college nonmajor biology students’ conceptual ecologies in association with an inquiry-based laboratory experience? (b) What are the relationships among students’ learning beliefs, science epistemologies, and conceptual learning in the context of an inquiry-based laboratory experience?

Theoretical and Empirical Frames

This study is framed by three areas of theoretical and empirical literature: (a) science conceptual learning, particularly in the biological sciences, (b) the influence of epistemology on learning, and (c) learning from laboratory in science. The seminal work of Ausubel, interpreted for science education by Novak (Novak, 1987; Novak & Gowin, 1984), on the construction of conceptual knowledge networks through meaningful learning has provided a foundation for many contemporary studies, including this one. Ausubel’s theory of meaningful learning posits that learners increase their conceptual knowledge bases when they choose to relate new information to prior knowledge. Ausubel named three cognitive functions involved in meaningful learning: (a) subsumption—the attachment of the concept to a network of other meaningful concepts; (b) progressive differentiation—categories for concepts become increasingly branched; and (c) integrative reconciliation—two or more concepts are seen as related in new ways. Thus, science learning consists of increasing levels of classification, clarifying hierarchical relationships, adding exemplars, and forming new links between concepts.

Thousands of studies have captured the significance of prior knowledge on students’ science learning. More recently, studies have documented the complexity and variability of learners’ conceptual ecologies for a science topic. For instance, Jones, Carter, and Rua (2000) researched the conceptual change of fifth-grade students for heat and convection topics. They noted that depending on the assessment or task at hand, students drew from many different prior knowledge experiences to form a response. They stated that, “Although there were commonalities and patterns for interpretive frameworks, the variation and idiosyncratic application of prior experience was individually contextual and therefore incredibly diverse” (p. 155). Thus, although conceptual
ideas discussed in the classroom made their way into the student’s interpretive frameworks, each student’s learning was unique.

A study of knowledge restructuring in college biology students by Pearsall, Skipper, and Mintzes (1997) found that 75% of additions to the knowledge base were small, incremental understandings. The researchers indicated that all major restructuring happened in the first 4 weeks of the course. Most of the biology learning that occurred in the course involved fine-tuning rather than major conceptual restructuring. In congruence with Ausubel’s theory, they found that meaningful learners added more to their knowledge bases than rote learners.

Additional studies of college or secondary biology learning have documented that instructional interventions designed to promote active learning, reflection, and metacognition have either improved learning outcomes for the treatment groups, or have solidified the learning for a longer period of time (Blank, 2000; Lin & Lehman, 1999; Marbach-Ad & Sokolove, 2000). For example, Blank (2000) found that students engaged in a metacognitive learning cycle exhibited richer and more critical dialogue during class discussion and retained ecology understandings longer than those in a traditional learning cycle group. Lin and Lehman (1999) tested the effects of reasoning prompts through computer programs for biology and found that reflecting on reasoning led to a better understanding of experimental design. Marbach-Ad and Sokolove (2000) have indicated that students in an active learning environment ask better biological questions than those in a traditional learning environment.

In summary, these studies suggest that biology learners in our study may have idiosyncratic prior knowledge bases that will interact with inquiry-based instruction in biology in unique ways. We expect that much of the learning may be incremental, rather than representing major restructuring of biology knowledge. Finally, we believe that reflection and questioning prompted by an inquiry-based environment may be beneficial for promoting biology learning.

A second major area of recent literature on the influence of epistemologies on science learning informs our study. Over the past 2 decades, researchers have become increasingly interested in the interplay between science conceptual learning and other affective and cognitive factors, such as personal learning frameworks (Hogan, 1999), learning beliefs, and science epistemologies (Edmondson & Novak, 1993; Pearsall, Skipper, & Mintzes, 2000; Tsai, 1998, 1999). It is posited that students with a positivist view of science, regarding science as a body of knowledge to be discovered by empirical means, will also have more rote strategies for learning science, including memorization and problem practice. Those with a more constructivist epistemology, regarding science as a creative or invented endeavor that changes over time, will use learning strategies such as making connections, imagining an experiment, and explaining. It is further suggested that those with a constructivist epistemology and learning beliefs will be more successful with meaningful learning (Edmonson & Novak, 1993; Tsai, 1998) and therefore be more apt to build their conceptual ecologies.

Most relevant to our research are studies conducted by Edmonson and Novak (1993) and Tsai (1998, 1999). Edmonson and Novak (1993) interviewed 19 college students enrolled in introductory biology. They found three groups of students, one set that aligned with a logical positivist epistemology, a second set that aligned with a constructivist epistemology, and a third set who had a mixed epistemology. Logical positivist-oriented students tended to be rote learners who were grade motivated. Constructivist-oriented students sought a deep understanding of the material and used meaningful learning strategies. Also notable in their study was the general lack of understanding of scientific thinking processes in general, including the relationship between actions in the lab, the positing of knowledge claims, and the relationship of knowledge claims to larger bodies of knowledge and theoretical ideas. Their research supported the conclusion that college students are masters of compartmentalizing their knowledge into specific
tracks for specific courses and suggests that these strategies run counter to meaningful science integration.

Tsai’s (1998) study provides strong support for the relationship between learning beliefs and science epistemologies among eighth-grade Taiwanese students. He purposefully identified students from a large pool who tended toward positivist, mixed, or constructivist epistemologies to identify their understanding of both the nature of science and their own learning strategies. Positivist-oriented students viewed science as a “logical and systematic collection of facts” (p. 477): that is static, valid, accurate, and precise, and proceeds by a rigid set of scientific methods. They viewed the ideal teacher as one who told them clearly what to memorize and their learning strategies consisted largely of practicing and repeating the facts and formulas. The positivist students saw little connection of science to everyday life. In contrast, constructivist-oriented students considered science to be an imaginative activity that relates to everyday life, is tentative, and employs a wide range of methods. In terms of learning, the constructivist-oriented students employed strategies such as verbalizing to others, applying knowledge to real life situations, asking questions, and using key concepts.

In a closely related study, Tsai (1999) investigated the relationships between eighth graders’ science epistemologies and their perceptions of laboratory. He found students with constructivist epistemologies tended to negotiate meaning for laboratory more often and were less satisfied with the laboratory learning environment, viewing it as less open-ended and theory related than students with positivist epistemologies. Furthermore, constructivist students thought that lab could illustrate theory, whereas positivist students thought that lab helped them rediscover scientific facts or truths. In summary, Tsai’s investigations of the relationships among science epistemologies, learning beliefs, and beliefs about laboratory suggest that constructivist-oriented students may prefer and possibly learn more from inquiry-based laboratory than would positivist-oriented students.

A third area of the literature related to this study is learning from laboratory. Because this topic has been reviewed many times (Wellington, 1998), we will concentrate on only a few contemporary findings. As mentioned earlier, traditional cookbook labs have been the target of much recent criticism for a variety of reasons including misrepresenting the nature of science, stifling students’ authentic voices, and being of questionable learning value. Although interest in inquiry is on the rise, there are still relatively few contemporary studies of learning from inquiry-based laboratories. In a recent comprehensive study of labsheet guidelines from European countries for both secondary and early college-level sciences (Tieberghien, Veillard, Le Marechal, Buty, & Millar, 2001), the researchers concluded that students were rarely asked to explore relationships, test predictions, or invent concepts. The labs focused on recording observations and there was little emphasis placed on learning about the relationships between domain-related objects and domain-related theory. Students are expected either to construct these relationships on their own or to use theory that has been already taught in other settings. In other words, there is no explicit teaching of how to construct science concepts from laboratory activities.

At the same time, research has shown that students prefer open-ended laboratories. Weaver (1998, p. 463) cited the following dialogue of three high school girls:

F1: I want to make up my own labs . . . I like it when they just say, “Here you go. Go to it.” That makes it easier because then you can find out everything for yourself.
[Two exchanges later]
F3: You learn from your failures . . . And if you turn to the people next to you and you ask, “What did you do?” and you realize, “Oh, that’s where I messed up,” then you kind of understand even more why it happened with theirs and why it didn’t happen with yours.
These girls appear to welcome the opportunity to explore in laboratory on their own, make mistakes, and realize the learning value of different approaches. Similarly, Keys, Yang, Hand, and Hohenshell (2001) found that seventh-grade students mentioned the chance to create their own laboratory questions as a primary factor in their own learning of biology concepts. Henderson, Fisher, & Fraser (2000) found a significantly positive correlation between open-endedness of laboratory and student performance on a lab practical test. Finally, when inquiry-based instruction has been instituted over a long time within a well-designed framework for instruction, it has been shown to be effective in improving students’ qualitative conceptual knowledge (White & Frederiksen, 1998).

Methods

Context of the Study

This interpretive study took place in a college biology laboratory for nonmajors at a large Southeastern university in the United States. The purposes of Organismal Biology Lab (BIOL 1104L) are to interest undergraduate nonscience majors in the remarkable diversity of life, support the construction of basic biology concepts, and acquaint students with the processes of doing science. Our research questions did not probe students’ interest but did probe conceptual understanding and the processes of doing science. In 1999, the course designer (fourth author), inspired by academic seminars on the teaching of biology, rewrote the laboratory manual to reflect a more inquiry-based approach. The new labs were characterized by being more exploratory in nature, providing a choice of observations, containing few step-by-step procedures, and consisting of various problems or challenges for the students to accomplish during the lab time. Many labs consisted of the open-ended exploration of various examples of organisms from each phylum: for example, protists and fungi collected from local sources.

Two major lab activities that each lasted several weeks shaped the inquiry-based nature of this laboratory course. The first activity was known as the ecosystem aquajar. Students in the lab class took a field trip to a nearby lake and made a physical and biological inventory of lake ecosystem characteristics. At the end of the field trip, the students, in teams of four, constructed a mini-ecosystem by collecting soil, plants, animals, algae, etc., and placing them in a plastic jar container. The following week, back in the lab, students could adjust their jars by adding or taking out certain elements. They began a systematic study of their miniecosystems by selecting several physical and biological characteristics to measure over time, such as temperature, pH, dissolved oxygen levels, algae growth rate, bacterial growth rate, nitrate level, phosphate, level, and plant and animal growth. They were explicitly taught the procedures for doing these measurements through written instructions and/or instructor demonstrations. They were required to make predictions for what they thought would happen to their measurements and give reasons in their laboratory notebooks. The student teams continued to monitor their ecosystem jars over 7 weeks, taking measurements and making observations. At the conclusion of the activity, they wrote a laboratory report summarizing their findings, according to guidelines given in the laboratory manual.

The second activity, known as the “experiment,” involved students in taking small samples of lake water from their jars to conduct a controlled experiment of their own design. Students conducted the experiment activity in pairs. They were encouraged to vary only one factor while leaving others constant, and they wrote their own research questions and hypotheses. Students collected data and measurements using procedures available to them from the ecosystem jar activity. At the end of 4 weeks, students recorded their final data entries and wrote a laboratory
report based on an outline given in the laboratory manual. Examples of experiments conducted by
the participants included testing the effects of increased nitrates on bacteria levels, the effects of
increased pH on aquatic plants, the effects of increased phosphate levels on aquatic plants, and the
effects of increased nitrates on algae growth.

Participants

One of the researchers explained the goals and parameters of the study to all students in one
lab section chosen at a convenient time. A total of 15 of 20 students volunteered to participate. For
purposeful selection, the researcher then administered a questionnaire on the nature of science
understandings to obtain a wider range of views of the participants on this topic. We followed the
methodology of Tsai (1998). We adapted a questionnaire developed by Pomeroy (1993) by
selecting 17 items representing the dichotomy between traditional and constructivist views of
science. For example, “Nonsequential thinking, that is, taking conceptual leaps, is characteristic
of many scientists” (high agreement represents a constructivist view). Each item on the question-
naire further asks how certain the respondent is about his or her answer with choices for “guessing,
uncertain, fairly certain, or sure.” This feature allowed us to select only participants who were sure
or fairly sure about their nature of science commitments [see Tsai (1998, 1999) for validation
and reliability information]. The questionnaire was used in this study for the purposes of participant
selection only; we did not include the questionnaire in data analysis, owing to our beliefs about the
limitations of questionnaire data in understanding learners’ epistemological commitments (Elby
& Hammer, 2001).

We selected five participants based on a range of scores on the questionnaire and repre-
sentative of both genders. The range in science epistemologies was chosen as a criterion because
we were interested in how students with different understandings of science would respond to
inquiry-based instruction. Gender was chosen as a criterion so that both male and female responses
to inquiry instruction would be represented. At the time of participant selection, other possible
criteria such as experience in college courses did not occur to us as being salient, although based on
the results this factor might be considered in future studies. The 5 participants included 2 men, and
3 women, all European-American, which is representative of the student population at this
university. Pseudonyms are used in this study. Elliot was a college senior majoring in nutrition,
Brittany was a college junior majoring in exercise science, Brad was a sixth-year college senior
majoring in psychology, Julie was a college freshman with an undeclared major, and Lisa was a
college freshman with an undeclared major.

Procedures, Data Sources, and Collection

This study was an interpretive within-case analysis of learning and epistemological beliefs for
the five case participants described above, relying on qualitative data. Two researchers (first and
second author) acted as participant observers in the weekly lab class. We attended every lab during
the first 9 weeks of the semester when topics related to lake ecology were being studied.

We used a variety of data sources in the study. The primary sources of data included pre- and
postsemistructured, individual interviews. The preinstruction interviews took place as early in the
semester as possible, although most participants had already participated in the first lab activity on
bacteria and may have read the “Lake Herrick Essay,” a rich source of conceptual knowledge for
lake ecology, in their laboratory manuals before the preinterview. The interviews took place in a
conference room near the researchers’ office and lasted approximately 50–55 minutes. There
were four sections of questions in the preinterview. All interview questions may be viewed in the
appendices. Section 1 dealt with learning beliefs to determine students’ views of and techniques for learning science. Interview questions were adapted from Tsai (1998). The second section dealt with the students’ science epistemologies, again adapted from Tsai (1998). The third section dealt with students’ reasoning about inquiry, including their understanding of experiments, and their initial ideas for experimental design, based on a scenario about fertilizer runoff into a lake from a soccer field. The questions were designed by the first author, loosely based on an investigation of the nature of science understandings of young adults conducted by Driver, Leach, Millar, and Scott (1996). The fourth interview section dealt with students’ conceptual knowledge for the topic of lake ecology, using questions designed by the first author.

The postinstruction interviews were conducted approximately 5 weeks after the conclusion of the lake ecology topics in the lab. They were conducted in the same place as the preinterviews and lasted approximately the same amount of time. During the postinterview, the same biology concept questions as in the preinterview were asked of the participants. Also, the same questions dealing with inquiry and experimental design were posed. The learning belief and science epistemology questions were not repeated. Finally, students were questioned on their own understanding of their knowledge growth during the lab, and their views on the sources and nature of their learning. Secondary data sources used for triangulation in this study included field notes, writing in students laboratory notebooks, and their written laboratory reports on the aquajjar and experiment activities (photocopied).

Data Analysis

Interview data on biology concepts were parsed into units representing unique conceptual ideas, transformed into declarative knowledge propositions, and then into concept maps, using an established methodology (Novak & Gowin, 1984). For example, when asked about how algae get their food, one participant, Lisa, responded, “Algae are photosynthetic, and so, they rely obviously on the light for photosynthesis and also, that’s how they get their food. They use photosynthesis to create sugar and make energy and to grow basically.” From this response, the following declarative knowledge propositions were generated: (a) algae conduct photosynthesis, (b) light is required for photosynthesis, (c) photosynthesis is used to get food, (d) the photosynthesis process results in sugar, and (e) sugar is used for energy and growth. From these propositions, appropriate nodes and links were created for a portion of the concept map showing relationships between algae and photosynthesis. The resulting concept maps nodes and links are shown in Figure 9 for Lisa in the central portion of the concept map.

The research group met twice to discuss the process of knowledge proposition generation and the subsequent design of the concept maps. It was learned that focusing on only two major clusters of conceptual growth was most illuminating; clusters for algae and the introduction of fertilizer into a lake ecosystem were chosen. Concept maps were drawn by hand and then adapted to graphical software by two members of the research group. Interview data on questions related to experimental design were mapped using the same methodology. Maps for experimental design are shown in the fertilizer cluster, because we asked the students to design an experiment to test the effects of introducing fertilizer in the lake ecosystem. Mapped Figures 1–10 include concepts from both the pre- and postinterviews. The shape of the node in the figures distinguishes pre- and postinstruction knowledge; oval shapes are ideas generated in the preinstruction interviews and may have been repeated in the postinstruction interviews, whereas rectangles represent new ideas emerging from the postinstruction interviews. Also, science ideas which we judged as scientifically accurate (correct) are represented with regular line thickness, whereas those we judged as scientifically inaccurate (incorrect) are represented with bold line thickness.
Interview data on students’ learning beliefs and science epistemologies were coded using a coding scheme emerging from the data and discussed by the research group. Two researchers coded two participants’ data independently and arrived at a mutual coding scheme. One researcher coded the remaining data and wrote interpretive memos (Miles & Huberman, 1994) depicting each participants’ learning beliefs and science epistemologies. Postinterview questions on students’ metacognition were read several times and compared with their learning beliefs data. Field notes and written report documents were read to confirm initial hypotheses about impacts on student learning as well as biology understandings. From this data corpus, profiles for each of the five participants’ learning were constructed. We did not pursue member checking of the data because the course had ended by the time the data were analyzed, and it was difficult to contact the students. The lack of member checking is a limitation to the validity of our interpretations. However, we believe that having three research team members discuss the data interpretations, and our triangulation with the field notes does establish validity in our study.

Results and Discussion

Julie

Julie readily admitted that science was “not my favorite area of study.” Her learning beliefs interview indicated she is motivated by grades and tries to reconstruct the information exactly as it is represented by the authority (instructor) to replicate it on an exam. Her main methods of learning include drawing, memorization, and verbalization of the material. She is a visual learner who uses charts, diagrams, and pictures extensively in her learning. When asked if she tries to relate science concepts to everyday life she replied, “Occasionally, if I notice something that related to science I would use it. But I don’t go out of my way to relate things to science.” When asked about what strategies she might use when studying difficult science concepts, Julie recognized that her approach to learning was inadequate: “In chemistry, uh, I just eventually figured it out, I tried to memorize. Probably the memorization of formulas. I don’t know if that worked out best because if an equation differed from what I had studied, then I couldn’t really change what I was doing to solve the equation, because I didn’t have that kind of flexibility with what I knew.” Julie’s approach to learning was to try to recreate the science as it was taught, although she realized her knowledge was inflexible and limited in terms of problem solving.

In terms of her science epistemology, Julie, a college freshman, relied on what she remembered from high school science classes. Her description of the scientific method is clearly recognizable as a traditional understanding: “Let’s see, first thing is you have a question and then you would, form a hypothesis about the question, um the question relating to something in science. And then you would set up an experiment to test your hypothesis, answer the question. Then, you would collect your data, review that, analyze and make conclusions to determine whether your hypothesis was correct and what it all means.” This stock response indicates little in-depth understanding of contemporary scientific processes.

Similarly, she indicated elementary understandings of the role of theory in science. At first, Julie described a theory as an entity that hasn’t been sufficiently proven to become a law (a common misconception in high school texts): “getting back to high school definitions . . . um, a theory would be, um, it’s not a law and that it hasn’t been proven to be a phenomenon.” Upon further questioning, she elaborated that scientists use evidence to support a theory—that it is an idea backed by evidence, that it can change with new evidence—and cited the theory of evolution as an example. However, she maintained that the theory of evolution will never be a law because it cannot be proven in a laboratory. Thus, we concluded that Julie’s science epistemology was not highly developed and tended toward a positivist view of science. Julie views science as a
Figure 1. Julie’s pre- and postinstruction concept map for the algae cluster.
Figure 2. Julie’s pre- and postinstruction concept map for the fertilizer cluster.
Figure 3. Brittany’s pre- and postinstruction concept map for the algae cluster.
Figure 4. Brittany’s pre- and postinstruction concept map for the fertilizer cluster.
Figure 5. Elliot's pre- and postinstruction concept map for the algae cluster.
Figure 6. Elliot's pre- and postinstruction concept map for the fertilizer cluster.
Figure 7. Brad’s pre- and postinstruction concept map for the algae cluster.
Figure 8. Brad’s pre- and postinstruction concept map for the fertilizer cluster.
Figure 9. Lisa's pre- and postinstruction concept map for the algae cluster.
INQUIRY-BASED LABS IN NONMAJOR BIOLOGY

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Figure 10. Lisa's pre- and postinstruction concept map for the fertilizer cluster.
body of knowledge that is out there to be memorized or to be discovered by the scientific method. Julie does not particularly enjoy science and does not view herself as a creative part of the scientific enterprise.

Figures 1 and 2 show Julie’s concept maps for learning in the algae and fertilizer clusters. Pre- and postconcept nodes and links in the algae cluster show that Julie added two basic types of knowledge: (a) incremental factual knowledge about types of algae, and (b) a number of misconceptions about algae metabolism and the chemical compounds involved in metabolism. In the center of the concept map, we observe that Julie has differentiated among some types of algae. In her postinstruction interview, she stated the misconceptions that photosynthesis produces heat, oxygen is needed as a nutrient by algae, oxygen is not used algae in metabolism, too much oxygen results in the death of algae, carbon is created from carbon dioxide in algae metabolism, and algae does not engage in respiration. She did make the correct connections that phosphorous and nitrogen are used by algae, although she referred to them as “nutrients,” and her meaning for this remains unclear.

In the fertilizer cluster, Julie made new correct connections between nitrogen and phosphorous in the fertilizer being used by algae and promoting algae blooms in the lake. These blooms would use up resources needed by other organisms. The other main change in the fertilizer cluster is Julie’s description of an experiment that she would create to test the effects of fertilizer on the lake. Her preinterview nodes indicate a vague understanding of tests she might implement to gauge the effects of fertilizer on populations, oxygen levels, and photosynthetic levels. Postinstruction nodes, however, indicate a clear and logical experimental design including, obtaining samples of the ecosystem, constructing control and variable samples, adding phosphorous and nitrogen to the variable sample, and measuring plant growth (Salavina) as a dependent variable.

What may be concluded about Julie’s biology learning in an inquiry-based class in light of her positivist science epistemology and traditional learning beliefs? First, there is evidence that Julie substantially increased her understanding of what it means to conduct an experiment in biology. She moved from vague notions to a concrete experimental design, including both subsumption and progressive differentiation of science ideas. Thus, an inquiry-based experience promoted a greater understanding of the purposes and practices of experimental design for Julie. Second, Julie was comfortable adding incremental facts about algae to her knowledge base. She also began to add some new conceptual understandings about the role of nitrogen and phosphorous in algae metabolism to her knowledge base, although the concepts appear to be somewhat tentative. The addition of facts and some basic concepts that were emphasized often in lab (subsumption) fit in well with Julie’s learning beliefs that basic information presented by the instructor or textbook should be learned.

Also congruent is the limited amount of conceptual knowledge she built from this experience. Without an understanding that she could construct her own biology knowledge, Julie’s learning remained bounded in nature. This was typified by Julie’s own understanding of her biology experiment, which she claimed did not work and could not be explained. Julie may not have believed that she had the constructive power to dig deeper to explain the results of her experiment. The creation of several misconceptions for algae metabolism for Julie is a puzzling phenomenon. Her incorporation of incorrect understandings suggests her inability to construct solid new science understandings from indirect teaching, such as that conducted in the inquiry-based laboratory classroom.

Brittany

Brittany described her ideal learning situation as one “where you have great activities and it’s more of a hands-on type thing, instead of the teacher just lecturing the whole time. And I guess
I understand it better when, it’s, somebody explains something and then we apply it to something. If you can apply it back to life, if it’s something you can use, I think, you grasp onto it better.” Brittany is an active learner who relates hands-on experiences to conceptual learning. She often tries to apply her previous learning to new situations: “I try to go back and use all the things I previously learned.” Brittany also uses verbalization and explanation extensively in her learning: “Uh, my best way is just to, if I really understand something to tell it to someone else. I live with four other girls and a lot of us take the same classes, um, and when we study, if I can explain it to somebody or we can sit down and have a conversations about it, then I know that I fully understand it.” Finally, Brittany realizes the limits of memorization and tries to avoid memorization when possible, “But usually, I don’t try to memorize because, like, it doesn’t help, really . . . but the stuff I’ve really learned, I’ve been able to apply.” Thus, Brittany fits in well with the previous literature’s (Tsai, 1998) descriptions of a constructivist-oriented learner who attempts to make connections, explain, and apply her science understandings.

Epistemologically, we classified Brittany as a postpositivist in that she holds a positivist view that there is an accurate answer to scientific questions, but she believes that hidden factors, prior knowledge, and differences in methodologies prevent scientists from arriving at the truth. When asked how two astronomers could hold different theories about the expansion or contraction of the universe, she remarked, “They’re probably full of knowledge from different, from different areas of study, like some might be, more knowledge in a certain area. . . . But I think, I think that there’s too many. . . . during an experiment, there are many conclusions and I think to get the, you know, the most accurate answer, it takes doing it over and over and over and seeing which one works out the most times.” We concluded Brittany believes there is one answer to a scientific experiment and the job of scientists is to get as close as possible to that one answer. She indicated that theories change because of new discoveries. On a more constructivist note, she indicated her beliefs that science is a “continuing learning subject,” and that scientists “get their ideas just like anybody else gets any, like any normal ideas, you know, just using what you know and trying to take it a step further.”

Figures 3 and 4 show conceptual knowledge growth for clusters surrounding algae and the introduction of fertilizer into a lake ecosystem for Brittany. Data revealed that Brittany added several important biology concepts to both her algae and fertilizer clusters. In the preinstruction interview, she demonstrated a relatively small number of nodes and links for algae and exhibited the misconceptions that oxygen is used by algae to produce energy, such as carbon dioxide and adenosine triphosphate. She expressed clear understandings in the postinterview that algae uses sunlight to conduct photosynthesis like any other plant, that light energy is required for the production of glucose, that glucose is used for growth, and that algae use oxygen and carry out aerobic respiration. She also added several links about algae habitats and types, exhibiting both subsumption and progressive differentiation.

For the fertilizer cluster, in the postinstruction interview Brittany expressed the scientifically acceptable understanding that large amounts of ammonia will be harmful to the ecosystem, owing to the promotion of bacterial growth. She stated that plants must convert ammonia into more usable forms such as nitrates, although she incorrectly named this process (nitrogen fixation). When asked to design an experiment to test the effects of fertilizer on the ecosystem, in the pre-instruction interview Brittany described a logical test for samples of lake water with and without fertilizer. However, her initial idea for the measurement of outcome variables was limited to looking at the death and behavior of fish. In contrast, during the postinstruction interview, Brittany described a clear experimental set up including model ecosystems, treatment and control jars, addition of nitrate to one jar, and the careful monitoring of outcome variables in the ecosystem.
including nitrate levels, pH, dissolved oxygen, and plant and animal growth. Her notion of experiment in the postinstruction interview is more elaborated and differentiated than in the preinstruction interview.

We consider that Brittany added substantially to her biology conceptual knowledge while participating in inquiry-based labs. Although she did not exhibit a completely contemporary science epistemology, Brittany did have learning beliefs congruent with meaningful learning. When she and her partner obtained unexpected results for their inquiry experiment, Brittany actively sought information from the Internet, her teaching assistant, and textbook to reason through an explanation for the results. By constructing an explanation for her anomalous results (having to do with anaerobic versus aerobic bacteria), she significantly contributed to her biology knowledge base. Furthermore, she was able to link understandings about the role of nitrogen in the lake ecosystem and the metabolism of algae together from her various laboratory experiences. She stated that writing her laboratory report was what caused her to learn, and not the actual experiment itself: “Just because you have to put it down on paper and you have to think about it and you have to think about what you’re writing … [you must] think it out.” Brittany enjoyed the challenge and interest of open-ended laboratory. Thus, we conclude Brittany is a constructive, reflective learner who used reasoning and thinking during inquiry and added significantly to her biology knowledge base during an inquiry-based lab.

Elliot

As a learner, Elliot is motivated by interest and a desire to manipulate information that interests him. He is confident in biology and believes he has much prior knowledge, so he filters new information, searching for that which he does not already know. Elliot believes he uses a combination of learning strategies in science including listening, reading, observing diagrams, writing, and verbalizing. Interview data indicated that Elliot has constructivist learning beliefs including strategies for explaining a concept thoroughly to someone else, asking himself questions to see what he does not understand, and using active problem solving techniques that he learned in his gifted education classes. He stated, “It was in third grade or something like that, and it helped me be the learner I am, that I can take any form of presentation and get what I need out of it. That’s what we were taught to do. We were taught to solve problems and use the information that we’re presented to our advantage and take it and make it what we need it to be.” Elliot asserts that interest is a strong motivator for learning; if he is not interested in a topic, “I just won’t learn it because it has no meaningfulness.” Wonder and curiosity are motivating factors for Elliot, not grades. Thus, Elliot has constructivist learning beliefs based on interest and active manipulation of information.

In terms of science epistemology, we classified Elliot as a postpositivist. He exhibited some mixed views regarding the nature of science. He holds a positivistic view that “data doesn’t lie” that there is one set of data that accurately represents the truth. Similarly, he believes that scientific theories change because of new technology that uncovers new information, rather than human invention of new ideas. He views data as a source of infallible evidence. At the same time, he demonstrated a number of more constructivist beliefs including a description of the scientific method as a systematic way of study, rather than a step-by-step formula. He also asserted that scientists can make conclusions based only on their own points of view. Elliot and Brittany had fairly similar conceptions of the nature of successful science learning and the nature of science.

However, unlike Brittany, Elliot did not substantially add to his biology conceptual knowledge base during an inquiry-based lab, as shown by the small and incremental additions
from his preinstruction maps to postinstruction maps for algae and fertilizer concepts (Figures 5 and 6). For the algae cluster, Elliot added one small set of nodes to delineate further the predators of algae as fish, insects, and snails. A second small set of nodes clarified that sunlight was needed as a source of energy to create food for algae, an understanding we suspect he held in the pre-interview but did not express. In the fertilizer cluster, Elliot added the concepts that concentration was an important factor in fertilizer runoff, and that additional nitrogen in the ecosystem may benefit plants.

One area of conceptual growth that occurred was Elliot’s concept of designing an experiment to test the effects of fertilizer on the lake ecosystem. In this area, Elliot moved from a vague notion of sampling pH, populations, insects, and the growth of organisms to a well-defined experimental design for making model ecosystems, including ecosystem elements, such as sediment, and using treatment and control systems. He described adding fertilizer to one model ecosystem and making specific measurements, including, thickness of stem, plant height, and length of leaves. Laboratory experience with designing experiments and monitoring variables may have led Elliot to a richer conceptual understanding of biology experiments.

Like the other two students described earlier, Elliot substantially improved his understanding of a biology experiment. The data indicated he did not add many new links about biological processes. When asked if the inquiry-based lab contributed to his biology knowledge in the postinterview, he stated, “Um, no. I wouldn’t say that increased my knowledge about biology, but it, um, helped me look at things more in depth and more of, in a more critical manner. Um, it made me look at things in a more roundabout, well, you know, all the way around something. You know what I mean?” When pressed to explain further, he stated, “The way it was designed it just helps you sit and think about what you’re sitting there looking at. Not just to look at it and say, ‘okay, this is what it’s supposed to be.’ It made you look at this and understand why, you were looking at it this way and what you were looking for.” Therefore, Elliot appreciated the process of inquiry as an intellectual endeavor. He intimated that inquiry helps you understand why you are looking at a problem, and what you hope to learn from investigating that problem.

We hypothesize that Elliot did not add much to his biology knowledge base because he felt he had a great deal of prior knowledge on the subject and did not take advantage of opportunities in lab to construct more knowledge, despite his apparent ability to do so. For example, Elliot and his lab partner (Brad, described below) designed a simple experiment to test the effect of pH on plant growth. Their experimental findings (that high pH prohibited growth and eventually destroyed plant tissue) provided no major discrepant event or anomalous findings, as did Brittany’s experiment. Because they were not required to provide in-depth biochemical explanations for the findings, they simply reported their data and conclusions in a straightforward fashion and were not propelled to dig deeper for information.

**Brad**

Brad described his ideal learning environment as being similar to a small English discussion class he took. In this environment, he was required to interact with the instructor and verbalize his understandings: “You couldn’t just sit back and take notes and listen to the teacher talk all semester. . . . Like if I didn’t know something, then it showed through when I was talking with my teacher about the stories.” Brad is an active learner who seeks to make sense of science material: “. . . if you’re talking about photosynthesis, if I can list every way, every step in photosynthesis and if it makes sense in my head, you know? Just not know the steps, but understand why they make sense.” Brad described understanding as being able to make connections, “when something clicks in your head.” Furthermore, Brad had a large base of prior knowledge about aquatic
ecosystems before lab instruction owing to his aquarium hobby. When asked if he related science to everyday life, he stated that he actively uses science knowledge to solve problems in his aquarium: “...If a fish gets fungus on its fins or whatever, you’ve got to go through steps to figure out what kind of fungus it is. If it’s really a fungus or water conditions that’s stressing him out...” We characterized Brad’s learning beliefs as constructivist. He actively seeks conceptual connections and uses scientific problem solving in everyday life. In the postinterview, he defined inquiry-based science as answering questions relevant to everyday life.

Epistemologically, Brad can be described as a positivist who places a large amount of confidence in firsthand observations of empirical data. He contrasted science with English in which interpretation has a large role in understanding: “If your teacher tells you this what this person meant by this poem, there’s no real evidence that that’s what they meant. You know? ... But I don’t think science is left up to interpretation as much. It is to a certain extent, but you know, like your biology teacher tells you, ‘This is why the ciliate moves the way it does.’ And you can actually see, well, uh, that makes sense. ... I don’t know if I’m much of one on faith, you know? Just to trust somebody’s word. I like to see it for myself and decide for myself.” Brad made direct connections between singular data measurements and explanations. He described himself as being “very confident” about the relationships between observations of his aquajar and conclusions he made in his laboratory report. He recounted one of these conclusions in the postinterview: “While the microorganisms were up in the water column all the fish were alive, but as soon as they depleted, the fish started depleting too.” Brad was sure of this cause and effect relationship as he relied on the data collected by the group as a source of science knowledge. In keeping with a positivist perspective, Brad believed science has “facts” and that theories change only because new information is discovered.

Brad’s conceptual learning for the algae and fertilizer clusters is shown in Figures 7 and 8. Figure 7 indicates that Brad had a large prior knowledge base for algae biology but that he also added substantially to correct conceptual nodes and links. Before instruction, he stated that sunlight, fish, pollution, and habitat were all factors affecting algae populations and species diversity. After inquiry-based instruction, Brad subsumed nodes for phosphate levels, temperature, and pH, which he described as hydrogen ion concentration, as factors affecting algae growth. He also added a cluster of nodes for different algae habitats, including sediments, logs, grass, top and middle of the water column. He elaborated his nodes for photosynthesis metabolism by stating that photosynthesis requires water and carbon dioxide, and provides food for algae just like a plant. Photosynthesis produces oxygen used by heterotrophs. In the fertilizer cluster, Brad added concepts that ammonia comes from fertilizer and also organic waste, and that it can both provide food for algae and become toxic in high levels. Unlike the other students, Brad did not change his design for an experiment dramatically in the postinterview, although he did mention more specific outcomes variables to measure including types of algae and plant growth.

We conclude that Brad was a meaningful learner who had a large prior knowledge base for lake ecology to anchor the addition of some important new concepts. As an active learner, he made use of inquiry-based experiences that interested him in making conceptual connections. This claim is supported by Brad’s postinterview statement: “It [the lab] gave me a basic understanding, you know, like stuff that was living in the sediment, in the water column ... you were interested in seeing change.” Although he, like Elliot, did not construct a great deal of new understanding from the experiment activity, Brad cited the ecosystem jar activity as having a large effect on his learning. In the postinterview, which occurred approximately 5 weeks after the conclusion of the ecosystem jar activity, Brad demonstrated an intimate knowledge of the jar data and its meaning, “Big air bubbles that were being produced, they just kind of stuck there. ... Our dissolved oxygen readings from week to week; they just kept going through the roof!”
Lisa described herself as a very good memorizer who is motivated by grades: “I can memorize a lot of facts, but, as far as applying the concepts behind those, it’s a little more difficult for some reason. . . . If I can memorize it without having to know why, then I do. That’s the way I have always gotten by, so that’s what I do.” She occasionally relates biology ideas to everyday life, but like Julie, she does not “go out of her way” to make applications. Grades are important to her because she is planning to go to graduate school. These learning beliefs led us to interpret that Lisa is a rote rather than meaningful learner. However, when asked to describe a good teacher, she noted that it is one who “gives the big picture.” She feels she learns best when the instructor clearly lays out the main ideas first and delineates the main ideas from the details. Thus, Lisa may be making some meaningful connections in her learning.

Epistemologically, Lisa is a positivist who believes that in science there is “a definite answer to everything.” She believes that science is a lot like math with clear right and wrong answers. She described the study of science as “You can’t really interpret it your own way. Things are the way they are. It’s more of a definite interpretation.” Her response to the question about dual views of the universe was that there are conflicting views because scientists cannot get enough empirical evidence. Her view is that if data are accessible, the correct answer can be found.

Figures 9 and 10 show Lisa’s conceptual maps for the algae and fertilizer clusters. For the algae cluster, Lisa demonstrated a solid conceptual understanding before lab instruction. She had detailed and scientifically accurate knowledge about algae metabolism including the processes and outcomes of photosynthesis. She also demonstrated knowledge of the importance of temperature, pH, and sunlight on algae population size and diversity in the preinstruction interview. Thus, Lisa added only small and incremental nodes and links in the algae cluster. She added some new nodes about algae habitats and a few other details to her various knowledge branches. Lisa had a large prior knowledge base and added only a small amount of biology knowledge for algae.

In the fertilizer cluster, Lisa added both correct and incorrect nodes and links about nitrogen metabolism. She noted correctly that too much nitrogen can be toxic to heterotrophs. Some misconceptions she developed included: nitrogen in fertilizer is fixed by nitrogen fixing bacteria which turn it into ammonia; ammonia is a useful form of nitrogen in the ecosystem; nitrogen is used by plants in photosynthesis; and nitrogen comes out of plants if there is an overload. The fertilizer cluster also indicates how Lisa changed her idea of an appropriate experiment for determining the effects of runoff. In the preinterview, she suggested sampling the water before and after the runoff events and testing for the type and concentration of fertilizer and the effects on algae growth rate. After lab instruction, she suggested running a series of tests on a certain section of the lake to test for nitrogen levels, plant growth rate and numbers, and related factors such as pH. Her ideas for an experiment became more viable and specific with instruction.

Lisa and her lab partner received unexpected results from their experiment activity. They added nitrogen to one of their sample jars and expected to see growth in an aquatic plant, hornwort. The hornwort did not grow, but the treatment jar exhibited a much higher level of algae growth than the control jar. Lisa noted this fact, yet insisted that they had not added enough nitrate to the jar or the experiment “just didn’t work.” Thus, she never made full connections between the results of her experiment and probable explanations.

What may we conclude about Lisa’s learning in an inquiry-based biology lab? Lisa had largely rote learning beliefs and positivist conceptions of science. Thus, she may not have sought out meaningful connections for her inquiry-based lab activities. Lisa added only a small amount of conceptual nodes and links to her knowledge base and she added quite a few misconceptions. She
stated in the post interview that for her, lab largely reinforced what she was learning in lecture. Although she was mildly interested in the inquiry activities, she did not exhibit a driving motivation to explain her findings or push her conceptual understanding to higher levels.

Conclusions and Implications

Each participant demonstrated unique conceptual ecologies in congruence with the findings of previous researchers (Jones, Carter, & Rua, 2000), despite the same instruction. In the inquiry-based laboratory, students had the opportunity to interact with activities in a variety of ways and each responded slightly differently to the experiences. For example, the experiment activity was a source of knowledge building for Brittany, whereas the aquajär was a source of knowledge building for Brad. Elliot did not respond to a specific activity in terms of learning but became intrigued with inquiry as a way of knowing. There was no evidence that any one event sparked Julie’s or Lisa’s learning. There may have been additional factors affecting students’ learning which were not explored in this study, such as the effects of the lecture portion of the course on the students’ conceptual ecologies, although there was no direct teaching of lake ecology concepts in the lecture. It is also interesting that the three students with constructivist learning beliefs were more advanced in their college careers and those with traditional learning beliefs were both freshman. It may be that students develop a more mature constructivist attitude toward learning as they become accustomed to the demands of college coursework, but this study did not investigate that possibility.

Some interesting parallels, patterns, and dichotomies arose across the cases, although it is important to remember not to draw cause–effect associations in this type of study (Figure 11). First, 4 of the 5 students added significantly to their knowledge base for designing an experiment. It is likely that the inquiry experiment was a significant learning tool for generating a deeper understanding of experiment in science. Substantial conceptual learning was evidenced for both Brad and Brittany. Both students had constructivist learning beliefs which may have promoted their conceptual learning. However, Brad had a positivist science epistemology, putting into question the importance of constructivist views of the nature of science for conceptual learning. Brad had a large prior knowledge base upon which to anchor new biology concepts and an interest in the material. Elliot, also a constructivist and a postpositivist like Brittany, may not have had the time or motivation to use laboratory opportunities such as the experiment to push for further knowledge construction. Both Lisa and Julie tended to be traditional learners, using a rote learning strategy with little problem solving or application. Both also tended to be positivistic in their outlook on science, and both developed small incremental learning, and several major misconceptions.

The data support prior research (Pearsall, Skipper, & Mintzes, 1997; Tsai, 1999) that constructivist learning beliefs are important for building new biology knowledge. However, a constructivist learning belief may not be sufficient to learn from open-ended opportunities, as

<table>
<thead>
<tr>
<th>Student</th>
<th>Learning Beliefs</th>
<th>NOS Beliefs</th>
<th>Conceptual Learning</th>
<th>Key Experience</th>
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<td>Brittany</td>
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<td>post positivist</td>
<td>substantial</td>
<td>experiment</td>
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<td>post positivist</td>
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<td>philosophy of investigation</td>
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<td>Brad</td>
<td>constructivist</td>
<td>positivist</td>
<td>substantial</td>
<td>prediction jar</td>
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<tr>
<td>Lisa</td>
<td>traditional</td>
<td>positivist</td>
<td>minimal and misconceptions</td>
<td>none</td>
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</tbody>
</table>

*Figure 11.* Summary of students’ learning characteristics during an inquiry-based biology laboratory.
shown by Elliot. The data do not support the contentions that constructivist views of the nature of science are always in congruence with constructivist views of learning (as in the case of Brad) or that constructivist views of the nature of science are necessary for meaningful learning (Edmonson & Novak, 1993). None of the participants in the current study held strong constructivist science epistemologies. The data suggest that rote learning strategies did not serve students well in the inquiry-based lab, as indicated by the conceptual maps of Julie and Lisa.

Several implications arise from this study of inquiry-based laboratory. The first is that the data support the continuation and development of inquiry-based laboratories. All students left the lab with a better understanding of the process and purpose of experiment in science. All students were at least mildly interested in the lab and all five indicated in the postinterview that they preferred the open-ended lab to one with step-by-step instructions. The data indicate that there is potential for students to build conceptual understanding from inquiry-laboratory activities, although it appears that tighter instructional scaffolds may be necessary for some students.

A second implication is that although explicit instruction in the contemporary nature of science may not be necessary to promote conceptual understanding, explicit instruction in constructivist learning strategies may be beneficial to students engaged in inquiry. For college science teachers, this could take the form of teaching the thinking strategies of scientists, including forming alternative explanations, active questioning, and constructing new explanations. Collaboration between college science teachers and science education specialists could promote understanding of meaningful learning in college science courses. Strategies such as concept mapping and the Science Writing Heuristic (Keys, Hand, Prain, & Collins, 1999) could be shared with college science teachers and designed into instruction. These overt teaching strategies may benefit students such as Julie and Lisa.

A third implication is that instructional design should be refined in such a way as to push students to ask inquiry-based questions that will increase their conceptual knowledge. Brad and Elliot’s experiment on the effect of pH on plant growth did not facilitate new questioning or knowledge growth for these two participants. This is difficult in inquiry because we desire to have students select problems that interest them. Some mechanisms for teaching about the authenticity of questions, or some assessments that promote the valuation of higher-level questions for able students, should be explored. In a similar vein, instruction for report writing could be honed so that students must create adequate alternative explanations for their findings that go beyond “our experiment didn’t work.” Students should be rewarded through their grades for thinking through the biological mechanisms at a level appropriate to their learning.

Appendix

Student Interview Questions

Part I: Learning Beliefs (Preinterview Only).

1. Describe a classroom situation where you felt you were really learning a subject well.
2. What do you think are your responsibilities as a student?
3. If you are studying a certain topic, like photosynthesis, how do you know when you really know the information?
4. Do you ever try to use science concepts in everyday life?
5. What motivates you to learn in science classes?
6. What was the science topic you found most difficult to learn and why? What did you do to learn that topic?
7. In your opinion, what is a good science teacher like?
Part II: Scientific Epistemologies (Preinterview Only).

1. What sets science apart from other disciplines, like literature or art?
2. Where do you think scientists get their ideas for what they want to research?
3. In astronomy, some scientists think the universe is expanding, some think it is contracting and others believe it is in a static state. How can these different conclusions be possible if these scientists are all looking at the same types of data?
4. Once scientists come up with an explanation or a theory, does it ever change? Why?
5. Please define scientific inquiry, based on what you already know.

Part III. Reasoning about Experiments (Pre- and Postinterviews).

1. In your opinion, is the following an experiment? Why?
   - Astronomer making predictions and then observing
   - Medical student dissecting a cadaver
   - Neurologist testing the effects of the concentration of a drug
   - Biology student making predictions and then observing a miniecosystem
   - Field biologist covering one section of the meadow to investigate effects of light

2. Imagine a scenario in which fertilizer from a soccer field runs off into a nearby lake.
   Will the fertilizer influx change the ecosystem in your opinion? Why do you think so?
   What kinds of tests could you do to see if fertilizer changes the ecosystem?
   Describe any other experiments you would do or data you would collect to see if fertilizer affects the ecosystem.

Part IV. Lake Ecology (Pre- and Postinterviews).

1. In general, what living and nonliving things are part of the lake ecosystem?
2. Tell me all the types of algae you would find in the lake ecosystem.
3. What are some basic biological processes that algae go through in their lifetime?
4. What factors in the lake ecosystem affect the total number of algae there, and the diversity of species of algae?
5. What organisms would you expect to find in the lightest and darkest parts of the lake?
6. Heterotrophs depend on other organisms for food. Tell me all the types of heterotrophs you would find in the lake ecosystem.
7. What are the basic biological processes that heterotrophs go through in their lifetime?
8. What factors in the lake ecosystem affect the total number of heterotrophs there, and the diversity of species of heterotrophs?
9. What do you predict would happen to algae (autotroph) populations when the weather becomes cold in winter, if there were an influx of acid rain?
10. Is there oxygen in the lake? Where does oxygen in the lake come from? Would it ever be in short supply? Why?

Part V. Learning from Inquiry (Postinterview Only).

1. What resources did you use when you were writing your laboratory reports?
2. Describe the process you used to write the report.
3. Was your partner a useful resource? Was the lab teaching assistant a useful resource? How?
4. How confident were you about the conclusions you stated in your reports? Why?
5. Has Biology 1104 Lab increased your biology knowledge?
6. What experiences in Biology 1104 Lab helped you learn the most?
7. Were you comfortable with not having step-by-step procedures for the experiments?

References


