Fostering Inquiry in Nonlaboratory Settings

Creating Student-Centered Activities

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Inquiry is an important learning strategy, even for students who cannot or do not perform actual experiments. We describe two activities, other than experimentation, that we used in introductory biology learning groups to emphasize inquiry abilities. We also provide recommendations for creating additional inquiry activities.

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Inquiry is an effective method for learning both science content and process (Keefer 1998), and science education reforms recommend incorporating inquiry into the classroom as both teaching methods and learning strategies [National Research Council (NRC) 2000].

Although originally designed for K–12 classroom instruction, the National Science Education Standards (NSES) are useful guidelines for college instructors as well (Siebert and McIntosh 2001). In situations where instructors are pressured to cover everything, the NSES (particularly the standards for grades 9–12) highlight the most fundamental elements of content. Also, as presented in the NSES, inquiry skills are relevant to all levels of scientific study from high school through professional research, and so are worthy of increased attention by college level faculty. The application of these inquiry standards to college-level science emphasizes that postsecondary science should ultimately be learned through practice (Siebert and McIntosh 2001). This practice can arise from the design and implementation of experiments and from engagement in other skills, as described in the NRC definition of inquiry.

Using inquiry in the classroom allows students to generate scientific explanations about common occurrences, observations, and other phenomena, thereby constructing knowledge. The NRC operationally defines inquiry as "a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of the student's experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires use of assumptions, use of critical and logical thinking, and consideration of alternative explanations" (NRC 1996, p. 23).

From the NRC's definition, it is clear that inquiry is a process, a mode of learning, and a mode of teaching that encourages the student behaviors described above. Different goals may motivate the use of inquiry in the science classroom, but most science instructors who are interested in student learning address at least some of the aforementioned abilities.

Given that inquiry is essential to science teaching and learning (NRC 1996), it is surprising that so many examples of incorporating inquiry into the classroom center on laboratory investigations, settings, or skills, to the

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exclusion of other scenarios that can lead to inquiry (e.g., Keefer 1998; Uno 1999; Ahern-Rindell 1998; but see Tolman 1999). That is, the majority of examples given in the literature frames inquiry as the ability to perform an experiment while disregarding other abilities necessary for inquiry.

While it is true that science proceeds by experimentation, a significant portion of scientific inquiry is accomplished through contemplation and evaluation (for example, making sense of data or providing evidence-based interpretations of data). For these reasons, we feel that these cognitive inquiry abilities have been neglected. Many good activities centered on inquiry exist; the vast majority of these require laboratory facilities or extended periods of time.

How does an educator include inquiry when constraints prevent laboratory-based investigations? To address that question, we developed inquiry activities and delineated general principles necessary for developing nonlaboratory inquiry curricula. We do not suggest that nonlaboratory inquiry activities should replace lab experiences; instead we suggest that alternative inquiry-based investigations can contribute to learning when lab experiences are not possible.

FIGURE 1

NSES for grades 9–12.

In this article, we apply these standards to college classrooms and lessons. In-text references to NSES are numbered as below. To do scientific inquiry, students need to be able to do the following:

1. Identify questions and concepts that guide scientific investigations.
2. Design and conduct scientific investigations.
3. Use technology and mathematics to improve investigations and communications.
4. Formulate and revise scientific explanations and models using logic and evidence.
5. Recognize and analyze alternative explanations and models.
6. Communicate and defend a scientific argument.

Course Descriptions

The introductory biology sequence at our university consists of three courses—Evolution and Diversity (lecture), Biological Mechanisms (lecture), and Introductory Biology Laboratory. These courses can be taken in any order, and students do not need to take the lab concurrent with either lecture course. The lecture courses meet two or three times per week, enrolling no fewer than 100 students and often as many as 300. Lectures are supplemented by once-weekly 50-minute discussion periods (learning groups), each having 25 students or fewer. These learning groups are led by graduate students or, more commonly, advanced undergraduates.

During the first semester of the 2002–2003 academic year, we attended the different sections of the two lecture courses to identify content themes and attended learning groups to clarify their use. Generally, time in learning groups was spent going over a worksheet students had filled out before class, in a review or question-and-answer session, or administering quizzes or other assessments. The learning groups were integrated with the lectures in content, and 10 to 15% of total course points were derived from worksheets, quizzes, or attendance in learning groups.

Subsequently, we developed several inquiry activities that met the following criteria:

- contains at least one ability necessary for scientific inquiry (hereafter, inquiry ability) as listed in the NSES (NRC 1996) (Figure 1),
- can be completed in 50 minutes,
- emphasizes student interactions,
- costs virtually nothing to implement,
- can be led by an advanced undergraduate, and
- is based on course content.

During the second semester of the 2002–2003 academic year, the faculty chose several of our inquiry activities to include in their learning groups, replacing the standard learning group activities described above.

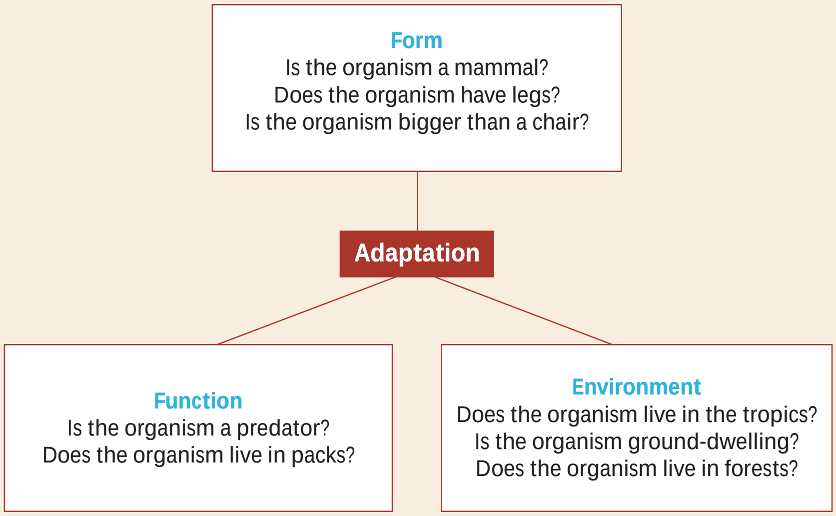
In Evolution and Diversity, seven activities were used during the semester; in Biological Mechanisms, one activity was used in one section and three were used in the other. The faculty individually chose the degree to which the inquiry activities were integrated into the lecture component of the course, although the total course points allocated to learning groups remained the same (students submitted written work that they completed during the inquiry activity as evidence of their engagement).

One professor included test questions covering the activities on the final exam, whereas the two others included the material from the inquiry activities in the lecture and on tests, but not in the same format as during the inquiry activities. Before the faculty implemented the inquiry activities, we trained them via demonstration and discussion during the weekly staff meeting. We then observed the learning groups.

Students were not required to complete any advance preparation for the inquiry activities, in contrast with their typical task of answering several questions on a worksheet. In the semester in question, no assessment of student learning was performed immediately after the inquiry activities. We have since developed pre-activity worksheets on the recommendation of one participating faculty member, short questions asking students to evaluate some component of the inquiry activity (i.e., a one- or two-question quiz), and take-home problem sets for some inquiry activities that allow students to further practice their new knowledge and permit later assessment of student learning. Each of these addi-

FIGURE 2

More informative questions from Exploring Organisms, mapped onto lesson content.



tions is available for use at the discretion of the faculty. Below, we describe two inquiry activities, one used in Evolution and Diversity and the other in Biological Mechanisms, and the outcomes we observed.

Exploring Organisms

First graders ask great questions; they are unbridled in their curiosity. College students ask great questions, but they are often few and far between, possibly because of reticence, fear, or other unknown factors. This lack of questions is especially true in the Evolution and Diversity lecture course. Therefore, we developed an inquiry activity, which was used in the third week of the course, that encourages students to ask questions; asking good questions is an essential inquiry ability [NSES number 1 (Figure 1)].

The activity began with the instructor circulating among students a box of animal-shaped toys (including insects, dinosaurs, fish, and other noncharismatic taxa; pictures could also be used). Each student chose an organism and kept it hidden from other students. In pairs, students attempted to determine their partner's organism by asking only yes-or-no questions, as in the common game "20 Questions." ("I don't know" was often an appropriate and informative answer). They also kept track of the number of questions they asked. After 2 minutes, students formed new pairs and repeated the procedure.

After two to five rounds, the instructor asked students how many questions they had had to ask to identify their partner's animal. Initially, students often required 20 questions or more, and some never guessed correctly in the given time. However, students reported asking fewer questions in the later rounds. When asked to reflect on this trend, students said they had learned to ask more informative questions the more they practiced, and so required fewer questions to guess their partner's organism in later rounds.

They also learned that the order of questions was important. For instance, asking if the animal was a chicken before determining if the animal had wings was an inefficient strategy. By practicing asking questions, students honed in on successful strategies while internalizing the main ideas of informative questions and order of questions.

The instructor also helped students reflect on the content of their questions by asking if particular questions were more informative than others. When students provided their responses, the instructor classified the more informative questions into three categories—form, function, and environment. These general categories describe adaptation, and the instructor used them to emphasize the connection between ecology and evolution. Students then created a graphical representation of the relationship among these categories, thereby taking ownership of the principle. Students shared their models of the interaction among form, function, and environment and were shown one prepared model as another example (Figure 2). In a few cases, discrepancies between student models of the interaction of these categories led to further analytical discussion about their models.

In terms of effect, we found that students engaged in lively interactions and became more acquainted with their peers. Also, Exploring Organisms established that class participation was essential and fostered a feeling of a student-centered learning community. The success of this inquiry activity prompted us to use it on multiple occasions as a training exercise for course staff and as a demonstration to encourage the faculty to use our other inquiry activities.

Sex and Reproduction

Many factors influence reproductive behaviors, strategies, and outcomes. In our experience, students do not appreciate the importance of reproduction to—or integration of reproduction with—most aspects of life. Additionally, students are sometimes surprised and awed by the reproductive strategies of other organisms. To stress the life history aspects of reproduction and tap into the novelty of nonhuman life, we designed an inquiry activity that explicitly makes comparisons among life history traits of both common and uncommon organisms. We incorporated multiple inquiry abilities into this activity, most notably analyzing data [NSES number 4 (Figure 1)]. Sex and Reproduction was implemented in the Biological Mechanisms course.

Working in small teams, students were given a table listing life history characteristics of a selection of viviparous organisms (Table 1). Some data were strategically listed as unknown. The instructor then asked students to answer questions about the possible relationships among the given variables and create an estimate of the unknown data based on their conclusions. Different teams reported their determinations regarding a relationship, possible reasons for that relationship (or its absence), and the missing values. As groups created different estimates, instructors used the opportunity to discuss making extrapolations and how to "recognize and analyze alternative explanations and models" (NRC 1996, p. 175) [NSES number 5 (Figure 1)].

From this inquiry activity, students discovered that graphical representations of data aid interpretation and can reveal the presence or absence of relationships among variables. Other inquiry abilities were mentioned during the student reports to the class. For example, teams were repeatedly encouraged to state their argument and then provide the appropriate supporting evidence [NSES number 6 (Figure 1)]. The content of the lesson, interactions among life history characters, was continually reinforced.

In this inquiry activity, students also ranked body systems in terms of their importance to the human reproductive system (using information from a textbook figure). This short component of the lesson encouraged students to create meaningful criteria and then make judgments using those criteria. As expected, no two groups created the same ranking or used the same criteria, yet students learned that these different ranking systems could be supported by reasonable evidence or arguments. Although students often challenged each other on the merit of the criteria, these challenges led to additional critical discussion of making judgments. This last component of the lesson demonstrated to students that the perspective one uses to make decisions in science can fundamentally alter the outcome of the decision (in this case, the ranking students made).

General Recommendations

Incorporating inquiry abilities into learning groups is easy in some respects and challenging in others, particularly in determining how to focus on inquiry abilities. To facilitate the development of inquiry lessons for nonlaboratory classrooms at other institutions and educational levels, we developed guidelines to help educators overcome the challenges we encountered.

Focus on one to three related inquiry abilities in a given lesson or class meeting. Decide what inquiry abilities to include before deciding on the content. For example, we focused an entire lesson on thinking graphically, [NSES number 5 (Figure 1)] using metabolism as the content. When we tried to cover too many elements, the lesson became muddied and rushed, particularly given short class times.

Ground the lesson in relevant content, and place the lesson appropriately with respect to position in the course curricula. We found that when students require a lot of background before beginning an inquiry activity, the instructor becomes the focus and the inquiry aspect of the lesson is lost. Use inquiry to solidify students' knowledge via applications of new skills to old problems, and do so at a time in the semester when students have already practiced the old problems. Using somewhat familiar content is particularly critical if the primary goal of the activity is the practice of inquiry abilities and the secondary goal is content mastery.

Always debrief students about the lesson. Draw the principles of the les-

TABLE 1

Data on the reproductive cycles of some viviparous animals. This was used in the sex and reproduction activity.

Species		Reproductive information			
Common name	**Latin name**	**Gestation**	**# cycles/year**	**Age at maturity**	**Litter size**
human	*Homo sapiens*	40 weeks	13	13 years	1-2
picked dogfish shark	*Squalus acanthias*	2 years	2	25 years	unknown
house cat	*Felix domesticus*	2 months	every 20 days*	5-9 months	3-5
standard horse	*Equus cabballus*	11 months	every 21-22 days*	10-15 months	1
vampire bat	*Desmodus rotundus*	8 months	unknown	9 months	unknown
Asian elephant	*Elephas maximus*	22 months	4	9-12 years (female) 10-15 years (male)**	1

* Length of cycle depends on photoperiod (length of day)
** Bulls often do not breed until 30 years

son from students, and use their words in a summation to reinforce their inquiry learning. Such summations provide critical feedback to students on their learning. Additionally, having students report to the class demonstrates that instructors expect participation and require accountability.

Ensure that students are active through writing, creating figures, drawing models, preparing flow charts, or doing other tasks that engage the mind. Engagement in the lesson makes manifest the inquiry abilities being practiced in the lesson. These aspects of the lesson are most successful when students work independently or in pairs. We find that in larger groups, some students will become disengaged as their peers work with the concepts. By working in pairs or alone, it is more difficult for students to escape from engaging in the inquiry activity.

Create problems or tasks that cannot be completed by a student working alone but that can be accomplished through collaboration with peers. No scientist works in a vacuum; students shouldn't either. Although not explicitly listed in the NSES as an inquiry ability, working with individuals possessing varying and complementary abilities is a requirement in the practice and communication of science. Developing such a skill will serve all students well.

Design and ask open questions that further inquiry rather than closed questions or set answers to student questions. By preparing questions in advance, one is more likely to rely on instructor-student interactions to facilitate inquiry as opposed to providing answers. Additionally, using these questions at the beginning of any activity establishes that the student, not the instructor, is the primary thinker. For example, if asked "What is the function of cellulose?" the instructor could reply "structural support." Alternatively, an open response would be "What characteristics lead us to deduce a function?" or "What possible functions are there, and how could you differentiate among functions?"

Consider lab activities as sources for nonlaboratory inquiry activities. For example, students need not perform gel electrophoresis to practice interpreting electrophoresis data. Other ideas can be found in textbook figures or the literature. Articles in *Discover* and *Scientific American* are written for intelligent (but not expert) readers, not unlike the biology student population. These articles can be starting points for making connections between evidence and explanation, for example. This journal (*JSCT*) often has articles that can be modified for use in inquiry-based learning groups (e.g., Crandall 1997; instructors could create mock data for students to analyze).

Keefer suggested criteria for inquiry lessons that follow a learning cycle approach. His recommendations are most appropriate for a laboratory setting, and we feel that they are rigid in terms of the roles or behaviors required of students. For example, Keefer states "Students must come to a recognition, on their own, that the approach offered by the instructor has promise in the solution of the problem" (1998, p. 160).

This criterion is valid only in the instance that students haven't created multiple approaches or solutions on their own, a task we feel is central to inquiry. Keefer's sixth criterion calls for "adequate time"; we arrive at a compromise with this criterion in our recommendation to focus on one or few elements of inquiry at a time. Uno's (1999) suggestions are more practical, yet also mostly invoke a laboratory investigation (six of 10 suggestions explicitly suggest some kind of experimentation). These works provide good general guidelines; our recommendations are more relevant to nonlaboratory settings.

We have had great success incorporating inquiry into our nonlaboratory classrooms. Keefer (1998) presented powerful evidence of the long-term retention of concepts learned by students during inquiry activities. We hope to see inquiry abilities and concepts increasingly being incorporated into nonlaboratory classrooms, especially those enrolling nonmajors (as is common at our institution and others like it). With inquiry recognized as a fundamental principle of science and science education, instruction in inquiry abilities should be included in all science classrooms. Should results similar to Keefer's occur in these courses, we can look forward to more scientifically capable students.

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