Lessons Learned About Implementing an Inquiry-Based Curriculum in a College Biology Laboratory Classroom  

By Cara Gormally, Peggy Brickman, Brittan Hallar, and Norris Armstrong

Inquiry-based instruction is widely promoted to increase both students’ conceptual understanding and their engagement in course content. What this means for day-to-day practices in the classroom is more elusive. Instructors adopting inquiry-based curricula often are unaware of the typical instructional challenges they may face. In particular, instructors new to inquiry-based instruction can anticipate changes to teacher and student roles, a shift that may be supported with instructor training and awareness of common student reactions. We describe our experience of developing and implementing an inquiry-based biology laboratory curriculum and offer suggestions to help others successfully implement their own inquiry-based courses.

This familiar scene—students working in small groups on a hands-on activity—seems to be an example of a “best teaching practices” moment. But are students engaged and fully participating in learning and what is required to complete the hands-on activity? Paying close attention to group interactions in our college biology laboratories, we observed two types of group conversations: either unrelated to lab or focused on clarifying procedural-based concerns. Groups spent little time discussing the science behind what they were doing. Instead, students raced through the lab, mindlessly following directions, with one goal in mind: to finish and leave quickly.

Our observations concerned us because students face both personal and societal decisions of a scientific nature. Whether evaluating claims of a new miracle diet or voting for candidates with competing proposals on climate change, students need to be able to articulate ideas in a scientific manner to make well-considered choices. Teaching these skills was particularly important because our introductory biology laboratory class serves ~1,300 students each year, mostly nonscience majors with limited college science experience (32%–45% indicated that this was their first college science course). For many, this is their single experience doing science in college, as most do not intend to pursue further study in science (20% indicated interest in a science career).
Developing an inquiry-based curriculum

A major objective of this course is to help students understand how science is carried out by giving them opportunities to perform scientific research. When scientists conduct experiments, they test ideas by collecting and evaluating data to answer a question. This is very different from the cookbook-style activities we were using, which asked students to follow step-by-step directions to get predetermined results. This approach did not meet our goals, and students rarely had the opportunity to experience the challenge and joy involved in making their own discoveries.

We chose to shift from a teacher-centered to a more student-centered course design to give students challenging and authentic assignments. Student-centered approaches have been recommended by the National Research Council (NRC; 1996), the American Association for the Advancement of Science (AAAS; 1993), the National Science Foundation (NSF), and the Association for Biology Laboratory Education (ABLE). Student-centered approaches have increased student engagement and improved learning gains in terms of exam scores (Ebert-May, Brewer, and Allred 1997; Crouch and Mazur 2001; Tien, Roth, and Kampmeier 2002; Burrowes 2003; Knight and Wood 2005; Smith et al. 2009), and conceptual understanding (Burrowes 2003; Knight and Wood 2005; Smith et al. 2009), and students have demonstrated higher levels of interest in science (Burrowes 2003) compared with teacher-centered instruction of similar content. By adopting student-centered instruction, we hoped to increase students’ conceptual understanding, help overcome their intimidation of science, and cultivate long-term interest in learning about scientific issues.

In 2005, we developed a new curriculum using an inquiry-based approach, the type of instruction that seemed best suited to support our student learning goals. Inquiry instruction includes a variety of activities requiring different levels of complex reasoning used by practicing scientists (Chinn and Malhotra 2002).

Our new labs fall on the inquiry continuum between two extremes: from authentic inquiry in which students choose the research question, variables, and protocol and explain their results in light of other studies and theories, to the other extreme in which students are given a question and protocol and told how to collect and analyze the data. We describe our labs as “guided inquiry,” using Chinn and Malhotra’s (2002) “authentic scientific inquiry scale,” or as process-oriented guided inquiry learning (POGIL) as explained in the POGIL project (www.pogil.org/about).

In guided inquiry labs, the instructor poses an initial problem and uses questioning to guide students in selecting variables, planning procedures, and identifying potential flaws (Magnusson, Krajcik, and Borko 1999; Buck, Bretz, and Towns 2008). This method avoids perpetuating a major misconception: Science only involves completion of simple tasks to confirm or reject hypotheses rather than reasoning about complex methodologies (Germann 1996; Chinn and Malhotra 2002). Guided inquiry provides more direction to students who are unprepared to tackle inquiry problems without support because they lack experience and knowledge or have not reached the level of cognitive development required for abstract thought (Lawson 1980; Purser and Renner 1983). We anticipated that guidance provided by questioning would help lower student frustration while maintaining a high level of intellectual challenge (Igelsrud and Leonard 1988).

Many universities have adopted inquiry lab curricula for introductory courses (Sundberg et al. 2005), but few have systematically assessed the efficacy of this curriculum compared with more traditional lab curricula (a detailed report on effects of our inquiry-based curriculum on student learning appears separately; Brickman et al. 2009). Further, few researchers have examined the experiences of students and teaching assistants (TAs) working in an inquiry-based laboratory for an entire semester. To understand students’ attitudes toward inquiry, one coauthor conducted two one-hour, end-of-semester focus groups with student volunteers solicited from each inquiry lab section (N = 10). Students responded to questions designed to gauge their beliefs on the role of students and instructors in the learning process, as well as questions about their laboratory experience. Individual one-hour interviews with TAs (N = 6) were also conducted; TAs were questioned about their experiences with inquiry, including teaching inquiry, TA training, and perceptions of students’ experiences in the labs.

Instructors shifting to student-centered teaching frequently encounter several common issues, in particular, a change in teacher–student roles associated with a shift in responsibility for learning and negative reactions from students resistant to change (Cooper 1995; Felder and Brent 1996; Weimer 2002; Keeney-Kennicutt, Gunersei, and Simpson 2008). We offer suggestions based on our own experiences, reflecting on what we have learned from implementing an inquiry-based curriculum. We hope to offer insights to educators in the process of adopting inquiry-based curricula, increasing awareness of changes to anticipate in the classroom such as student resistance (Keeney-Kennicutt, Gunersei, and Simpson 2008), and directing the focus of future studies of inquiry-based instruction.

Student reactions to innovative instructional practices

One major difference between student-centered (e.g., inquiry-based)
and teacher-centered classrooms is the shift in responsibility for learning (Weimer 2002; Keeney-Kennicut, Gunersei, and Simpson 2008). In student-centered instruction, students are more responsible for their learning, with the instructor playing a supportive and evaluative role. This change is reflected in the instructional materials we created and, consequently, in students’ roles in the classroom: few “directions” are provided in our lab manual for students to follow. Instead, students work in groups of three to four to investigate a given question, usually based on a real-life scenario (e.g., assessing the health of a stream or determining the optimum conditions for a brewing enzyme similar to project-based science curricula of Schneider et al. 2002; see Table 1). Students are supported by basic content knowledge gained through prelab readings taken from popular science media reports such as a Consumer Reports article on contamination of chicken with

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Laboratory topic</th>
<th>Description of Laboratory activity</th>
<th>Assessment used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scientific process experiments</td>
<td>Students are introduced to the scientific process and learn skills, including how to graph data.</td>
<td>Worksheet</td>
</tr>
<tr>
<td>2</td>
<td>Scientific process experiments Media intro: chimp learning</td>
<td>Students read a scientific report from the popular media and create graphs to represent the data in the article.</td>
<td>Worksheet</td>
</tr>
<tr>
<td>3</td>
<td>Stream quality analysis field trip Media intro: water pollution linked to dog poo</td>
<td>Students collect and analyze data to assess stream quality, and develop an approach to interpret multiple types of data.</td>
<td>Experimental write-up</td>
</tr>
<tr>
<td>4</td>
<td>Stream quality analysis</td>
<td>Students present their findings in the context of what this means for health of the stream, in a format suitable for a general (non-scientific) audience.</td>
<td>Oral presentations</td>
</tr>
<tr>
<td>5</td>
<td>Enzymes I^a Media intro: brewing beer like the Egyptians</td>
<td>Students design experiments to qualitatively measure starch concentrations.</td>
<td>Prelab homework and experimental designs</td>
</tr>
<tr>
<td>6</td>
<td>Enzymes II^a</td>
<td>Students design experiments to quantitatively measure starch concentrations.</td>
<td>Prelab homework and experimental designs</td>
</tr>
<tr>
<td>7</td>
<td>Enzymes III^a</td>
<td>Students design experiments to measure changes in starch concentrations in response to an enzyme.</td>
<td>Experimental designs and lab report</td>
</tr>
<tr>
<td>8</td>
<td>Antibiotic resistance Media intro: Consumer Reports article</td>
<td>Students isolate, culture nonpathogenic bacteria from their environment and design a protocol to identify antibiotic resistant strains.</td>
<td>Experimental write-up</td>
</tr>
<tr>
<td>9</td>
<td>Genetic testing^b Media intro: Huntington's</td>
<td>Students use the Case-It program to identify methods to examine inheritance of genetic traits in a family.</td>
<td>Prelab homework</td>
</tr>
<tr>
<td>10</td>
<td>Genetic testing^b Media intro: genetic testing</td>
<td>Students present their findings from the previous lab in a format suitable for a general audience.</td>
<td>Oral presentations</td>
</tr>
<tr>
<td>11</td>
<td>Genetics I^c</td>
<td>Students design and conduct multiweek experiments to investigate the genotype of a mutant C. elegans.</td>
<td>Problem sets and experimental design</td>
</tr>
<tr>
<td>12</td>
<td>Genetics II^c</td>
<td>Students continue experiments of C. elegans.</td>
<td>Problem sets and experimental design</td>
</tr>
<tr>
<td>13</td>
<td>Genetics III^c</td>
<td>Students analyze their data and describe their experimental findings in the style of popular media reports.</td>
<td>Lab report</td>
</tr>
</tbody>
</table>

antibiotic-resistant bacteria (see Table 1) and guidance from their TA’s active questioning.

Students in inquiry-based courses must modify their perception of their role in the classroom from passive follower to active designer. To facilitate this transformation, we changed our assessments from beginning-of-lab quizzes to writing-to-learn tasks that asked students to document their thought processes throughout each learning unit. In addition, instead of standard lab reports, students wrote reports in popular news article styles, to encourage them to describe their work in their own words. These “writing-to-learn” methods are beneficial for students, as they are asked to organize and analyze their thought processes in a way that encourages transfer of knowledge (McCrindle and Christensen 1995).

Students often expressed frustration about the amount of work involved, as well as the process of struggling to design and conduct experiments. From previous science experiences, they were accustomed to following detailed directions to reach predetermined results. Grappling with failure and confusion, which are sometimes involved in doing science, was at times overwhelming for them. Encouragingly, reports from TAs indicated that students’ strong initial negative reaction to inquiry instruction generally lessened over the course of the semester, similar to previous observations by Sundberg and Moncada (1994) and Keeney-Kennicutt, Gunersei, and Simpson (2008). Although we cannot explicate the process of students’ attitudinal change, both TA and student interview data have suggested that working in groups supported the recognition and acclimation to increased responsibility for learning.

Students repeatedly commented on their newfound abilities as learners and increased understanding of course content. Several students recognized that although they would prefer the easier traditional laboratory instruction, they would not have been challenged to learn as much. This was similar to the reaction of first-year chemistry students, 70% of whom recognized the value of the innovative instruction they experienced, but with few (26%) enjoying it (Keeney-Kennicutt, Gunersei, and Simpson 2008). Our students’ reactions may be explained by findings that the characteristics primarily influencing positive student attitude toward lab are excitement, time efficiency, and relative ease of material (Basey, Sackett, and Robinson 2008). Multiple students expressed an appreciation for their own ability to apply what they had learned to real-life problems, similar to Keeney-Kennicutt, Gunersei, and Simpson (2008). One student summarized what this recognition of changing roles as a learner meant: “You’re used to being told what to do . . . [I] had to take the initiative to start asking questions . . . [n]obody is telling me what to do.” Inquiry lab students frequently expressed that they “understood why” they were doing things and that they were “figuring out rather than just being told,” which led to deeper conceptual understanding of biological ideas and changed their views of themselves as learners.

Although mentioning group work usually elicits groans from students, group interactions and the level of discussion in the inquiry classroom significantly improved. Students commented that collaborative aspects of struggling together were both rewarding and critical to learning in the inquiry classroom. One student explained: “[W]e know that we need to understand it and so whoever understands part A will explain it . . . [i]t’s a learning from each other kind of thing.” Another student explained that group dynamics were “completely different from any group work” he or she had done before because “everyone was so excited about working together and teaching somebody else.” The student went on to explain that this enthusiasm “really helped everybody to learn and got everybody included” so that “moochers” were not a problem in the inquiry classroom. However, students also expressed that group work was at times frustrating because “you’ve got four or five people there throwing out ideas that sometimes aren’t the same and you end up at a standstill,” a feeling that perhaps reflects more frustration with the process of struggling to understand how to design and carry out an experiment than with group interaction.

Other instructors incorporating similar student-centered instruction should anticipate that students may be frustrated as they are given more responsibility for learning and accomplishing a task. To counter this, we explicitly communicated clear expectations and explained the purpose of inquiry-based instruction, setting expectations for students at the very beginning of the semester, as students then felt a greater sense of involvement and awareness of their shifted role (Sundberg et al. 1992; Anderson 2002; Keeney-Kennicutt, Gunersei, and Simpson 2008). Further, instructors must have realistic expectations of the level of challenge involved. For students unfamiliar with inquiry, it may be desirable to begin the course with simpler activities, introducing the approach gradually, increasing the level of difficulty as the semester progresses. We changed the structure of our 13-week lab course, creating 2–3 week lab sequences so that students not only worked on each topic in more depth, but were also able to design increasingly more complex experiments within each lab sequence as their conceptual understanding grew (see Table 1). Changing to multiweek units facilitated the need for significantly more class time for inquiry-based activities, especially those dependent on collaborative group efforts (Keeney-Kennicutt, Gunersei, and Simpson 2008). We believe student frustration with the process of strug-
gling to “figure out” how to address a particular scientific question was an indicator of success—truly engaging students with course content and offering a more realistic view of what it means to “do science.” We encourage instructors to continue to modify their implementation strategies and curriculum as needed, to work through student resistance.

Supporting instructors’ implementation of innovative instructional practices

Just as students are expected to change their role in an inquiry-based classroom, the instructor’s role also changes. Instead of simply telling students what to do, instructors using an inquiry-based approach help students find their own answers by asking guiding questions and having the students describe their ideas both verbally and in writing. Novice instructors often have difficulty implementing inquiry instruction (Gallagher 1989; Crawford 1999), with successful implementation of inquiry-based tasks varying across a teaching population (Luft 2001). Though most of our TAs found teaching inquiry labs difficult at first, and several were resistant to changing their teaching strategies, by the end of the semester most had been won over and said they would not want to go back to the old, scripted versions of the labs. As one TA commented when asked if he or she would prefer to teach an inquiry or traditional lab in the future:

“Definitely inquiry, because the onus is on [the students] to do what needs to be done, not me to tell them, to hold their hand and do everything. . . . The question makes them be on top of things. They know they have to do it for themselves so they really have to pay attention."

The most common problem our TAs experienced was how to help students with guiding questions. It is easy to give too much information, essentially telling students what to do, or too little, causing them to flounder unnecessarily. One TA commented that “students were used to step-by-step protocols [and . . .] they would ask questions to get answers out of the TA instead of seeking answers for themselves.” Using guiding questions is a learned skill that can take a good deal of practice to master. This is especially true of beginning TAs, as many have never been exposed to inquiry-based teaching methods in their own classes. Another difficulty is the apparent “randomness” of an inquiry-based lab. Compared with highly scripted cookbook labs, inquiry labs can seem much more haphazard as students try to find their own solutions to problems. It is not unusual for different groups to use varying approaches and for some to be faster at planning and doing their work than others. Adjusting to the apparent lack of control the instructor has over the lab can be very disconcerting to an inexperienced teacher.

Variability in instructor skill can have a significant effect on student learning outcomes (Akkus, Gune!, and Hand 2007). To reduce variability, instructors new to inquiry-based methods need to be supported in their efforts. This may be through training workshops, mentoring by experienced instructors, collaborative curricular development, and opportunities for self-reflection and assessment of their teaching (Rushin, De Saix, and Lumsden 1997; Luft et al. 2004; Bouwma-Gearhart et al. 2005; Tanner and Allen 2006; Trautmann and Krasny 2006; Schussler et al. 2008; Austin et al. 2009). Our TAs were given two-hour, weekly preparatory meetings as well as a four-hour, presemester orientation to inquiry methods that included participation in an inquiry-based physics exercise—an exercise with basic but unfamiliar content—that helped TAs appreciate how students might experience inquiry activities, observation of videotapes of inquiry and traditional classroom exercises, and discussion of questioning techniques.

Training sessions emphasized the importance of using questioning to redirect the thinking and learning processes back to student groups—questions addressing high-order learning and understanding versus basic procedures. An unplanned but invaluable aspect of the training was the informal peer mentoring that developed between TAs during discussions about teaching and learning in the inquiry labs. TAs also attended a weekly, one-hour semester-long workshop taught in collaboration with the campus’s Writing Intensive Program on how to effectively and efficiently respond to student writing.

Last, TAs were observed twice during the semester by their supervisors and peer TAs, using a modification of the Reform Teaching Observation protocol (Sawada et al. 2002). The follow-up conversations between TA and supervisor, as well as between TAs, provided TAs with opportunities to discuss and reflect on their teaching practices. Many TAs were initially unhappy about the extra time commitment required for training to teach inquiry-based labs. However, most acknowledged that the training improved their teaching skills, and a few indicated it also helped their own speaking and writing skills.

Final thoughts

Inquiry instruction has been widely incorporated in science classrooms in recent years and lauded for enhancing
student learning. Here, we reflected on our experiences of implementing an inquiry-based curriculum for an introductory college biology laboratory. The outcomes from our experience may offer insights to instructors following in our footsteps and alert them to anticipated challenges. We found that adopting an inquiry-based curriculum required not only a substantial investment in curriculum development but also instructor training to facilitate the shift in instructional practices. Further, innovative instruction such as inquiry-based learning is often met with resistance from students as they are challenged to approach problems at a higher level. Similarly, though to a lesser extent, novice instructors may be hesitant to teach using an inquiry-based format because of a perceived lack of control in the classroom and changes in their teaching practices. We cannot overemphasize that developing our curriculum was a long-term process and that it proved essential to incorporate student and TA feedback to fine-tune activities and classroom assessments that were central to creating a successful curriculum.

We caution administrators evaluating the success of innovative instruction that student evaluations cannot be the sole indicator of the quality of instruction. Our inquiry lab students rated their experience lower on course evaluations but exhibited an interesting trend toward a more honest appraisal of their own abilities and an increased appreciation of their accomplishments. A mixed-methods approach incorporating quantitative evaluations and qualitative assessments was critical to effectively evaluate the success of our curriculum. Further, findings from our qualitative assessment proved to be essential for improving our curriculum and enhancing student learning.

References


Brickman, P., and C. Gormally. 2006. The creature from beneath: An inquiry genetics exercise for introductory non-science majors. Paper presented at the conference for the Association for Biology Laboratory Education (ABLE), Purdue University, West Lafayette, IN.


Cara Gormally (cara.gormally@biology.gatech.edu) is a faculty member in the School of Biology at the Georgia Institute of Technology in Atlanta. Peggy Brickman is an associate professor in the Plant Biology Department at the University of Georgia in Athens. Brittan Hallar is a postdoctoral fellow in research administration in the Division of Science and Research at the West Virginia Higher Education Policy Commission in Charleston. Norris Armstrong is an associate professor in the Genetics Department at the University of Georgia in Athens.