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Incorporating Inquiry-Based Laboratories in a Large First-Year Biology Course: Problems and solutions

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Introduction

Biology 231 is the first introductory biology course taken by students at the University of Calgary. Both majors and nonmajors take this course, with a typical class consisting of students who plan to go to medical school, as well as Science, Nursing, Kinesiology, and Education majors. Biology 231 deals with the key concepts in biology (cells as the fundamental unit of life; energy transformations; inheritance of genetic information; natural selection and evolution) as well as the basics of microbiology. Traditionally, the laboratories in this course have consisted of students conducting experiments designed for them. These types of laboratory exercises all too often end up being "cookbook" laboratories, in which the students follow a step-by-step procedure, with little idea why each step is being done, and which often emphasize obtaining a certain "right" answer rather than the process of doing science. Important aspects of doing science such as critical thinking, data analysis and interpretation, are rarely part of this traditional approach. In addition, "cookbook" lab exercises reinforce the role of students as passive recipients of knowledge from an instructor. Many studies have concluded that skills such as critical thinking and experimental design are accomplished more readily through investigative laboratories than by traditional means (Sigma Xi, 1989; NSF, 1990). In investigative laboratories, students become active learners (Glasson and McKenzie, 1997), and the process of science is emphasized (Sundberg et al., 2000). We could see obvious advantages to incorporating investigative labs into Biology 231; however, we could not simply adopt an existing model as the majority of such models were developed by and for smaller institutions with much lower enrollments. Enrollment in Biology 231 can be as high as 1000 students in a single term, which requires 42 lab sections per week. There are only two technicians to prepare material for labs and maintain the lab rooms, so technician workload and logistical concerns were another important consideration.

Another consideration in developing investigative labs was that graduate teaching assistants (TAs) teach all laboratories in this course, and these TAs vary widely in academic background as well as experience and interest in teaching. This situation contrasts sharply with that of smaller institutions where the course lecturer either teaches the labs or at least is able to be present as a resource in all lab sections. Development of investigative laboratories required training and mentoring of GTAs, who had to learn a new and very different approach to teaching. TAs need to be able to: guide students in designing an experiment without telling them what to do; answer student questions with questions without causing too much frustration for the students; and most importantly, be able to deal with such frustration when it arises (Arce and Betancourt, 1997). Students who have been trained to succeed by memorizing correct answers are often angry and discouraged when they first are exposed to inquiry-based laboratories (Sundberg, 1997; Sundberg et al., 2000).

Development of investigative labs and TA training

Given the limitations described above, we believed that a "guided inquiry" approach would be best, in which students are provided with some guidelines as to possible questions to investigate, equipment and materials that can be used, etc. (D'Avanzo and McNeal, 1997) Below is an outline of the general approach we used:

- Lab Week 1: TAs give brief review of the concept or problem under investigation; students learn to use necessary equipment to do a basic procedure (e.g. measure enzyme activity using a spectrophotometer). A series of questions is then posed (such as, "What would happen to enzyme activity at a higher temperature?"). Each group then selects one question that interests them, develops a hypothesis, and designs an experiment to address that hypothesis; students are given a list of equipment, solutions, etc. that will be available to them (a sample experimental design sheet used by the group to guide them in this process is shown in the Appendix). Groups discuss their experiment with TA; feedback from the TA helps them refine their design, which will be conducted in the following week.

Each module requires two to three weeks to complete, depending on whether student reports are to be oral or written:

- Lab Week 2: groups carry out their experiments, and begin to analyze their data. In between weeks 2 and 3, students will examine the scientific literature for information to help with interpretation.
- Lab Week 3: Oral presentations (present their findings and conclusions to the class). In some modules, students will hand in written reports instead, and the module will take only two weeks.

This basic approach was repeated several times over the term; in some labs, the investigative approach was either one component of a lab (e.g. used in the "osmosis" component of a microscopy lab) or was the only activity for the lab period.

Training of TAs

Currently, all TAs in our department are required to complete a 2-day workshop that covers common problems and challenges in teaching biology labs, such as handling disruptive students; problems and concerns related to marking; creating a positive lab environment. In the first year that these investigative labs were introduced, TAs in Biology 231 received additional information and mentoring on issues specifically related to teaching investigative labs (student learning styles; teaching strategies for inquiry-based teaching; use of guiding questions to direct students' thinking). This training consisted of background reading, discussion at the first TA meeting, with follow-up at weekly TA meetings.

Evaluation of investigative labs

Following consultation with colleagues in the Faculty of Education, qualitative evaluations were designed for students and TAs (Sundberg et al., 2000); the questions asked in these evaluations are given in the Appendix. The majority of TAs (all but 2 of 16) reported better satisfaction with teaching these labs vs. "traditional" ones. Below are samples of comments from TAs:

> "Great to see the students being able to apply scientific design into experiments —learning themselves instead of being told. Throughout the term, the design worksheets were becoming second nature to them (without my telling them what to do); that is a sense of accomplishment!"
>
> "I really like the set-up for the labs this year. From teaching last year's labs, I find that this year the students are understanding more of why they perform certain steps…I am able to interact more with the students."
>
> "I had a huge sense of satisfaction teaching these labs. Because the students had a lot more freedom in their choice of experiments, we had a lot of one-on-one discussion… and I got to bring in some of my own research experience. I felt more like a guide in their education rather than someone just shooting out facts and instructions."
>
> "I think the more independent approach worked well and fostered more questions from the students. I think that this approach is good for the students and increases their interest in the different subjects."
>
> "There is definitely more interaction between the TA and students in this approach. The fact that they ask more questions also makes me think more and prepare more."
>
> "This new method was much more interesting to teach. It kept me on my toes [and] made it more interesting in marking — not all of the reports were the exact same experiment.
>
> "Group work made it much easier on me. Instead of 24 students asking me questions, only groups asked — much better! However, I had one group where one member did not contribute to the group discussion at all; this greatly upset the other members."
>
> "They are …less wary about asking a question and more enthusiastic about what they are doing. [But] some team members tend to take things easy since they know the others will get it done anyway."

> "[This approach] brings out their creativity and really reflects the difference between "good" students and satisfactory students."

Problems identified by the TAs fell into two main categories: student frustrations and TA anxiety. Many students were accustomed to laboratories in which they followed step-by-step directions to obtain a single "correct" answer and many students were worried about doing the "wrong" experiment or getting the "wrong" results. Some TAs expressed concerns that students would give them poor evaluations if the experiment "didn't work" (in the students' view). For this reason, or if the TA was not comfortable with guiding rather than directing students, some TAs resorted to telling students what to do. The variability among TAs in terms of the level of direction given to students was a significant problem from our perspective. Some TAs reported feeling anxious about teaching these labs because they did not know what would happen, or what questions might come up.

Student Feedback
A large majority of students (~85%) had a positive response to these labs. Typical student comments were:

> "[This approach] increased my interest because it made us think, not just follow instructions."
>
> "I liked this approach because you could do your own experiment on what really interested you, that was different from other peoples' experiments."
>
> "Gave me hands-on experience of what biologists do."
>
> "Forced us to understand the topic and to think for ourselves."
>
> The best thing about these labs for many students was the group work:
>
> "Working in a group helped me understand ideas I didn't understand on my own."
>
> "[Group work] was my favorite part of the lab; I learned from others and it was a good way to meet people."

The major problems identified by students were: anxiety about getting the "right" results; problems with others in group; feeling that they were spending too much time designing experiments and not enough time actually doing the experiment.

Future Directions

Our overall assessment of the new investigative labs, based on our observations as well as on comments from TAs and students, is that they are a valuable addition to our laboratory curriculum; the majority of both TAs and students found the new labs not only were more interesting but also helped the students understand topics better. This year, we are making changes to address the major problems that arose this past year: (1) the inconsistency among TAs in terms of level of guidance given to students and TA anxiety about teaching investigative labs; and (2) ineffective student groups.

It is likely that, as TAs become more familiar with this approach to labs, they will become less anxious about their role. However, expanding the training of TAs will also be necessary. As mentioned above, some training specific to investigative labs was done at the start of the term and follow-up discussions were part of the weekly TA meetings. However, most of the follow-up discussions were reactions to problems that had arisen, rather than ways to head off problems. We plan to hold more formalized and intensive training in a one-day workshop on teaching strategies for investigative laboratories at the start of each term. We will involve TAs who have taught these new labs, who can share information about what problems are likely to arise, and make new TAs more active participants in the training process, e.g. use role-playing exercises to give GTAs a feeling for how these new labs will operate.

To minimize problems, with student groups, we can change the composition of groups periodically. We will also provide more guidance to both students and TAs on creating and maintaining effective groups, so that we can (hopefully) prevent problems arising in groups rather than trying to solve them after the fact.

We would like to thank the participants in our mini-workshop for the interesting and helpful discussion, and we would welcome any additional comments or suggestions.

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Appendix

Sample of Design Worksheet used in Biology 231

1. What is the question/problem that you are investigating?
2. What is your hypothesis? What is/are your prediction(s) if your hypothesis is supported?
3. What will be the manipulated (independent) variable? What will be the responding (dependent) variable(s)? Indicate units for your measurements, and how you will summarize the data (e.g. ml/sec, mean +/- SEM, etc.).
4. What is/are your control(s)? What variable(s) will you hold constant?
5. How many replicates will you have for each treatment and the controls? Consider how long it takes to make one observation/measurement and how much time you have.
6. Outline the step-by-step procedure for making a single observation/measurement; be specific about the parameters (how many, how long, when, how much) and the equipment needed for each step. This must be clear and detailed enough that someone else could repeat it.
7. How will you summarize, analyze and present your data (in a table? a graph? what kind of graph? why?)

Evaluation of new labs in Biology 231: Questions for TAs

This fall is the first term in a new approach to the lab component of Biology 231. In the past, all labs were planned out completely for the students, and students followed a detailed outline of steps to carry out each lab. As you know, in this new approach, students design and carry out their own experiments. We will be continuing to refine and modify this approach, based on feedback from students and TAs in this course. Your input is critical to make these labs a better learning experience for students.

1. How would you describe your sense of satisfaction about teaching in Biology 231 labs this term, keeping in mind your previous experience teaching "traditional" labs?
2. To what extent did the approach used in the labs affect your interest in teaching in this course?
3. Can you identify ways in which teaching in these labs complemented your research program?
4. How did the fact that these labs involved students working in groups affect your experience?
5. What aspects of this approach to labs (i.e. having students design and carry out their own experiments) do you feel worked well?
6. Please describe any aspects of this approach to labs (i.e. having students design and carry out their own experiments) that you feel need more refinement.

Evaluation of new labs in Biology 231: Questions for Students

(This form had the same introductory paragraph as did the form completed by TAs, above).

1. To what extent did the approach used in the labs (students designing and carrying out experiments) enhance your interest in biology?
2. To what extent did the approach used in the labs enhance your interest in engaging in research?
3. To what extent did the approach used in the labs affect your willingness to attend the labs?
4. Can you identify any ways in which these labs helped you integrate lecture and lab material, or helped you understand lecture material?
5. How did the fact that these labs involved group work affect your experience?
6. What aspects of this approach to labs (i.e. having students design and carry out their own experiments) do you feel worked well?
7. Please describe any aspects of this approach to labs (i.e. having students design and carry out their own experiments) that you feel need more refinement.