Reinvigorating Introductory Biology: A Theme-based, Investigative Approach to Teaching Biology Majors

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Reinvigorating Introductory Biology

A Theme-based, Investigative Approach to Teaching Biology Majors

Making Science More Meaningful at an All-Women’s College

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The biology department at the College of St. Catherine in St. Paul, Minnesota, a private liberal arts college for women, recently developed and implemented a theme-based, investigative introductory biology curriculum. Faculty began this process of reform after intensive self-assessment and reflection and in conjunction with a campus-wide “Women in Science” initiative.

Although our biology majors had definitely learned their share of content and most, by their senior year, had learned to think like scientists, we had high attrition rates among potential majors between the first and second years. It became obvious to us that our traditional introductory course suffered from many of the problems identified and described by those involved in curriculum reform (Project Kaleidoscope, 1991 and AAAS, 1990).

The hierarchical approach of studying atoms, molecules, and cells on up to ecosystems was simply boring and unconnected to the issues facing most students in their daily lives. By adhering strictly to a lecture format and “cookbook” laboratory exercises, we were perpetuating a passive classroom climate in which the professor had all the answers and the students were receivers of that knowledge. By performing experiments where the outcome was known in advance, students rarely experienced the creativity and challenge produced when addressing biological problems. They sought the “right” answer and hoped that their experiments would “work.”

A review of science curriculum and pedagogical literature (AAAS, 1990; Project Kaleidoscope, 1991; Tobias, 1991) indicates that students, women in particular, become more interested and motivated if they are actively involved in the process of doing science. If scientific information is presented in a context of relevant social issues rather than strictly as content, and it relates to their experiences as well as to other disciplines, students remain more interested and engaged in the learning process. We wanted to make the class-
Table 1: Examples of Research Questions Posed by Students in Introductory Biology Laboratories.

- What is the effect of the order of mating on paternity in Drosophila melanogaster?
- Does the pond snail, Helisoma trivolvis, have preferred sites for egg laying?
- Do differences between Hmong and Caucasian cultures affect pregnancy, labor, and delivery?
- Do mice caged together exhibit estrus synchrony?
- Do different sugar sources have an effect on growth of Escherichia coli?
- Which mechanical stress (shaking, wind, or human touch) causes the greatest thigmomorphogenic response in the tomato plant, Lycopersicon esculentum?
- Do squirrels that experience daily human contact accept a wider variety of food types than those in more "natural" habitats?
- How does soil texture affect soil acid buffering capacity?
- How does light regime affect regeneration in Planaria?

room more interactive and to encourage students to take responsibility for their own learning. Faculty could then act more as mentors than the source of all knowledge, modeling how to think critically, solve problems, and work collaboratively.

In 1992, funded by a National Science Foundation Course and Curriculum Development Grant, we began intensive curriculum reform of our introductory course with the following objectives: 1) to provide a classroom climate that fosters collaboration and self-directed learning and minimizes lecturing by the professor, 2) to teach science in a manner that emphasizes process over content and stresses connections to the students' personal lives, other disciplines, and societal issues, and 3) to offer students laboratory experiences that model the way to acquire scientific knowledge.

IN THE CLASSROOM

We have developed two semester-long courses taught in thematic units. The first semester features a human biology course entitled “Biology of Women,” which examines issues in women’s health and reproduction. The second semester course, “Environmental Interactions,” focuses on plant biology, ecology, and evolution and centers around interactions between organisms and their environment. The courses are organized according to theme topics and the basic biology is taught on a “need to know” basis. For example, in order to understand the menstrual cycle, the students must be familiar with the structures of the reproductive and endocrine systems, cell and membrane structure, and the mechanism of hormone action.

The lectures include most of the basic principles taught in traditional courses, but integrate these principles with discussion of practical issues relevant to students. When studying reproduction, we address decisions about contraception and reproductive technologies as well as the underlying biology necessary to understand these topics.

We have also changed the format of the courses by reducing lecture time from three to two hours per week. With a shorter lecture period, we hope to encourage and foster students’ abilities to learn certain concepts on their own. The instructors provide students with study questions to guide their reading and give them clear expectations of what they are to learn. In addition, we placed course materials on Hypercard tutorials developed by one of our biology majors (Tharaldson, 1995). These tutorials address topics covered in lecture, but from a different perspective—biological processes are introduced in an interactive format, and diagrams are animated to show the truly dynamic nature of biological systems. The tutorials also include concepts and information not explained in lecture. Students may access the information on their own time and at their own pace, and self-tests are available at any point during the session.

Students meet one hour per week in discussion sections mediated by a faculty mentor. Together they solve problems, apply what they have learned to relevant issues, analyze case studies, and teach one another, with the faculty “coach” guiding them and helping them sort through material. The entire department is involved in this aspect of the course, as each faculty member serves as a mentor for a group of eight to 12 students. The students are therefore exposed to a variety of teaching styles and approaches. They receive one perspective in lecture, another in discussion, and yet another in their laboratory section.

IN THE LABORATORY

Perhaps the most dramatic change we have made is in the laboratory session, where students initiate and design semester-long research projects. Our philosophy is that the laboratory experience should model the scientific process. Each semester the instructors chose a theme. (Two instructors, usually the lecturer and a laboratory instructor, are present in each laboratory section.) The topic is related to lecture themes but does not correspond directly to lecture topics, as is usually the case in traditional labs. Originally the themes were fairly narrow (“Vaginal Microorganisms” for the first semester, and “Acid Rain” for the second), but they have now been broadened to “Reproduction” and “Organisms and Their Environments” to allow for more variety in projects and techniques. Expanding students’ choices of research projects

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has allowed for a greater degree of creativity and further enhanced student interest.

During the first few weeks of the semester, the instructors present the general laboratory topic, usually through discussion, a film, and scientific literature. The students then work in groups to generate questions based on what they have learned. The questions are divided among students who are responsible for researching more information and reporting their findings to the group. During this time, the instructors also introduce basic laboratory equipment and techniques, e.g., using the microscope, soil and water testing, field sampling, etc. Teams of three or four students then begin to formulate a specific research question and design a set of experiments to answer the question they are asking. (See Table 1 for examples of student-generated questions.)

Each team submits a research proposal that outlines their question, hypothesis, and the specific experiments they will perform. An extensive laboratory guide (Gildensoph, et al., 1995) that includes sections on searching the literature, designing experiments, graphing, analyzing, and presenting data, and writing scientific papers is available to aid them in their tasks. The instructors review the proposal and consult with each group, providing practical suggestions and encouragement. Following the revision and refinement of experimental plans, the teams conduct research in the laboratory or field for the next six weeks. Teams meet weekly with the instructors during their regularly scheduled laboratory time to assess progress, discuss group dynamics, and troubleshoot. As students gather data, they must rely on the computer as a research tool for both analysis and presentation of their results. Their training consists primarily of hands-on experience with spreadsheets, graphing, and word-processing.

Unlike the traditional laboratory, the “research lab” becomes filled with a range of organisms and equipment as the students are involved in a wide variety of projects. In the past two years, students have measured the effects of physical manipulation on tomato plant growth, observed the effect of acidification on goldfish, looked at the effect of “home remedies” on in vitro growth of vaginal yeast, assessed menstrual synchrony in college dormitories, investigated the effect of temperature on mouse development, and the list goes on. Each semester is different as 15 to 20 groups of students pursue research questions of their own choosing.

After students have finished the investigative phase, they interpret their data. Interpreting results often proves challenging for all involved (including faculty mentors) as many student experiments are original research. Finally, the research teams submit a paper to the instructors in draft and revised forms. Fall semester students present posters of their work to classmates, biology department faculty and students, and the wider campus community while during the spring semester, students prepare oral presentations. Throughout the process, students function as scientists in the quest for answers to questions they have posed; professors function as guides and collaborators rather than experts with all the answers.

**Skill Development**

So what have the students learned from this course sequence? They have been introduced to basic biological principles in areas of cell biology, anatomy, physiology, genetics, microbiology, plant biology, ecology, evolution, and behavior, areas usually covered in more traditional courses. In addition, they have been taught to gather, critically read, and synthesize scientific information from a variety of sources. They have developed critical-thinking and communication skills by working in small groups to solve problems, both in discussion sections and laboratory research teams. Lastly, they have learned to use the computer as a research and communication tool.
Table 2: Evaluations of Introductory Biology Laboratory, Fall 1994. (Percentages are based on 71 student responses.)

<table>
<thead>
<tr>
<th>QUESTION</th>
<th>STRONGLY AGREE</th>
<th>AGREE SOMEWHAT</th>
<th>NEITHER</th>
<th>DISAGREE SOMEWHAT</th>
<th>STRONGLY DISAGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am confident with equipment and techniques in the laboratory</td>
<td>53%</td>
<td>20%</td>
<td>14%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Instructors usually decide the best way to carry out the laboratory</td>
<td>13%</td>
<td>20%</td>
<td>34%</td>
<td>17%</td>
<td>17%</td>
</tr>
<tr>
<td>experiments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students make most of the decisions about how to carry out experiments</td>
<td>56%</td>
<td>35%</td>
<td>5%</td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>in consultation with the instructors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have used creativity to solve a problem this semester</td>
<td>48%</td>
<td>41%</td>
<td>10%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>I could design an experiment to answer almost any question about the</td>
<td>32%</td>
<td>50%</td>
<td>12%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>some biological system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I felt like I knew more about my project than did the instructors</td>
<td>45%</td>
<td>23%</td>
<td>23%</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>I missed out on some basic biological concepts by not doing traditional</td>
<td>3%</td>
<td>20%</td>
<td>15%</td>
<td>23%</td>
<td>34%</td>
</tr>
<tr>
<td>laboratory exercises</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At the beginning of the semester I felt confident using computers for</td>
<td>37%</td>
<td>30%</td>
<td>13%</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>word processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By the end of the semester I feel confident using computers for word</td>
<td>75%</td>
<td>23%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At the beginning of the semester I feel confident using computers for</td>
<td>3%</td>
<td>16%</td>
<td>9%</td>
<td>30%</td>
<td>38%</td>
</tr>
<tr>
<td>data presentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By the end of the semester I feel confident using computers for data</td>
<td>48%</td>
<td>30%</td>
<td>6%</td>
<td>6%</td>
<td>3%</td>
</tr>
<tr>
<td>presentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This laboratory experience has been exciting and has increased my</td>
<td>58%</td>
<td>34%</td>
<td>5%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>interest in biology</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Most importantly, they have practiced obtaining scientific information in the lab—conducting experiments like a professional researcher. They have also learned the importance of creativity, innovation, careful planning, hard work, and critical analysis. Their newly-acquired laboratory skills are highly project dependent; students master only those skills needed to answer their specific question, which may be different than the skills acquired by another team. Our second-year courses (cell biology and genetics) are more skill and technique oriented in the laboratory, ensuring that students will learn extensive laboratory skills before they graduate.

WHAT DO THE STUDENTS THINK?

Each semester, students evaluate the courses and laboratories as part of the process at The College of St. Catherine. In addition, we have developed our own evaluation process that includes an objective/quantitative evaluation of the course, written comments, and exit interviews with a faculty member not involved in the grading process.

In general, student response has been overwhelmingly positive. In the classroom and discussion groups, they are vocal and questioning. They are able to learn on their own and score well on exams, even when a concept has been self-taught. For example, the students learn reproductive anatomy on their own, using their books, Hypercard stacks, models, and diagrams available in discussion groups, and they perform consistently well on this section of exams.

The same is true in the laboratory, although students are initially hesitant about this approach. In the first few weeks they lack confidence in their abilities to design a research project and seem overwhelmed by the open-ended nature of original research. However, as they become more involved in their projects, they become more focused and self-motivated.

Students appreciate the freedom to test their own ideas. They are excited by the material, and the process of research makes them feel important. The students truly feel like scientists and seem to gain an appreciation of science as a creative, although sometimes frustrating endeavor (Table 2). By the end of the first semester, they are confident of their abilities to work with the equipment and to apply what they have learned to a new project. This self-assurance is evident as students go on to the second semester and begin another project with a new group—they are eager to begin and know they can do the research.

Students enter the fall course with varying computer proficiency (Table 2). Student experience with word processing varies, depending on their high school and home experiences. By the end of the semester, however, 99 percent feel confident writing papers on the Macintosh. Most students are initially much less secure using the computer as a data analysis or presentation tool, but again, by the end of the semester 84 percent report confidence in their computer abilities. We have actually observed first-year students instructing third- and fourth-year biology majors in a new graphing program!

The program makes students feel part of a community of scholars, an important facet of their education as young scientists (PKAL, 1991). This is probably largely due to the fact that the entire department is involved with the course and has been actively involved in the process of curriculum reform. One faculty member teaches the lecture portion of the course in the fall and another in the spring, two faculty members teach each lab section, and all seven full-time faculty members guide discussion sections. Faculty also try to attend poster sessions and oral presentations. This par-
ticipation does not go unnoticed by students. "I am really impressed with how the whole department works together and all are involved in our education," wrote one woman on her final course evaluation.

WHAT DO THE FACULTY THINK?

Biology faculty are also excited about the curriculum reform. Although the work load seems tremendous, the positive response of students and the challenge of presenting material in a new way is much more rewarding than teaching in the traditional setting. The faculty are also encouraged to see students becoming confident, active learners and intellectually stimulated by the new data in the lab—a much greater challenge than trying to determine why a tried and true experiment just did not work this time.

Since all faculty are involved, common concerns and issues emerge, and we spend time as a faculty talking about methods of teaching and learning in all the courses we teach. The process and the results of this reform have increased collegiality within the department and have promoted continuing efforts to actively engage students in their learning. The impact of the course changes is beginning to be felt on campus beyond the biology department as well. Discussion of our approach with colleagues from other disciplines has generated interest and provoked others to consider making curricular and learning environment changes.

IMPACT ON THE BIOLOGY PROGRAM

Perhaps the most concrete evidence that this curricular reform is working is the increased retention of students, both from first to second semester (Figure 1) and from the first-year to the second-year major courses (Figure 2). Overall enrollment has increased in the first year courses; in 1989 first semester enrollment was 37 and in 1994 it reached 76. Second semester enrollment has increased from 29 to 51 during the same time period. We now teach four laboratory sections of approximately 20 students in the fall and three sections of similar size in the spring. Registration for the second year courses (cell biology in the fall and genetics in the spring) has more than doubled in the past three years from an average of 20 students in each course during the 1992-93 academic year to over 40 in 1994-95.

Another measure of how well the program works is the improved attitude and preparation of students in these second-year courses. Faculty teaching these courses report that students are actively engaged in scientific explorations and have the ability to recognize good research. They understand the value of questioning how and why experimental procedures are used, and do so regularly. They are also more willing to reflect on the significance of each step in an experimental protocol. In class, students are more interactive and question more than past groups. They see that active engagement during lecture enhances their learning.

SUMMARY

The theme-based, investigative approach to teaching introductory biology offers faculty a way to emphasize the process of science over content. Students are excited by what they are learning and become actively involved in their own education. The independent research project teaches students how to acquire scientific knowledge and convinces them of their ability to become scientists. The format also serves as a model for keeping interested students in the program, rather than filtering them out like some traditional programs do if students cannot or will not compete. The small group sessions with faculty members, in both discussion sections and the laboratory, help these first-year students feel part of a learning community, particularly when the class size climbs above 80.

In many institutions, introductory biology already has very large enroll-
ments (often 100, 200, or more), so one might ask if this approach can work as class sizes increase. We answer with an enthusiastic, yes! The thematic approach can be applied regardless of class size, and smaller discussion groups can be led by teaching assistants. Independent laboratory projects require no more supply money or equipment than traditional laboratories, and since students use a variety of equipment, long lines at one or two shared pieces of equipment would be eliminated. Faculty time becomes more valuable in the laboratory since projects are varied and students often need individual training in techniques. Well-trained teaching assistants could play an important role here as well. We have been fortunate to have administrative support so that two faculty members are present in each laboratory section.

The curriculum reforms described here have proven extremely effective with our women students, but they are the types of changes that can enhance the learning of all students, particularly freshmen (Erickson and Strommer, 1991). As students become active participants in the learning process and are given the freedom to be creative, they are truly stimulated.

While reforms have enhanced student learning, they have also been very good for our faculty. The process has garnered energy and support for innovative teaching techniques, enhanced communication among colleagues, and given us a shared vision for teaching and learning biology. The changes have certainly been successful for our biology program, and we advocate this approach not only for science but for all disciplines.

Figure 1. General Biology enrollment from 1989 to 1995.

Figure 2. Upper division Biology course enrollments from 1989 to 1995.

Notes
Anyone wishing additional information about this project can contact Dr. Cynthia Norton (address based on bottom of page 121). We will provide syllabi, suggested readings, the laboratory guide, and information about the hypercard stacks.

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