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Suggestions for manuscripts include: announcements, web site and book reviews, labs/field studies that work, course development, technological advice, software reviews, curricular innovation, history of biology, letters to the editor, undergraduate research opportunities, professional school, funding sources, current issues, etc.

Deadenlines for Submissions
July 1, 2002 for the August 2002 Issue
November 1, 2002 for the December 2002 Issue
Evolution Lab with *Drosophila*

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**Abstract:** In order to demonstrate certain aspects of evolution, a hands-on laboratory exercise was designed. Two distinct populations of *Drosophila*, wildtype and *ebony*, were used in the exercise. *Ebony* flies were chosen for three reasons: 1) they can be distinguished by the naked eye from the wildtype morph; 2) the allele causing *ebony* phenotype is recessive; and 3) they have a decreased fitness in comparison to wildtype flies. Each one of these characteristics helped simplify the mechanics of the experiment. Given an introduction on raising *Drosophila*, Mendelian genetics, and population genetics, students were well prepared to conduct the exercise, predict the outcomes, and analyze the results. Students displayed their understanding of the semester long exercise by writing a journal article based on the results and participating during an open discussion period about Mendelian genetics and population dynamics.

**Keywords:** evolution, *Drosophila*, laboratory exercise

**INTRODUCTION**

Students tend to learn about evolution at the macro level through textbooks and at the micro level through games. Few laboratory exercises are created to teach evolution principles by using living organisms. This situation may lead students to think of evolution as an abstract and untestable concept. An upper-level evolution biology course was designed to include laboratory exercises with living organisms. This paper describes one of those exercises that demonstrate significant population genetic change over a thirteen-week period by using the common fruit fly, *Drosophila melanogaster*. In fact, the genetic change was observable even after the first five weeks of the experiment. The flexibility of the laboratory exercise is not only one of time, but also of depth of the lesson. Depending on the level of student understanding and objectives of the course, the instructor may choose from the following list of topics and expand on them: 1) *Drosophila* life cycle and Mendelian genetics; 2) maintenance of *Drosophila* populations with proper feeding conditions; 3) density dependence of populations; 4) geometric growth of populations; 5) carrying capacity; 6) population genetics; 7) microevolution; 8) natural selection and fitness; and 9) evolution.

With today’s technologies and access to the World Wide Web, computers have added another dimension to biological education and have become a mainstay in educational initiatives. For example, one can download a population genetics program that allows manipulation of imaginary populations to show microevolution in graphic form. The laboratory exercise presented here provides the benefits of a hands-on experience with living organisms allowing students to see microevolution in real time.

A previous paper titled, “Using Species of *Drosophila* to Teach Evolution,” (Rosenthal, 1979) briefly discusses using breeding competition experiments in which two species of *Drosophila* were placed into the same container. The students then assess the “reproductive success…by counting the number of each species in the container” (p.554). Rosenthal’s experiment is an eloquent demonstration of competition, but not of evolution.

**MATERIALS**

The following are materials necessary for either fifteen students working alone or thirty students working in pairs:

- 200 *Drosophila melanogaster* - wildtype *
- 400 *Drosophila melanogaster* - *ebony* *
- 15 plastic rectangular containers with lids
- anti-mite paper *
- 450, 15ml conical tubes
- sterile cotton
- dry *Drosophila* food *
- active dry yeast
- 2 to 6 stereoscopes
- 15 paintbrushes or fly brushes *
- 2 carbon dioxide tanks or Fly-Nap*
30, 250ml beakers
a source of distilled water
*from Carolina Biological Supply

EXPERIMENTAL DESIGN AND METHODS

This experiment demonstrates evolution principles with a simple design - one favored allele (wildtype over ebony). Ebony flies were chosen for three reasons: 1) they can be distinguished by the naked eye from the wildtype morph; 2) the allele causing the ebony phenotype is recessive; and 3) they have a decreased fitness in comparison to wildtype flies (Lindsley and Zimm, 1992). Each of these factors helps simplify the mechanics of the experiment.

Food storage containers were adapted for use as population cages. Each container was fitted with six 15ml conical tubes. Six holes, no larger than the caps of the 15ml conical tubes, were created in the bottom of the container. Holes were made in the tube caps such that the threads were still intact. Then the tube caps were adhered to the container over the holes with a silicon-based adhesive, and left to dry overnight. Four empty conical tubes were screwed into four caps (B1, B2, C1, and C2) of the storage container (Figure 1). Two conical tubes were each filled to the 1.5ml mark with dry fly food, distilled water, and five to ten pellets of active dry yeast. They were screwed into caps A1 and A2. Then in order to begin with a high ebony allele frequency in the population containers, fifteen wildtype and thirty ebony fruit flies from homozygous stocks were added to each food storage container. All transfers of fruit flies were done using CO₂ fly pads under stereoscopes with paintbrushes to gently separate the flies. On every third day subsequent to starting the population cage a fresh food tube was exchanged for an empty tube or sample tube. The order of replacement was as follows: B1, B2, C1, C2, A1, A2, B1, and so on. This allowed fifteen days for the original food tubes, placed in A1 and A2, to give rise to a second generation of flies.

During these fifteen days students began an additional experiment which would help them explain their results from the population cages. They estimated the relative fitness of the ebony flies by isolating virgin flies of ebony and wildtype and doing all four crosses (Figure 2). The total number of offspring from ebony females was divided by the total number of offspring from wildtype females to calculate relative fitness.

![Drosophila Population Cage](image)
Females | Males
---|---
**ebony** | **wildtype**
| |  
**(n=3)** | **55** 
**(n=4)** |  
| **27** 
**(n=4)** | **41** 
**(n=4)** |  
| **Total Offspring** |  
| **74** | **96** |

Relative Fitness 74/96 = 0.77

*Figure 2. The relative fitness of ebony was calculated by the students in a separate experiment by crossing virgin fruit flies and counting offspring of ebony and wildtype females (n=number of matings, each cell contains the average number of offspring per mating).*

On the fifteenth day the first sample tube collected was plugged with cotton and dated. All adult flies trapped in the tube during collection were discarded. Flies that emerged from the sample tube’s food over the next few weeks were identified by sex and morph type (either wildtype or ebony). Each student kept a record of his/her individual population cage’s data. At the end of the semester all data were compiled and tabulated. Students individually wrote the combined population cage results as a journal article according to a sample layout provided to them.

**RESULTS**

The students followed the instructions for the exercise. Variation existed between individual cages; however, the general tendency for the homozygous ebony population to decrease in frequency occurred (Figure 3). The students’ calculation of ebony’s relative fitness to wildtype was 0.77 (Figure 2). The reference text states that ebony’s relative fitness is, “about 80%” (Lindsley and Zimm, 1992). Students submitted journal articles that expressed their understanding of the nine topics mentioned in the introduction of this article. One student applied the lesson in population genetics and fitness in a graphic display of the decline of the ebony allele in the population (Figure 4).

*Figure 3. Data compiled and averaged from fourteen individual population cages. The ebony morph frequency decreases from 67% to less than 5% over a thirteen-week course.*
DISCUSSION
This exercise can be adapted for different laboratory courses. It can be part of an evolution course or incorporated into a genetics, population biology, or molecular biology laboratory. Some variations of the exercise are also possible. The relationship between homozygous wildtype, homozygous ebony, and the heterozygous cross can be developed into a deeper discussion on dominance and competition amongst the three types. Rendel (1951) provided evidence that the ebony males are more successful when mating in the dark. Possibly one variation of the laboratory exercise is to have half of the population cages in a dark room. Kyriacou et al. (1978) showed that the heterozygote cross of wildtype and ebony may even have a selective advantage over both homozygotes. This leads to the interesting question, “How many of the wildtype morphs identified in the laboratory exercise are actually heterozygotes?”

A molecular identification of the ebony locus, perhaps using specific oligos for PCR and a subsequent DNA agarose gel, would provide the students with the opportunity to learn another common laboratory technique. Backcrossing the sample flies with the parent population would be more time consuming, but it would also provide an answer to the same question. Even without the quantification of the heterozygote population in the samples, the information from the aforementioned journal articles could be used to deepen the student discussions.

NOTES
1. Fly-Nap from Carolina Biological Supply may also be used according to the instructions of the manufacturer without stereoscopes.
2. Virgin flies may be provided to the students at the beginning of the fifteen days if isolating them is not one of the course objectives. The experiment can also be dropped since the relative fitness of ebony homozygotes to wildtype is known (Lindsley and Zimm, 1992).
3. Sample tubes may be collected a day early or late if the third day falls on a weekend; however, tubes should be collected as close to the third day as possible.

ACKNOWLEDGEMENTS:
Drs. Doug Taylor and Jennifer Secky for helping implement the exercise and consultation.

REFERENCES:
Linking Art and Science with a Drawing Class

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Abstract: Strong observational skills are important to students and professionals of both the arts and the sciences. In order to help science students improve their observational skills and show them the interconnectedness of the arts and the sciences, we designed a drawing class for students who were concurrently enrolled in the first semester of a two semester General Biology sequence. Drawing assignments required students to observe and draw specimens that would subsequently be studied in the biology course thus causing students to examine them closely and potentially enabling them to have a deeper appreciation for the similarities and differences between organisms. Surprisingly, students who were enrolled in the drawing course performed significantly worse on biology assignments than students who were not enrolled in the drawing class. We believe that relatively weak students who expected to have difficulty in biology chose to enroll in the drawing course hoping that it would serve as a tutorial for the biology class. Students in the drawing course clearly improved their drawing skills as evidenced by student comments and pre- and post-instructional drawings. Importantly, student comments indicate that the drawing class helped them make better observations in the biology course.

Keywords: observational skills, drawing, biology, interdisciplinary connections

INTRODUCTION

In 1959, C.P. Snow described practitioners of the arts and of the sciences as belonging to two very different cultures (Snow, 1959). Artists were described as having little understanding of science while scientists were ignorant of history and literature. Members of the two groups were described as being unable to comprehend each other’s fields of endeavor (Snow, 1959).

The arts and the sciences are often seen as separate and independent spheres of human activity. However, this incomplete and widely held perception is undergoing revision. For example, students studying art may think of themselves as working in a subjective field that is unconnected to the world of science. But a strong case can be made that the process of creating a piece of art requires objectivity and cognitive skills that are typically associated with scientific work (Hanrahan, 2000). Students majoring in the sciences may just as easily believe that their work has little to do with the humanities. However Snow himself wanted to bring the two cultures closer together (Ruprecht, 1999) and many educators now recognize that the two cultures continuously interact with each other in productive ways (Hallett and Kalman, 1975).

How can we as educators more effectively communicate to our students the interdisciplinary nature of all knowledge? There has been a concerted effort to connect the natural sciences with mathematics (see Czerniak et al., 1999 for a review of this literature). More relevant to Snow’s dichotomy, innovative curricula have been developed that attempt to bridge the perceived gap between the humanities and the sciences. There are many published examples of courses that integrate biology, chemistry or physics with literature, art or history (Allchin et al., 1999; Flannery and Hendrick, 1999; Carstens-Wickham, 2001). It seems clear that knowledge that is typically associated with one discipline can be easily connected to other disciplines.

Perhaps less widely appreciated is the fact that skills can be interdisciplinary as well. The ability to make careful observations is an example of a discipline-independent skill that benefits all students and professionals regardless of with which of the two cultures they identify. A common model of the scientific process describes it as beginning with observations that lead to questions, hypotheses, predictions, data collection and interpretation, and then conclusions (Purves et al., 1998; Solomon et al., 1999).
A fundamental act of science, then, is making observations; developing observational skills is therefore a crucial element in science education. Students in our first semester General Biology course have been asked for several years to draw and label specimens in lab with the intent that this task would help students to observe specimens more carefully than they might otherwise. Other biology instructors have required students to make labeled drawings in lab for similar purposes, and they have reported success (Matern and Feliciano, 2000). Although observational skills are important, our experience with students has led us to believe that freshmen often have weak observational skills.

Making careful observations is clearly the foundation for the scientific process but it is crucial for other endeavors as well. It is difficult for us to imagine how meaningful work in the fields of music, history, or creative writing can be conducted in the absence of sound observations. In fact, work in the humanities requires some of the same skills as does work in the sciences (Adams and Fuchs, 1985). Here, then, is a fundamental attribute held in common by both the arts and the sciences: work of good quality in both spheres of endeavor depends on the practitioner’s ability to make careful observations.

One possible way to help students recognize and benefit from the shared skills required by the two disciplines is to have them study a single body of material in the context of both an art course and a science course simultaneously. We developed a drawing course for students who were concurrently enrolled in an introductory biology course. The primary goal of the drawing course was the improvement of students’ ability to draw. However, we had an additional goal; we wanted to use the teaching of observational skills as a platform from which students could clearly see and benefit from the connections between the arts and the sciences.

METHODS

Biology 202 is the first biology course taken by freshmen at Pacific University. It has no prerequisites and is offered in the second semester of the academic year so the majority of students enrolled in the course are second semester freshmen. It is taken by non-science majors as well as by students majoring or minoring in Biology, Chemistry, Environmental Science or Exercise Science; many of these students intend to become health care professionals.

The course covers evolution, the diversity, structure and function of organisms, and ecology. The course requires students to learn what they commonly perceive as a large volume of detailed material. Lecture and lab activities are synchronized so that students are exposed to topics in a lecture setting several days before they explore those same topics in a lab setting. For example students may be exposed to the idea of transpiration via stomata in lecture and then in lab they will actually make measurements of transpiration rates and prepare epidermal peels to observe stomata under the microscope. While each lab activity is different, almost every lab meeting requires students to look carefully at organisms, make labeled sketches, ask questions and use the scientific method to reach conclusions.

The authors met weekly for one semester prior to the drawing course to discuss the goals of the course and the methods by which they might best achieve those goals. We decided that students should be exposed to biological specimens in the drawing class before they acquired any knowledge of them from the biology class. Hopefully this would ensure that the students would make observations and drawings based upon skills and techniques learned in the art class without being influenced by the knowledge of structures and functions that should be drawn and labeled in a biology class.

We also decided that assignments made in the art class would not require the students to actually learn any biological content. We wanted to make sure that the drawing course did not become a “help session” for the biology course. This was important to us for two reasons: 1) We wanted to see what influence (if any) learning how to draw might have on students’ performance or attitudes in the biology course without the confounding variable of making drawings assignments that amounted to studying biology. For example, we agreed that asking students to include labels on their drawings of biological specimens before the material had been studied in the biology course was tantamount to asking them to study and learn biology. We therefore made every effort to avoid creating drawing assignments that resembled biology homework. 2) Biology 202 had an enrollment of 143 students, only 18 of whom were enrolled in the drawing class. We did not want the vast majority of biology students who were not enrolled in the drawing class to feel that the students in the drawing class had an unfair advantage as a result of “studying biology” in the drawing course.

The drawing course used the approach described in the text entitled The New Drawing on the Right Side of the Brain (Edwards, 1999). This approach requires students to learn to ignore messages from the left hemisphere of the cerebrum that tell them to think about and draw objects logically and analytically. Edwards encourages students to draw in a more intuitive mode. Students who avoid affixing biasing labels to their subjects and who are not concerned about whether the final drawing is “stupid” or “horrible” are more likely to explore different ways of thinking and drawing, and so are more likely to make good progress with their drawing skills.

Students in the drawing class spent the first several weeks learning basic drawing skills designed
primarily to engage students in new modes of thinking. Exercises included making drawings of upside down subjects, drawing the missing half of an object and doing drawings without looking at their paper (“blind contour drawings”). Subsequent drawing assignments were correlated with Biology 202 (Table 1). One or two weeks before a given Biology 202 topic was to be covered, drawing students were given an assignment related to that material. Students were not expected to know the biological names or functions of any of the parts of these specimens. Students were simply asked to make the best drawing they could. They then studied the subjects of their drawings in biology lecture and the following week they observed specimens in biology lab.

Table 1. A partial outline of the weekly assignments in the drawing class and their relationship to material under study in the biology class. Note that specimens are drawn in the drawing class before they are studied in the biology class.

<table>
<thead>
<tr>
<th>Week</th>
<th>Drawing assignments</th>
<th>Biology topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pre-instructional drawing: tree</td>
<td>Evolution</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Evolution</td>
</tr>
<tr>
<td>3</td>
<td>Note-taking graphics: Protists (from text)</td>
<td>Taxonomy; cells</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Bacteria; Protists</td>
</tr>
<tr>
<td>5</td>
<td>Negative space drawings: plants</td>
<td>Fungi; plants</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Plants</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Plants</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Plants</td>
</tr>
<tr>
<td>9</td>
<td>Scratchboard: biological subject chosen by student</td>
<td>Animals</td>
</tr>
<tr>
<td>10</td>
<td>Final project: three-part drawing of an organism, its environment, and detail of its anatomical structure</td>
<td>Animals</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Animals</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Ecology</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Ecology</td>
</tr>
<tr>
<td>14</td>
<td>Post-instructional drawing: tree</td>
<td>Ecology</td>
</tr>
</tbody>
</table>

We created five assignments that were connected to the biology course. The first was a pre-instructional drawing of a tree, completed during the first week of the semester (Fig. 1), that could be compared to their post-instructional drawing of a tree, completed at the end of the semester (Fig. 2), as an indicator of their progress. The second was to draw several groups of protists and/or fungi from their biology textbook (Fig. 3). This activity served both as an exercise in contour drawing and as an introduction to the concept of “note-taking graphics”, which is an alternative way for students to study and record information. The third was to make “negative space” (Edwards, 1999) drawings of plants (Fig. 4). Negative space drawings required students to ignore the focal object and instead draw the space surrounding the object. The space around an object is unlikely to resemble any shape or icon (for example, “chair” or “face”) that already exists in the students’ mind. Because they had no pre-existing mental model from which to work negative space drawings forced them to make unprejudiced observations. The fourth assignment was to bring in a small biological specimen that could be magnified and represented on a scratchboard. Students used a very finely pointed metal tool to precisely scratch off some of the black coating of the scratchboard and reveal the underlying white material. This is a technique that allows for expression of value and fine detail. Students selected subjects such as grasshoppers, dandelion fruits, and flowers (Fig. 5). The fifth assignment was the last of the semester and students were given approximately three weeks to work on it because of its complexity. Students were asked to design a three-part drawing that showed an organism, its environment, and some detail of the anatomy of the organism. This assignment required students to select from a wide variety of options and compose and execute the final product using the skills they had acquired throughout the semester. Examples of these final projects include: ants on a hill, an ant, and a close-up of the ant’s head (Fig. 6); a robin pulling an earthworm out of the ground and a close-up of a feather; a fish in a reef environment and a diagram of counter-current gas exchange in the gills; an anemone eating a fish with a close-up of the anemone’s mouth. (Additional examples of all drawing assignments can be seen at http://cas.pacificu.edu/art/Hewlett.html.)
Figure 1. A sample pre-instructional drawing of a tree by a student who was concurrently enrolled in both drawing and biology courses.

Figure 2. A post-instructional drawing of a tree by the same student whose pre-instructional drawing is seen in Figure 1.

Figure 3. A student drawing exemplifying the technique of graphic note-taking.

Figure 4. One student’s drawing using the technique of negative space.
Figure 5. One student’s work using the scratchboard technique.

Figure 6. One student’s final project showing an organism, its environment, and an anatomical detail of the organism.

In addition, students were asked to keep a sketchbook containing a variety of their drawings from the second half of the semester. Students created several drawings each week, both in and out of the drawing class, and at least one of these each week was to relate to their biology class. Students were free to draw images from their biology textbook and from live or preserved specimens. Drawings included note-taking graphics and detailed drawings of anatomical structures or biological processes (Fig. 7). Students often chose to label these drawings although they were not asked to do so.

Funding from the Hewlett Foundation made it possible for us to provide students with a set of materials including pencils, paper, a viewfinder, and magnifiers. In addition, Hewlett funding allowed us to purchase biological charts, models and books (e.g., field guides) to serve as both resources and stimuli for students enrolled in the drawing class.

We wanted to ensure that any subsequent differences in student performance in the biology class between biology students who were enrolled in the drawing class and those who were not would not be attributable to initial differences in their academic abilities. As indicators of academic ability we collected the following background information about each student: high school GPA, first semester GPA at Pacific University (Biology 202 is almost exclusively enrolled by second-semester freshmen), and SAT scores (verbal, analytical, and total). Z-score histograms showed that these variables were not distributed normally. The distributions of these variables were compared using Mann-Whitney U tests.

We compared the scores in biology of students who were enrolled in the drawing course to the scores of students who were not. We compared the final course grades and grades for all lab assignments and lecture exams. Assignments with grades that were not distributed normally were analyzed using Mann-Whitney U tests; t tests were used to compare the means of assignments with grades that were normally distributed. All data were analyzed using Statview® version 5.0.1.

Students enrolled in both courses were also asked to write an evaluation of their drawing skills and to comment on the relationship between the two courses.
Table 2. A comparison of the academic profile of 18 students who were enrolled in both the biology and drawing classes to that of 125 students who were enrolled only in the biology class. Values are means and are indicated as + or – values for the percent difference between students who enrolled in both biology and drawing classes and those who enrolled in only the biology class. With the exception of values for College GPA, all measurements indicate lower values for the students enrolled in both classes. Some pieces of information were not available for every student thus the ranges of “n”.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Students enrolled in Biology and Drawing (n = 16 -17)</th>
<th>Students enrolled in Biology only (n = 97-119)</th>
<th>% difference between B&amp;D and B (n=16-17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>College GPA</td>
<td>2.806</td>
<td>2.677</td>
<td>+4.60</td>
</tr>
<tr>
<td>Verbal SAT</td>
<td>517.5</td>
<td>544.0</td>
<td>-5.12</td>
</tr>
<tr>
<td>Total SAT</td>
<td>1069.4</td>
<td>1106.0</td>
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</tr>
<tr>
<td>High school GPA</td>
<td>3.493</td>
<td>3.567</td>
<td>-2.12</td>
</tr>
<tr>
<td>Analytical SAT</td>
<td>551.9</td>
<td>559.7</td>
<td>-1.41</td>
</tr>
</tbody>
</table>

RESULTS

Eighteen students enrolled concurrently in the drawing class and the biology class. An additional 125 were enrolled only in biology and two were enrolled only in the drawing class.

There were no statistically significant differences between the high school GPA’s, college GPA’s, verbal SAT scores, analytical SAT scores or total SAT scores of students who were enrolled only in the biology course and those who were enrolled in both courses (Table 2). However the means of four of these five attributes were lower in the students enrolled in both courses.

In 14 of 17 biology assignments (five exams and 12 labs), the mean scores of students enrolled in the drawing class were lower than those of students who were not enrolled in the drawing class. Although their mean scores were significantly lower on only two assignments (lab exercises) (t test, p < 0.0274), the fact that these students enrolled in the drawing class had lower mean scores in 14 of 17 assignments was a statistically significant finding (Chi-squared test, d.f. = 1, p < 0.01). In addition, the overall mean score for all lab assignments was significantly lower for students enrolled in the drawing course (t test, p = 0.0447).

Post-instructional student comments about their ability to draw can be seen in Table 3. Many indicated that the drawing class improved their ability to “pay attention to detail.” Student comments about the drawing class and its relationship to the biology class indicated that they expected the drawing class to have a more direct connection to the biology class, and that the drawing class helped them make better observations in their biology class (Table 4).

Table 3. Some post-instructional comments by students on their drawing ability, written at the end of the semester by students enrolled in both drawing and biology classes.

- “My ambitions for being a much better artist have increased.”
- “I did learn some very useful skills in the art class, and I am glad that I decided to take the class.”
- “I hope that the class is offered again so others can learn how to draw the world around them just a little bit better and know that they can draw just fine. It was a good confidence booster for people not so artistically inclined in the drawing department.”
- “…I think I have become a better artist by taking this course. I came into the course as one of the few students who thought they had any idea how to draw, however, I found that I didn’t know how to draw quite as well as I thought.”
- “I like being able to look through my sketchbook and seeing my improvement….I thought I could never learn to draw but I proved to myself that I could.”
- “…I have learned to draw what I actually see instead of what I think I should see….I did learn to pay attention to details….”
- “I felt that this drawing class really helped me improve my drawing ability. (The instructor) helped us realize the importance of truly examining the object that we are drawing, rather than using our imagination and draw what we thought we were seeing.”
- “I became an all around better artist by merely using something that I had taken for granted, the ability to see and pay attention to detail.”
- “The class taught me to pay attention to detail.”

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<td>Total SAT</td>
<td>1069.4</td>
<td>1106.0</td>
<td>-3.42</td>
</tr>
<tr>
<td>High school GPA</td>
<td>3.493</td>
<td>3.567</td>
<td>-2.12</td>
</tr>
<tr>
<td>Analytical SAT</td>
<td>551.9</td>
<td>559.7</td>
<td>-1.41</td>
</tr>
</tbody>
</table>
Table 4. A sampling of post-instructional comments on the relationship between drawing and biology, written at the end of the semester by students enrolled in both courses.

<table>
<thead>
<tr>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I think it is great to know how to draw for biology. Becoming a better artist will help me be able to study better and fully understand the material.”</td>
</tr>
<tr>
<td>“I didn’t think that there was a relationship but after taking the class I payed (sic) more attention to details.”</td>
</tr>
<tr>
<td>“I don’t really know, I just know that it is much easier to study biology, if you can draw. And vice versa.”</td>
</tr>
<tr>
<td>“It helped me not only learn how to draw but also with my studying for biology….In labs we did a great amount of sketching and knowing hoe (sic) to observe the organism helped me draw a more accurate picture of the organisms we studied.”</td>
</tr>
<tr>
<td>“I have realized, during my labs, how much more attention I pay to what I am trying to draw. Before I took this drawing class, I would’ve drawn a worm like a long skinny line and not given it its true justice of what it is really composed of.”</td>
</tr>
<tr>
<td>“Our (biology) tests asked us specifically for features of certain organisms. The drawings helped me remember what the organism that we were studying looked like.”</td>
</tr>
</tbody>
</table>

DISCUSSION

The primary goal of a drawing course must be improvement in the ability of students to draw. The student comments (Table 3) and pre- and post-instructional drawings (Figs. 1 & 2) are strong evidence that this goal was achieved. These findings are consistent with those of Edwards (1999) who describes tremendous gains made by novice drawing students during a five-day course. Edwards’s text includes sample pre- and post instructional drawings as evidence of improvement. Because similar methods were used by the drawing instructor (O’Day), similar results are not surprising.

Although students have long been asked to make sketches in biology labs as a means of carefully observing the features of different specimens, drawings have not been graded for their accuracy or artistry but rather on whether all structures were recognizable and properly labeled. Other biology instructors have asked students to draw and label specimens as an aid to learning morphology and reported that this technique is both effective and well received by students (Matern and Feliciano, 2000).

Differences in performance in the biology course between students who were also enrolled in the drawing course and those who were not cannot be attributed to statistically significant differences in their academic histories (Table 2). However it is interesting to note that all indicators of previous academic performance except for “College GPA” were lower in the students who chose to enroll in both courses. Furthermore, internal studies by the Biology Department at Pacific University have shown that verbal SAT score has historically been the strongest predictor of performance in our introductory biology course. The mean verbal SAT score differed between the two groups of students by a greater percentage than did any other attribute measured before the course started (Table 2); this suggests that students who were statistically less likely to perform well in Biology 202 were more likely to enroll in the drawing class than were other students. It is possible that the drawing class was perceived as a “tutorial” for biology. Students in biology were told about this course during the first day of the semester and although the two courses ran in parallel we tried to avoid describing the course as a tutorial for biology. For whatever reason, it appears that students who chose to enroll in the drawing course were relatively, although not statistically, weaker academically.

The apparent non-random enrollment of students in the drawing course may explain why students enrolled in the drawing class tended to perform worse in Biology 202 than their peers. (It is possible that the drawing course itself caused students to perform worse in biology by giving them a false sense of biological knowledge as a result of their frequent observations of specimens, but this possibility strikes us as unlikely.) Perhaps these students anticipated correctly that the biology course would be difficult for them and hoped that the drawing class would help them perform better. Clearly a challenge for future versions of this course will be to make clear to students and academic advisors that while the drawing and biology courses “go together”, neither should be regarded as a tutorial for the other.

Student comments about the relationship between the two courses tended to center around two themes (Table 4). The first was that some students expected that there would be a greater number of assignments that were directly relevant to the biology course. This first iteration of the course had five assignments that were connected to the biology course (in addition to the weekly sketchbook entries as selected by each student) but the potential for many more exists. Since we know before the semester starts what organisms will be under study in biology each week we can design drawing assignments that mesh more frequently and directly with the biology course. For example, mosses and ferns, cone-bearing trees, and flowers and fruits could
each be drawn for one week before the weeks during which those groups are studied in Biology 202.

The second theme in student comments was that the course helped some of them pay attention to details better and that this helped them study for biology. We interpret this as an indication that the observational skills of some students improved and that they were cognizant of the fact that this skill was helpful in studying science. This indicates that our secondary goal for the drawing course (that students recognize the significance of observational skills to both artistic and scientific endeavors) was met for some students. We expect that by incorporating more assignments that connect directly with Biology 202 into future versions of the drawing course, we will meet that goal for a greater percentage of students.

ACKNOWLEDGEMENTS
A grant from the Hewlett Foundation made it possible for us to design, offer and supply students with materials for this course. Data analysis and writing took place during E.A.’s sabbatical leave funded by Pacific University. The manuscript benefited from the comments of two anonymous reviewers.

LITERATURE CITED

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Investigating Reformulated Gasoline in an Issue-based Environmental Science Course

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Abstract: Project- or case-based education is an excellent means of providing students with hands-on, inquiry-driven educational opportunities. Developing effective course units, however, requires rethinking pedagogical strategies and sometimes teaching material with which we are unfamiliar. This paper describes a case-based unit on reformulated gasoline that was used in an introductory environmental science course for Honors students, most of whom were not science majors. In the unit, students were asked to wrestle with a conceptually difficult but very relevant issue: “Should the EPA have waived the reformulated gasoline requirement for the Milwaukee area in the summer of 2000?” They were required to learn a variety of scientific concepts, as well as to understand the process of scientific research. Student assessment indicates that they were frustrated by the confusing and contradictory nature of the topic, but also found value in working through the complex issue.

Key Words: Case Study, Environmental Science, Inquiry-based Instruction, Reformulated gasoline

INTRODUCTION

In 1995, a national convention on science education was held at the National Academy of Sciences, co-sponsored by the National Science Foundation and the National Research Council. The most critical goal identified in that convention was that “all students should have access to supportive, excellent programs in science, mathematics, engineering, and technology, and all students should acquire literacy in these subjects by direct experience with the methods and processes of inquiry” (NRC 1996:4). Such a conviction requires rethinking traditional science education. In particular, it requires new approaches to teaching: “cooperative learning, project-centered classes, investigation-oriented laboratories, courses centered on case studies, self-paced instruction, techniques that solicit immediate feedback on teaching and course content, etc. These approaches help students to analyze, criticize, and communicate…. They help students take responsibility for their own learning” (NRC 1996:22). Rothman and Narum (1999) document that over the last decade, science education has been actively involved in a variety of reforms designed to accomplish that goal. More importantly, they document that the reform efforts are having a significant, positive effect on student learning in science.

Many faculty members, however, resist making the types of innovative reform efforts that reports such as those cited above encourage. In courses for science majors, the challenge is often in finding a balance between covering the content that is the foundation to the discipline and encouraging inquiry necessary for success in the field. In courses for non-science majors, coverage of a particular body of content is less of a concern, facilitating a less traditional course structure (HHMI:29). However, even in non-majors courses, instructors may be reluctant to deviate from a traditional course structure for a variety of reasons. For example, instructors may not be aware of alternative teaching techniques, may be hesitant to relinquish ‘control’ in the classroom, or may not feel they have sufficient expertise to facilitate a case or problem-based course structure. In addition, students often feel more comfortable with a traditional class format and are reluctant to take a more active role in the classroom (Narum 1997:20).

In the fall of 2000, I taught an introductory course in environmental science for Honors students at Carroll College. For a variety of reasons (outlined below), I decided to move away from the typical survey-course structure to one centered around three units, each focused on investigation of a particular local problem or issue. This paper describes how the first three units were structured, as well as how the students responded.
to the non-traditional format. This is done not to provide an exemplary model of the “perfect” course (which it clearly was not), but rather to present a realistic picture of efforts at curriculum reform. The objectives in this paper are: 1) to share resources and strategies for designing a unit centered on reformulated gasoline and ground level ozone, and 2) to share the successes and concerns associated with teaching a student-driven, case-based instruction unit. It is hoped that this may stimulate others to try a new approach to teaching. Although pitfalls were encountered along the way, the students in this course wrestled with a real, science-based issue. In the process, they developed skills and confidence that will help them be more successful in facing other similar issues, not only as students but as informed citizens.

THE SITUATION

Carroll College is a primarily undergraduate institution with approximately 2000 undergraduate students. Students in the Honors program are admitted by invitation, based on academic success at the high school level. They are required to take six courses from a menu of designated Honors courses (such as this one) and to complete a Senior Honors Project in order to graduate with Honors from Carroll. Students in this introductory environmental science course ranged from sophomores to seniors. Only one of the twelve students in the class was an environmental science major. The other students were majoring in a diverse array of fields including History, Computer Science, Business Administration, Education, and Art. Many of the non-science majors were ambivalent (at best) about taking a science course. They had registered for the course because it: 1) fulfilled a requirement in our general education curriculum, 2) was an honors course, and 3) sounded more interesting that other science alternatives.

The course satisfied requirements of the college-wide Liberal Studies Program, in the areas of “Science as a Way of Knowing” and “Understanding the Natural World”. It also satisfied departmental core requirements for the Environmental Science Major. For these reasons, the specific course objectives (Box 1) were externally defined. One of the most important forces exerted on the design of the course was that it really needed to teach science. We observed that students taking courses in environmental science learn very little about what science is and how science is done; it was essential to counter that trend in this course. Because it was an Honors course, the students should have an opportunity for self-directed learning about real environmental issues. The course also needed to involve research and critical thinking. Finally, it was important that each unit connect lecture/class activities to laboratory activities in a meaningful way.

**Box 1: Course Objectives**

At the conclusion of this course, students should be able to:

- Demonstrate an understanding of the physical and biological worlds and methods of investigating them that is sufficient to assess and use scientific evidence in making intellectually responsible decisions.
- Assess various societal impacts and implications of global environmental change.
- Measure environmental quality in various qualitative and quantitative ways.
- Demonstrate an ability to use modern methods to access, analyze, interpret, and communicate effectively both qualitative and quantitative information.
- Cultivate a set of personal values and attitudes concerning the environment that will motivate oneself to actively address environmental problems and effectively participate in their solutions.
- Demonstrate competency in written and oral communication, use of information technology, critical thinking, and understanding contemporary relevance.
- Demonstrate increased self-confidence with respect to understanding and using scientific information, including an understanding of the role of uncertainty in science.

The issue selected for the opening unit of the course centered on the question: “Should the EPA have waived the reformulated gasoline requirement for the Milwaukee area in the summer of 2000?” The question was chosen for a variety of reasons. First, the issue had immediate relevance to the students. They had a stake in understanding the rationale behind the EPA’s decision. Students had watched gasoline prices soar to over $2.00 per gallon throughout the summer. State and local governments had initiated legal action against the EPA for not waiving the RFG requirement. Media coverage was full of contradictions, finger pointing, and questionable information.

Second, the issue involved a great deal of science. Students needed to understand the basics of combustion chemistry, the composition of gasoline, how air pollutants are formed, and what impacts such air pollutants have on plants and animals. They also needed to understand how scientists carried out the research upon which policy-makers were basing their decisions. By pairing in-class activities with field research on the effects of ground-level ozone on milkweed plants, students directly experienced the process of scientific investigation, from posing a research question through analyzing and presenting data and drawing conclusions.
Third, the issue had political and social ramifications. Students had an opportunity to see firsthand how political decisions were made. They could also see the economic ramifications of those decisions— not just at the gas pumps but also on agricultural systems, etc. This provided opportunities for many of the students in the class to have a greater sense of ownership of the issue by allowing them to draw connections to their experiences in other courses, including their academic major.

Finally, and perhaps most importantly, the issue had no clear answer. This meant that students would be pushed to critically evaluate the available data and arguments and to draw their own conclusions from that analysis. The ambiguity of the problem did not become apparent until well into the study. It was a vivid example of how decisions are made in spite of scientific ambiguity.

UNIT STRUCTURE

The course was organized in two 2-hour blocks for lecture/discussion and one 3-hour laboratory each week. On the first day of class, the issue was introduced and students were given the opportunity to develop a list of what they felt they needed to understand in order to answer the question posed. They also brainstormed potential sources of that information. These discussions guided the development of the subsequent four weeks of the course. Sessions included lectures, guest speakers (a Wisconsin Department of Natural Resources Air Quality Expert and the Waukesha County Executive, as well as other environmental science professors), group presentations, and class discussions. For the group presentations, students were divided into groups of three. Each group was charged with researching and presenting to the class information on one of the following topics: air quality regulations; ethanol and MBTE; the supply and distribution of reformulated gas; or the economics of reformulated gas. Class sessions were supplemented by readings from the National Academy of Sciences report on reformulated gasoline (NRC, 1999) and readings from a general environmental science textbook (Cunningham and Saigo, 2001). One class session was spent touring a local vehicle-emissions testing station.

In the laboratory portion of the unit, students investigated the effects of ground-level ozone on milkweed leaves (A. syriaca; KanCRN 1997; Spring Harbor, 2000). Once students became familiar with identifying ozone damage (Figure 1), they developed hypotheses regarding the relationship between the level of ozone damage on leaves and variables such as whether the plants are growing in urban or rural settings, near or far from major roadways, etc. These hypotheses were further developed into formal research proposals. Proposals were peer-reviewed, and then returned for revisions. Then the class spent five weeks visiting milkweed patches in various locations collecting data. These data were statistically analyzed and each group presented their research project in a class symposium. Each group also wrote a paper in formal scientific format.

**Figure 1**: Ozone Damage on Common Milkweed (A. syriaca). Bioindicators such as milkweed are used to monitor ground-level ozone levels within a given area. Ozone causes formation of black stippling on the leaves of the plant. Photograph courtesy of Kathryn Yurkonis.
Various measures of student learning were incorporated into evaluation of the unit. The group report on reformulated gasoline was assessed for both quality of the presentation and understanding of the critical concepts (class mean = 22.5 of 25 points). At the end of the unit, students prepared a written paper or project focused on their answer to the original question posed (“Should the EPA have waived the reformulated gasoline requirement for the Milwaukee area in the summer of 2000?”). Many students completed a traditional “term paper” type report, but others chose to format their response as a brochure or booklet with a more educational focus. The class mean on this assignment was 42.5 of 50 points. Students also took a written examination covering the basic scientific concepts. The class mean on the exam was 58.9 of 70 points. Assessment of the laboratory portion of the unit was based on quality of the preliminary research proposal (mean = 18.4 of 20 points), the final oral presentation (mean = 18.5 of 20 points), and the final written report (mean = 26.4 of 30 points).

THE STUDENTS’ RESPONSE

Students’ course evaluations indicate that the unit achieved, at least in part, the learning objectives established for the unit. Ten of the twelve students in the course (83%) responded that each of the following four statements was either accurate or somewhat accurate:

- The reformulated gas unit helped me learn more about environmental science.
- The reformulated gas unit was appropriate for an honors level course.
- The milkweed/ozone study helped me to learn more about scientific research.
- The milkweed/ozone study was appropriate for an honors level course.

When asked to evaluate to what extent each student believed s/he accomplished particular course objectives, the results were similarly positive. Eleven of the twelve felt they were able to apply research methods to the analysis, synthesis, and evaluation of environmental information (fully achieved = 5, mostly achieved = 6). Ten of twelve felt they had cultivated a set of personal values and attitudes concerning the environment that will motivate them to actively address environmental problems and effectively participate in their solutions (fully achieved = 6, mostly achieved = 4). Most students also felt that the course had helped develop increased self-confidence with respect to understanding and using scientific information, including an understanding of the role of uncertainty in science (fully achieved = 2, mostly achieved = 7). The lower proportion of students indicating the objective was fully achieved indicates this was not accomplished as successfully as the others. Written comments from student evaluations (Box 2) reflect the students’ frustration and confusion, but also indicate that they perceived value in their struggle with the material.

Box 2: Comments from Student Course Evaluations

- Honestly, for the first few weeks of the course, I was lost. I found this to be an uninteresting unit to begin with until a DNR representative came in and explained everything in an informative, easy to understand manner.
- We needed more background information from the instructor.
- The problem we were trying to address was more political than scientific.
- It was no doubt a challenging unit, bringing a lot of issues together. Maybe it would be more effective at the end of the semester.
- I was very confused. I think I needed more of a definitive answer to some of my questions.
- Was difficult as it was with such a new subject to study. At times, it seemed that there was way too much information because we had trouble deciding what was true/untrue or important/unimportant.
- More substantial information, if possible.
- Confusing

REFLECTIONS AND CONCLUSIONS

"Confusion" was a major hurdle for the students, as reflected in their comments on the course evaluations. They were frustrated at the level of uncertainty and apparent contradictions in the research they reviewed. This was a particular challenge for those students who began the course feeling uncomfortable with science. The students' confusion was actually both positive and realistic. The data are contradictory and incomplete. Political maneuvering does play a significant role. This is the real world. Many of the students came to appreciate these realities. However, the frustration tended to set a negative tone for the rest of the semester. Were I to teach the course again, a unit with this level of complexity and ambiguity would be moved to the end of the semester. An initial focus on smaller-scale, more concrete issues would allow students to build skills in critical analysis and establish their self-confidence with the vocabulary and processes of science incrementally throughout the semester, and then reinforce their growth and learning by tackling a very difficult issue as the capstone project.

The reflective judgment model of adult intellectual development developed by Kitchener and King (1981; cited in King, 1992) suggests that people
in early stages of intellectual development tend to view issues in terms of black/white dichotomies. Subsequent developmental stages begin to recognize ambiguity in issues, to the point where no decision or action is possible because the uncertainty is too overwhelming. At an advanced level of development, however, one is able to critically evaluate the evidence in light of the uncertainty, and select the most appropriate action or response based on that critical analysis. The class clearly followed this developmental sequence throughout the reformulated gasoline unit, with various students reaching different developmental “end-points” during the semester. Their papers reflected this variability, with some students conducting extensive analyses and drawing conclusions from that, and others focusing more heavily on the ambiguities in the data and the difficulties in making decisions in light of that ambiguity.

Constructing this unit took a sizable “leap of faith” on my part – I’m a behavioral ecologist who knew about as much about reformulated gasoline at the beginning of the semester as the students. Perhaps this was part of the problem, as the students clearly wished for more guidance. However, my lack of expertise also had a positive side. I was a partner in learning with my students rather than the “sage on the stage”. As such, they were forced to seek other resources to understand the issue. There were times when we experienced “aha!” moments together in the classroom – when we shared information with one another and suddenly we all understood the issue more thoroughly. There were also times when I could share their frustration at contradictions we encountered in information from various sources (or sometimes even from the same sources). In conclusion, I don’t feel that expertise in the subject area of the investigation is essential to a successful educational experience.

One of the objectives of this project was for students to get a sense of how scientists think, talk, and act; and although there was no concrete data to support this, it could be detected in their voices as they presented their ozone/milkweed projects. Students who, at the beginning of the semester, freely and vocally admitted that they were not scientists, discussed their data with a level of critical analysis and self-confidence that one would be excited to see in Biology majors. Similar gains were seen in their writing. Each group was given the opportunity to rewrite their research proposal. Grades on the final draft were about two letter grades higher than would have been awarded on the initial drafts. Finally, students also provided anecdotal accounts of how proud they were when they could explain to their roommates what reformulated gasoline was and why it mattered.

In conclusion, I feel that the reformulated gasoline unit pushed students to critically analyze a contemporary environmental issue. In doing so, they had to learn a variety of scientific concepts and also how science is done. Most vividly, they wrestled with the role of uncertainty in science and how that uncertainty comes to play at the interface between science and public policy. This was a difficult and frustrating unit for many of the non-science majors. Yet student evaluations and my own impressions suggest that despite the frustration, many students found value in the experience. Most importantly, it allowed the students to work through the type of process they’ll need to undertake when they are trying to analyze an issue they read in the newspaper, but to do so with a variety of academic support structures in place. My recommendation for others interested in trying a similar approach in their courses would be to more intentionally develop the skills of critical analysis throughout the semester, using incrementally more difficult issues as stepping stones toward a final issue at the level of the reformulated gasoline issue investigated here.

**Literature Cited**


Additional References on Reformulated Gasoline and Ground-Level Ozone

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Ampicillin Sensitivity In *Serratia marcescens*:
A Model System for Undergraduate Genetic Studies

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**ABSTRACT:** Bacteria are excellent organisms for genetic analysis, due in large measure to the relative ease of mutant isolation and characterization. The red-pigmented, environmental bacterium *Serratia marcescens* was used to develop a system of genetic analysis for the undergraduate genetics or microbiology curriculum. Mutants resistant to 25 µg/mL ampicillin \( \text{Ap}^r \) were scored with respect to several phenotypic properties: maximum cell densities in liquid medium; growth rates in liquid and solid media; prodigiosin pigment expression (Pdg); and expression of beta-lactamase enzyme activity (Bla). All of six independent mutants showed decreased stationary phase cell densities and slower growth rates without antibiotic. In contrast, Pdg and Bla were variously affected across this spectrum of mutants. These data allowed construction of a tentative, testable genetic model based on mutant phenotypes. The model hypothesizes both regulatory and structural genetic elements to provide a simple conceptual framework for the complex interrelationships of growth rate regulation, pigmentation production and ampicillin sensitivity \( \text{Ap}^s \). Since mutants like these can be isolated with positive selection and at high frequency, \( \text{Ap}^s \) in *S. marcescens* Nima constitutes a safe and effective classroom system for the teaching of genetic analysis through mutant studies.

**KEY WORDS:** *Serratia marcescens*, antibiotic resistance and genetic modeling.

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**INTRODUCTION**

The field of genetics was born as a result of the realization that the passage of observable characteristics from parent to offspring could be predicted and quantified. Genes, entities responsible for these characteristics, were later shown to consist of nucleic acids. As chemicals, genes can be modified by physical and enzymatic means. This current age of recombinant DNA technology has given humans unprecedented control over cell structure and function. Genetically engineered viruses, bacteria, plants and animals are now routinely used to further the purposes of humankind.

Genetic analysis has traditionally relied on the study of mutant organisms and their phenotypes. Mutants can present a loss-of-function phenotype (e.g., an inability to grow in medium lacking a nutrient) or a gain-of-function phenotype (e.g., the acquisition of antibiotic resistance). Gain-of-function phenotypes are particularly valuable in positive selection schemes, since the selective agent eliminates the nonmutant organism background.

Bacterial systems provide a powerful but conceptually simple introduction to genetic analysis for at least two reasons. First, bacteria are single-celled organisms which can be cultured in broth medium under uniform conditions of temperature and aeration. Under these circumstances bacteria grow to large numbers in relatively small volumes, and genetic variants arise in easily-detectable numbers. Second, bacteria are predominantly diploid organisms with relatively small genomes. These features promote excellent phenotypic penetrance and easy environmental selection for nonlethal mutations. Many
conceptual advances in cellular gene regulation and physiology have come about using microbial genetic systems (1).

The phenotypic characterization of six spontaneous, Ap' mutants of S. marcescens Nima are described. Several simple assays are utilized that are easily adaptable to a genetics or microbiology laboratory. Further, it is shown that the variety of mutant phenotypes in this system allows students to design testable genetic models incorporating biosynthetic and regulatory genes as well as larger aspects of cellular physiology.

MATERIALS AND METHODS

Bacteria, media, and growth conditions. Serratia marcescens Nima (ATCC # 29632) was subjected to ampicillin selection at 25 µg/mL. Spontaneous Ap' mutants were isolated on ampicillin plates from separate cultures begun from less than 1000 non-mutant cells (7). These mutants were designated APR1 through APR6 and follow the nomenclature established previously (8). Escherichia coli HB101 and HB101 (pBR322) are common molecular cloning vehicles (13); here they were used as beta-lactamase negative and positive strains, respectively, for reference assays of this enzyme. The latter strain expresses Bla constitutively from a multicopy plasmid. All bacteria were stored as frozen stocks and were initially cultured on blood agar base slants at 30°C. Bacteria were then subcultured in either nutrient broth + 0.5% maltose monohydrate or M9 minimal salts + 0.5% (w/v) glycerol with aeration in shaken flasks (8). Experiments were performed on cells grown to late stationary phase with one prior pregrowth under identical conditions unless otherwise indicated. The highly purified agar noble (Sigma Chemical Co., St. Louis) was included at 1.5% for growth on solid medium.

Bacterial growth kinetics. Broth cultures of S. marcescens were grown with shaking at 30°C ± 0.5°C for measurements of cell density and Pdg expression. Early log phase broth doubling times were calculated from cultures begun at a calculated optical density at 620 nm (OD₆₂₀) of 0.2 as detailed earlier (8). The linear relationship between bacterial colony area and time (4) utilized to measure strain growth rates on solid medium as detailed below.

Cells from 30°C slants were pregrown in nutrient broth + 0.5% maltose broth for up to 24 hours. Approximately 1 microliter of the pregrowth culture was inoculated onto the center of a partially dried agar plate. One inoculation was made per plate to eliminate products from neighboring colonies. The inocula were allowed to dry at room temperature, and the plates were incubated at 30°C for about 24 hours. Small, nearly circular colonies were then visible. At that time the plate bottoms were marked with two perpendicular lines which intersected at the colonies' centers; these identified two fixed colony diameters per plate. Incubation was continued at 30°C. The plates were briefly removed at 24-48 hour intervals for measurement of the two diameters, and average diameters were used to calculate colony areas. Colony areas were then plotted as functions of time over 7 to 11 days. Despite the development of asymmetric shape over time, colony areas as calculated from these two diameters consistently showed linear increases. Slopes of linear regression lines from plots of colony area in square millimeters vs. time in hours constituted the colony growth rates. Final solid medium growth rates were calculated from three to eleven growth assays whose regression lines gave squares of correlation greater than 0.9000.

It was determined to be convenient to measure colony diameter as magnified by an overhead projector (12). Consistency in magnification was achieved by projecting the colony image against a wall marked with two intersecting, perpendicular lines to match the lines drawn on the plate bottoms. Linear magnification was calibrated using common United States coins and a standard 10 cm diameter Petri dish; the average value was found to be 5.51X. Areas determined from colony images were therefore 30.4 times as great as actual colony areas. All solid medium growth rates reported here have been corrected for this magnification and represent true colony growth rates in square millimeters per hour.

Pdg assay. Pdg expression in actively growing cultures was assayed using a Beckman DU-640B spectrophotometer as detailed earlier (8). One unit of cell-associated Pdg expression is defined as 1000 • ([A₄₉₉ - 1.3831 • OD₆₂₀] ÷ OD₆₂₀), where A₄₉₉ is the culture absorbance at 499 nm.

Bla assay. Beta-lactamase activity in stationary phase broth cultures was assayed with the chromogenic substrate nitrocefin (11). 10 mg nitrocefin (Calbiochem, San Diego, CA) was reconstituted in 1 mL dimethyl sulfoxide (Sigma Chemical Co. St. Louis, MO) according to the manufacturer's instructions. This stock solution was diluted to 500 µg/mL as a 5% (v/v) solution in phosphate-buffered saline (PBS) pH 7.0 for use in Bla assays (13).

Bacteria from 30°C slants were pregrown and grown for 22-25 hours in nutrient broth + maltose with shaking to stationary phase. A 0.1 mL inoculum was added to 0.8 mL PBS pH 7.0. Nitrocefin stock at 500 µg/mL (0.1 mL) was then added, and the mixture was transferred to a 1 mL cuvette. A₄₉₀ increase was recorded for 3 minutes in a Beckman DU-640B spectrophotometer. Units of Bla activity were defined as 1000 multiplied by the slope of the regressed line from the linear portion of the reaction curve divided by both culture OD₆₂₀ and 0.1 mL. Duplicate assays were performed at room temperature (24°C to 26°C). Because prodigiosin-pigmented cultures showed
significant A_{486} background, control assays lacking nitrocefin were performed to ensure that the observed A_{486} increases were due to nitrocefin hydrolysis and not spurious increases in prodigiosin. A_{486} values varied insignificantly during the assay (data not shown).

Qualitative Bla assays were performed by adding 500 µg/mL nitrocefin directly to bacterial colonies (data not shown). These tests readily produced the yellow to red color change indicative of nitrocefin hydrolysis in the medium surrounding E. coli HB101 (pBR322) colonies. Plasmidless HB101 showed no color change. Unfortunately, most S. marcescens isolates did not produce a clear color change on nutrient broth + maltose agar plates. The only exception was strain APR5, which produced a definite but much smaller red zone relative to HB101 (pBR322).

**Statistical analysis.** Two-sample t tests of growth yields and least-squares linear regression to determine growth rates were performed with Axum 6.0 software (Mathsoft, Inc.).

**RESULTS**

*S. marcescens* Ap’ mutant growth phenotypes in broth culture. One phenotype common to all six Ap’ mutants characterized was readily apparent: reduced broth culture stationary phase cell yield. Data presented in Table 1 show that the mutants grew to approximately one-half to three-quarters of the cell density of their Ap’ parent strain as measured spectrophotometrically. Pairwise comparison of parent to individual mutant growth yields using standard one-sided, two-sample t tests indicate significantly reduced mutant growth yields at the 5% significance level.

Table 2 lists early log phase doubling times for Nima and its Ap’ derivatives. The time required for the cell division cycle is significantly reduced only for strain APR2. Strain APR6 showed unexpectedly high variation in broth growth rates, suggesting either a genetic instability within populations of this mutant or a stable phenotype that is unusually sensitive to slight fluctuations of environmental conditions.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Early Log Phase Doubling Time in Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nima</td>
<td>54.0 (n = 4; s = 3.87)</td>
</tr>
<tr>
<td>APR1</td>
<td>62.1 (n = 3; s = 5.48)</td>
</tr>
<tr>
<td>APR2</td>
<td>83.0 (n = 3; s = 4.08)</td>
</tr>
<tr>
<td>APR3</td>
<td>51.5 (n = 3; s = 2.91)</td>
</tr>
<tr>
<td>APR4</td>
<td>57.6 (n = 3; s = 2.37)</td>
</tr>
<tr>
<td>APR5</td>
<td>54.6 (n = 3; s = 3.85)</td>
</tr>
<tr>
<td>APR6</td>
<td>61.9 (n = 3; s = 13.1)</td>
</tr>
</tbody>
</table>

**TABLE 1. MUTANT GROWTH YIELD IN BROTH CULTURE.** Inocula from 30°C slants were grown to saturation in shaken flasks at 30°C in nutrient broth + maltose. Stationary phase OD_{620} values for Nima and mutant cultures were determined from two separate growth experiments as described previously (8).

**TABLE 2. MUTANT GROWTH KINETICS IN BROTH CULTURE.** Growth was begun by dilution of overnight pregrowth cultures into fresh nutrient broth + maltose to a calculated OD_{620} = 0.2. Cultures were grown with shaking for approximately 9 hours, and optical density readings were taken at 30 to 60 minute intervals. Points in the early phase of logarithmic growth (see Figures 1 through 7) were used to calculate doubling times.
final Nima cell yield of $\text{OD}_{620} \approx 10$. This is most striking for APR2 and APR4, which virtually cease growth after the early log phase maximum of $\text{OD}_{620} \approx 3$. All mutants show distinct growth kinetics, suggesting that different genetic loci are affected in each strain. Taken together, growth yield and growth kinetic data suggest that an impaired growth rate, particularly through late logarithmic phase, leads to the $\text{Ap}^\prime$ phenotype.

Figure 1. Growth and pigmentation of $S$. marcescens Nima in nutrient broth + maltose at $30^\circ$C.

Figure 2. Growth and pigmentation of $S$. marcescens APR1 in nutrient broth + maltose at $30^\circ$C.
Figure 3. Growth and pigmentation of *S. marcescens* APR2 in nutrient broth + maltose at 30°C.

Figure 4. Growth and pigmentation of *S. marcescens* APR3 in nutrient broth + maltose at 30°C.

Figure 5. Growth and pigmentation of *S. marcescens* APR4 in nutrient broth + maltose at 30°C.
The Ap' mutants’ growth rates on solid medium were determined. Because most undergraduate laboratory sessions cannot accommodate the approximately 11 continuous hours needed to perform broth growth curves, this assay provides a convenient alternative. A solid-liquid growth profile of strain Nima and its six Ap' derivatives is presented in Figure 8. This figure incorporates the early log phase doubling times of Table 2 to present a complete description of mutant growth rates. The data clearly show that mutation to ampicillin resistance is associated with reduced growth rate on solid medium and may include a significant reduction in early log phase broth growth rate.
Mutant pigmentation. Figures 1 through 7 also show Pdg expression by Nima and strains APR1 through APR6. APR1 expressed Pdg normally, while APR3 overexpressed the pigment. The latter strain expressed about twice the wild type level when stationary phase cells were compared (data not shown). APR2, APR4 and APR6 underexpressed Pdg. Strain APR5 did not make Pdg under any growth conditions tested. Altogether, four of the six mutants characterized showed reduced or eliminated Pdg expression. These data suggest that mutations which reduce Pdg expression are a common means of promoting the Ap' phenotype in S. marcescens.

Bla expression by Nima and its Ap' mutants. Beta-lactam antibiotics are irreversible inhibitors of the transpeptidase enzymes which function to cross-link elements of the bacteria cell wall (5). Bla enzymes mediate Ap' by hydrolyzing ampicillin's beta-lactam ring. Because many beta-lactam resistant clinical isolates have been found to have significant Bla activity, we decided to test our mutant strains using a simple broth assay and the chromogenic substrate nitrocefin.

Strains APR1 through APR6 were isolated and purified on rich, solid medium containing 25 µg/mL ampicillin. Early mutant characterization suggested that the Ap' phenotype is not expressed at low cell density (data not shown). If growth to late logarithmic or stationary phase can provide an inducing signal, this pattern of Ap' becomes consistent with the established pattern of Gram-negative ampC (chromosomal beta-lactamase) gene expression (2). Therefore, Bla activity in stationary phase cells was assayed, and the results are presented in Table 3.

Bla expression by strain Nima was minimal when the cells were grown in nutrient-poor medium and at high temperature, conditions which promote poor Pdg expression (Table 3). Bla expression in four of the six mutant strains was relatively unaffected. Strain APR4 showed below-normal expression, and strain APR5 showed an increase in Bla expression. Earlier data suggested that the level of Bla activity in strain Nima is insufficient to provide Ap' in the absence of a mutational event (7). Unfortunately, it cannot be determine from these data whether the Bla increase seen with APR5 is sufficient to mediate resistance. Taken together, these data lead to the surprising conclusion that increased Bla activity is not a primary mechanism for mediating 25 µg/mL ampicillin resistance in S. marcescens Nima.
TABLE 3. BETA-LACTAMASE ACTIVITY OF S. marcescens Nima AND ITS Ap' DERIVATIVES. Activity values shown are averages of duplicate assays with standard deviations. Room temperature assays were performed on stationary phase cells pregrown and grown in shaken flasks of nutrient broth + maltose. Values marked with the * symbol were determined in separate experiments whose E. coli controls performed similarly to the ones reported here. Values marked with the # symbol were determined from cells pre-grown at 21°C to 25°C and grown to early stationary phase at 37°C.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Broth Growth Medium</th>
<th>Growth Temperature</th>
<th>Activity in Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. coli HB101</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>0.350 (s = 0.495)</td>
</tr>
<tr>
<td>E. coli HB101 (pBR322)</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>4073 (s = 114)</td>
</tr>
<tr>
<td>Nima</td>
<td>M9 + glycerol</td>
<td>30°C</td>
<td>* 9.00 (s = 3.11)</td>
</tr>
<tr>
<td>Nima</td>
<td>nutrient broth + maltose</td>
<td>37°C</td>
<td>*# 3.90 (s = .990)</td>
</tr>
<tr>
<td>Nima</td>
<td>nutrient broth + maltose</td>
<td>37°C</td>
<td>*# 9.40 (s = 1.41)</td>
</tr>
<tr>
<td>APR1</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>17.4 (s = 2.19)</td>
</tr>
<tr>
<td>APR2</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>18.3 (s = 4.45)</td>
</tr>
<tr>
<td>APR3</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>17.8 (s = 0.0707)</td>
</tr>
<tr>
<td>APR4</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>1.2 (s = 0.707)</td>
</tr>
<tr>
<td>APR5</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>27 (s = 4.24)</td>
</tr>
<tr>
<td>APR6</td>
<td>nutrient broth + maltose</td>
<td>30°C</td>
<td>14.6 (s = 0.283)</td>
</tr>
</tbody>
</table>

DISCUSSION

The Ap' mutant phenotypes described above are summarized in Table 4. One assumes that each mutant phenotype is the result of a single loss-of-function event, the corresponding gene may easily be assigned a function in wild type Nima cells. A table such as this is a helpful first step toward student construction of a working genetic model explaining cellular physiology in non-mutant cells. The next step should include a review of the current scientific literature. This will facilitate appropriate connections between experimental observations and published work in related systems. These skills constitute the heart of scientific investigation, and they are best learned through individual contemplation of experimental data in the context of an existing knowledge base.

TABLE 4. SUMMARY OF MUTANT PHENOTYPES AND GENETIC FUNCTIONS. Down arrows indicate a slower growth rate or reduced gene product levels relative to strain Nima; up arrows indicate an increased amount of gene product. A dash indicates no gene product.
LITERATURE REVIEW

Prodigiosin is expressed by *S. marcescens* as a secondary metabolite in the general method of gene regulation known as quorum sensing (6, 8, 15). Another strain of *S. marcescens*, ATCC 39006, is also known to express the beta-lactam antibiotic carbapenem in a similar fashion (15). Additionally, a genetic locus called *rap* (for regulation of antibiotic and pigment) has been identified as a common activator of both Pdg and carbapenem expression (14). Although the mechanism of carbapenem resistance for cells which produce it remains obscure, it is possible that Pdg could be coregulated with a Bla enzyme in some *S. marcescens* strains.

The chromosomally-encoded Bla enzymes of Gram-negative bacteria, collectively known as AmpC proteins, are inducible by beta-lactam compounds such as ampicillin (2). The DNA-binding regulatory protein AmpR functions as a repressor when no beta-lactam compound is available and as a co-inducer when these compounds are present. Mutations in *ampR* lead to a noninducible phenotype with AmpC levels two to three times that seen in noninduced cells. Several other Amp proteins have been identified. Some of these are postulated to transduce an upregulatory signal across the cytoplasmic membrane from periplasmic beta-lactam binding proteins bound to their ligands. This is thought to convert AmpR from its repressor form to its inducer form and induce *ampC* (9). Null mutations in the *ampD* locus can also lead to increased levels of AmpC.

GENETIC MODEL CONSTRUCTION

It is reasonable to assume that cells whose growth is impaired could show the Ap' phenotype, since ampicillin is a cell wall synthesis inhibitor (5). Indeed, ampicillin selection to eliminate growing, nonmutant cells has been used to isolate auxotrophic mutants of *E. coli* (10). Ampicillin selection was therefore expected to produce *S. marcescens* mutants which show impaired growth yields and growth rates; this was found to be the case (Tables 1 and 2; Fig. 8).

Our thinking about the genetic regulatory cascade which leads to the Ap' phenotype in *S. marcescens* Nima begins with the observed correlation of Pdg expression and late logarithmic growth (Fig. 1). Conditions of growth medium and temperature that do not promote Pdg expression lead to growth shutoff at lower cell densities and no apparent late logarithmic growth (8). Therefore, it is postulated that Pdg expression is required for late logarithmic growth. Further support for this idea is found in the growth phenotypes of more than half of the Ap' mutants. Strains APR2, APR4, APR5 and APR6 (Figs. 3, 5, 6 and 7, respectively) showed reduced or eliminated Pdg expression and a concomitant inability to grow through late logarithmic phase. Reduction or elimination of Pdg expression appears to be a major means of Ap' in *S. marcescens* Nima.

A tentative genetic model describing the physiology of ampicillin sensitivity in *S. marcescens* Nima is presented in Figure 9. Bacteria growing in rich medium, for example nutrient broth + maltose, reach the appropriate density for the onset of secondary metabolism. This density is not reached by APR2, perhaps due to its decreased growth rate. Rap, or a similar positive regulatory protein, then initiates expression of both Bla and Pdg. Support for this is found in the phenotype of APR4, which underexpresses both gene products. One or more Pdg positive regulatory genes then activates the pigment biosynthetic genes. The existence of these gene(s) is suggested by reduced Pdg but unaffected Bla expression in APR6. Because no pigment was detected in APR5, its affected gene probably encodes an enzyme which is directly involved in Pdg biosynthesis. APR5's phenotype indirectly allows identification of Pdg as a feedback repressor of its own synthesis. Since Bla is overexpressed in this mutant, repression in non-mutant cells must be mediated at a common point (e.g., *rap*). Pdg expression then allows late logarithmic growth and subsequent ampicillin sensitivity. Because neither Pdg nor Bla is affected in APR1, its defect must be at a late point in the second phase of logarithmic growth.

While our model is consistent with the literature and our experimental data, it does not easily account for the behavior of all Ap' mutants. The drug resistance of APR3 may be explained by its reduced growth yield (Table 1) and its reduced growth rate on solid medium (Fig. 8). However, this strain overexpressed Pdg (Fig. 4), suggesting that a feedback repressor of pigment biosynthesis has been inactivated (Fig. 9). Because we believe Pdg is required for late logarithmic growth, a hyper-pigmented strain could be predicted to be Ap'. One possible resolution to this paradox is the idea that prodigiosin is only one of a series of interdependent factors required for full growth through late logarithmic phase. A second factor, defective in APR3, could act genetically “downstream” of Pdg and inhibit pigment synthesis. Some support for this notion is found in Table 1, which shows that APR3 grows to a higher yield than the other mutants.
**FUTURE WORK**

Our model portrays growth rate regulation in *S. marcescens* as an intricately-controlled process. Characterization of more than these six mutants will probably reveal distinct phenotypes and more genetic loci. APR5’s phenotype suggests that the affected gene is an *ampR* homologue. More mutations in this locus can be visually detected by two properties: non-pigmentation and chromogenic colony identification on plates with nitrocefin (see Materials and Methods).

Finally, the details of late logarithmic growth present an attractive area for further work, since these Ap\(^r\) mutants can be distinguished from others by retention of strong pigmentation.

Our model also suggests that other changes which down-regulate Pdg or slow growth rate could lead to Ap\(^r\). This is easily testable with non-pigmented, stationary phase cells grown in minimal medium or in rich medium at 37°C (8). The dependence of Ap\(^r\) on high cell density also suggests that the average
mutation rate of 1.53 events per $10^8$ cell divisions (7, 16) may be different if early logarithmic cells are assayed instead of cells grown to stationary phase. The influence of low levels of ampicillin on Bla activity also remains to be investigated.

Projects unrelated to genetic model building are also possible. One simple and inexpensive approach to cloning the Nima $ampC$ gene would use a $phoA$ reporter gene delivered on a suicide plasmid (3). Because APR5 overexpresses the Bla gene product, it would be ideal for this work.

CONCLUSIONS.

Bacteria are excellent organisms for mutant studies, since variants can be isolated with positive selection and at high frequency. The gap between traditional genetic analysis and molecular biology is also easily bridged in bacterial systems, since molecular cloning strategies based solely on positive selection and screening schemes are widely available. If desired, many parts of the $S. marcescens$ system may be adapted to fit single undergraduate laboratory sessions. These include measurements of mutation rate (7), broth growth rate (8), plate growth rate (this work) and beta-lactamase (this work). The analysis of mutant phenotypes detailed here provides excellent training in scientific problem-solving. Furthermore, it provides students with a critical link between experimentation and a broader appreciation of gene regulation and cellular physiology as a coordinated unit.

ACKNOWLEDGMENTS

The authors wish to thank Harris-Stowe State College and the National Science Foundation (grant # 9650766) for generous financial assistance with the purchase of laboratory instrumentation. We are grateful to the National Center for Biotechnology Information and Washington University (St. Louis) for bibliographic and library resources. Finally, we thank Ellen Ritchie for technical assistance and Bill Bowman for his critical review of this manuscript.

REFERENCES AND NOTES

16. This value is a refinement of the $2.4 \times 10^{-6}$ value published in reference 7. This new figure is based on an experimentally-determined, more precise relationship between optical density and Nima cell number: $1 \text{ OD}_{620} = 8.89 \times 10^8$ stationary phase Nima cells per mL.

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**Biocomplexity in Undergraduate Education: From Hard Data to Hard Decisions**

A BioQUEST Curriculum Consortium Workshop

**Integrate** biocomplexity into undergraduate education.  
**Develop** a framework for biocomplexity education.  
**Explore** new ideas.  
**Share** teaching strategies.  
**Discuss** new classroom approaches with professional peers.  
**Create** biocomplexity problem solving experiences for students, and investigate BioQUEST software.

**When:** June 15-23, 2002  
**Where:** Beloit College, Beloit, WI  
(Located 1.5 hours from Chicago’s O’Hare Airport)

**Cost:** The workshop, funded by the Howard Hughes Medical Institute, provides workshop development, private campus rooms, and all meals.

For more information, **workshop application** and workshop updates go to:  

or contact BioQUEST by email at bioquest@beloit.edu or by phone (608) 363-2784.

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**Call for Nominations**  
**President-Elect & Steering Committee Members**

ACUBE members are requested to nominate individuals for the office of President-Elect and two at large positions on the ACUBE Steering Committee. Self-nominations are welcome.

If you wish to nominate a member of ACUBE for a position, send a **Letter of Nomination** to the chair of the Nominations Committee:  
Dr. Lynn Gillie, Dept. of Biology, Elmira College  
One Park Place, Elmira, NY 14901  
Voice – (607) 735-1859, E-mail – lgillie@elmira.edu
The Association of College and University Biology Educators (ACUBE), placed the organization’s rich archive of materials online for the benefit of the members and interested biology educators. Nearly 45 years of the society’s publications and resources are currently accessible.

Featuring the Online ACUBE archives:

- Bioscene: Journal of College Biology Teaching (1975-present)
- AMCBT Newsletter (1964-1974)
- AMCBT Proceedings (1957-1972)

ACUBE Organizational Information:
- ACUBE Executive Committee
- Editorial Board of Bioscene
- ACUBE Annual Meeting Information
- Meeting Abstract Submission Form
- Searchable Membership Database
- Online Membership Application
- Scientific Meetings of Interest
- ACUBE in the News
- Sustaining Member Links

Call For Resolutions

The Steering Committee of ACUBE requests that the membership submit resolutions for consideration at the 2002 Annual meeting to the Chair of the Resolutions Committee. Submit proposed resolutions to:

Dr. Richard Wilson, Dept. of Biology, Rockhurst University, 1100 Rockhurst Rd Kansas City, MO  64110, Phone  (846) 501-4048, wilson@vax1.rockhurst.edu
Columbia College Chicago is located in downtown Chicago, in the south Loop area, at the hub of America’s heartland, and easily accessible by air, rail and road. Columbia is within walking distance of the lakefront, and three world-class museums; the Field Museum of Natural History, the John G. Shedd Aquarium, and the Art Institute of Chicago. Columbia College Chicago is itself the home of the Museum of Contemporary Photography, and numerous other museums, cultural and shopping venues are readily accessible via public transit or automobile. Because of our downtown location, Columbia College Chicago can be conveniently reached using private vehicles, or public transportation from anywhere in the metropolitan area, in particular from O’Hare International Airport and Midway Airport.

Columbia College Chicago

Columbia College Chicago is an independent liberal arts college in downtown Chicago. With an enrollment of over 9,400 students, it is the country’s largest arts and communications college. For additional information, visit our website at www.colum.edu.

Science and Mathematics Department

Since its inception, the Science and Mathematics Department has served as an important extension of the professional development of Columbia’s students. The curriculum, designed specifically for those concentrating in performing, visual, and communications arts, provides basic scientific instruction and a mastery of mathematics fundamentals.

The primary objectives of the department are to provide students with a comprehensive scientific and mathematical background, the adaptability and flexibility they will need in order to evolve with continuing changes in the world, and the ability to deal effectively with specific changes in their professional disciplines. Thus, critical thinking and problem solving are major objectives of the various departmental programs.

The Department also seeks to fill in the knowledge gap between scientific and political decision-makers and the lay public on current issues such as energy policy, global warming, the economy, education, genetic engineering, and nuclear energy. The curriculum is designed to educate students so that they may participate intelligently in the national debates of such survival concerns. In order for every citizen to understand and participate in discussions of such issues, they must have some level of scientific literacy.
ACUBE 46TH Annual Meeting
September 12-14, 2002
Columbia College
Chicago, IL

Visualizing and Communicating Environmental Issues

Preliminary Program

Thursday, September 12th

Noon – 6:00 PM  Field Trip to Mazon Creek
                Preregistration ($40.00), includes box lunch
6:00 - 8:00 PM  Registration and Reception
8:00 - 9:00 PM  Opening Session

Welcome to ACUBE:
ACUBE President: Malcolm Levin, University of Illinois – Springfield

Welcome to Columbia College:
Program Chair: Bob Wallace, Ripon College
Local Arrangements Chair: Abour Cherif & Gerry Adams, Columbia College

OPENING ADDRESS (Public Welcome to Attend)
Waters of Wisconsin to the World — Drop of Life
David Kuckuk
Director, E.H. May Environmental Park
Sheboygan Co., WI

9:15 - 10:15 PM  Executive Committee Meeting

Friday, September 13th

7:00 AM - 5:00 PM  Registration table
7:00 - 8:00 AM  Buffet Breakfast  (by Interest Group)

9:00 AM - Noon  SUSTAINING MEMBER EXHIBITS
(refreshments provided)

8:15-9:45 AM  CONCURRENT WORKSHOP SESSIONS I

1. Developing distance courses in science in compliance with the A.D.A.  
   Ateegh Al Arabi  (Johnson County Community College)
2. Implementing computer technologies in the classroom: some new approaches.  
   Robert Mahoney  (Columbia College)
3. Investigative cases by community college faculty.  
   Margaret Waterman & Ethel Stanley  (Southeast MO State University & Beloit College)

9:50 – 10:20 AM  SUSTAINING MEMBER EXHIBITS
(refreshments provided)

- NewSci Publishing Corporation
- Pearson Custom Publishing

9:50-10:20 AM  POSTER SESSION I

1. Bimodal distributions,  
   Gillie, Lynn  (Elmira College)
   Nowicki, Alan  (Highland Community College)
3. Recasting your Curriculum Vitae according to the Boyer (1990) of faculty development,  
   Wallace, Robert  (Ripon College)

10:30 AM - noon  CONCURRENT WORKSHOP SESSIONS II

1. Using a webcam to visualize biological processes with pedagogically inconvenient time scales.  
   Steven D. Brewer  (University of Massachusetts)
2. Cell receptors.  
   Ann M. Larson  (University of IL, Springfield)

10:30 - 11:15 AM  CONCURRENT PAPER SESSIONS I

1. The digital field trip.  
   Austin Brooks  (Wabash College)
2. Microbial community profiles of alkaline saline wetlands.  
   Barbara J. Clement  (Doan College)
3. Impacts of an inquiry-based Introductory Biology curriculum on student learning and attitudes.  
   Terry Derting & Claire Fuller  (Murray State University)
4. Protein Synthesis.  
   Gregory Grabowski  (University of Detroit–Mercy)

11:20 - 12:05 AM  CONCURRENT PAPER SESSIONS II

Toward a better understanding of the environment.  
Ben Ofari-Omoah & Abour Cherif  (University of Wisconsin–Stevens Point; Columbia College)
Study abroad: cultural & natural history of St. Eustatices Island.  
Nancy Sanders  (Truman State University)
"Dealing" with functional group recognition.  
Michael J. Welsh  (Columbia College)

Student creative final projects as effective tools to maximize learning.  
Sharon Doering, Joella Sinda, & Abour Cherif  (_____: Illinois Institute of Art; Columbia College)

12:15 - 1:00 PM  Luncheon and First Business Meeting

First and Final Call for Nominations!!
1:00 - 1:45 PM  Luncheon Program

_Gone in 60 Seconds: The Evanescence of Scientific News_

_Jeff Lyon_, Professor of Science Journalism, Columbia College & Senior Science Writer, _The Chicago Tribune_; author of _Playing God in the Nursery_

2:00 - 5:00 PM  SUSTAINING MEMBER EXHIBITS

(refreshments provided)

- NewSci Publishing Corporation
- Pearson Custom Publishing

2:50 - 3:20 PM  POSTER SESSION II

_Repeat of Poster Session I_

3:30 - 5:00 PM  CONCURRENT WORKSHOP SESSIONS III

1. _Nutrition and you_  Sharron K. Jenkins (_Columbia College_)
2. _Distance education like white elephants: insect ID at a distance._ Wyatt Hobach & Leon Higley (_University of Nebraska, Kearney_)
3. _Roundtable discussion for department chairs._ Tom Davis (_Loras College_)

5:05 - 5:45 PM  Web Committee Meeting

6:00 - 7:00 PM  Social

(resumes of candidates available for review)

7:00 - 9:00 PM  BANQUET and Second Business Meeting

(two-minute speeches prior to banquet; balloting after dinner presentation)

_Dinner Presentation_

_Teaching & communicating about integrative issues of health & disease_

_Helen Davies_, Ph.D., Department of Microbiology, School of Medicine, _University of Pennsylvania_

_Saturday, September 14th_

7:30 - 8:45 AM  _Buffet Breakfast_ (by Interest Group)

7:45 - 8:45 AM  Bioscene Editorial Board

9:00 - 9:45 AM  CONCURRENT PAPER SESSION IV

1. _Bioinformatics and environmental problem solving._ Buzz Hoagland (_Westfield State College_)
2. _Ecology through art._ Zachia Middlechild (_______)
3. _An international collaborative course on recombinant DNA technology._ Presley Martin & Cynthia Bauerle (_Hamline University_)
4. _Photodynamic therapy of cancer cells._ Mahmoud Khalili (_Northeastern Illinois University_)

10:00 - 10:45 AM  CONCURRENT PAPER SESSIONS V

1. _Developing an environmental ethic: perspectives on the use of environmental philosophies in non-majors and majors courses._ Kathleen Marr (_Lakeland College_)
2. _The ongoing popularity of creatinoism among biology teachers._ Randy Moore (_University of Minnesota_)

_Preliminary Program_  Bioscene  37
3. **Illusions: the eye, the brain, and the mind.** Peter Insley (Columbia College)

4. **Science and technology in forensic science.** A. Karl Larsen

11:00 AM - 12:15 PM  **Luncheon and Third Business Meeting**

**BUSINESS MEETING**

Election Results:

Lynn Gilley, Elmira College

Resolutions:

Dick Wilson, Rockhurst University

Executive Secretary Report:

Pres Martin, Hamline University

Bioscene:

Ethel Stanley, Beloit College & Tim Mulkey, Indiana State University

Presidential Address:

Malcolm Levin, SIU-Springfield

2003 Meeting:

12:30 - 1:15 PM  **Steering Committee Meeting**

Includes newly elected Steering Committee members!

12:30 – 3:30 PM  **SPECIAL FACULTY DEVELOPMENT OPPORTUNITY**

Open session for local educators & ACUBE Participants.

2:00 – 6:00 PM  **Post conference Field Trip**

John G Shedd Aquarium

Preregistration ($20.00)

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**Housing Preview**

45th Annual ACUBE Fall Meeting

Columbia College, Chicago, IL

September 12-14, 2002

**Lodging:** The following hotels are within walking distance of the meeting facilities at Columbia College. A block of rooms has been reserved at the Best Western Grant Park Hotel for meeting participants. Please make your reservations early.

- **Best Western Grant Park Hotel**
  1100 South Michigan Avenue.
  Chicago, IL 60605
  Phone: 312-922-2900
  FAX: 312-922-8812
  $89 (plus tax) single occupancy
  $99 (plus tax) double occupancy

- **Chicago Travelodge-Downtown**
  65 E. Harrison St.
  Chicago, IL
  Phone: 312-427-8000
  FAX: 312-247-8261

- **Congress Plaza Hotel**
  520 South Michigan Avenue
  Chicago, IL 60605
  Phone: 312-427-3800

- **Hilton Chicago and Towers**
  720 South Michigan Avenue
  Chicago, IL 60605
  Phone: 312-922-4400
Call for Abstracts

Association of College and University Biology Educators (ACUBE)
46th Annual Meeting
Columbia College – Chicago, Illinois
Thursday, September 12 – Saturday, September 14, 2002

Visualizing and Communicating Environmental Issues

Paul Ehrlich and John Holdren proposed that a powerful tool for understanding environmental issues is through a very simple equation,

\[ \text{Human Impact} = \text{Population} \times \text{Affluence} \times \text{Technology} \quad (I = P \times A \times T) \]

How can the perspectives of the arts, communications and media, the social sciences, and others regarding these factors enhance biology and inform biologists evaluating them, to identify problems and reach solutions?

Presentations and workshops addressing other topics are welcome. Below are some examples of potential presentations:

- Curricula – Environmental Studies/Environmental Sciences – content/method/delivery
- Sampling and Reconstructing Environments: What the past and the present tell us
- Imaging/Digital Video/GIS as Forms of Communication
- Environmental Ethics
- Teaching Identification/Taxonomy: why/how
- Interdisciplinary Problem Solving

Many of you have addressed these issues in creative ways. Please consider sharing your ideas and techniques at the ACUBE 46th Annual Meeting at Columbia College in Chicago in 2002.

Please email your abstract AND mail a hard copy of the abstract with the completed form BEFORE July 1, 2002 to:

Robert Wallace, Department of Biology, 300 Seward St., Ripon College, Ripon, WI 54971
Ph: 920-748-8760       Fax: 920-748-7243       email: WallaceR@Ripon.edu

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Proposed Title:_____________________________________________________________ ____________________

Presentation type _______ 90 minute workshop           _______ 45 minute paper           ________ Poster

Equipment/facility needs: _____35 mm slide projector _____Overhead projector

_____Macintosh projection system _____Macintosh computer lab

_____PC projection system _____PC computer lab

_____Other: (explain)

Name of presenter:_____________________________________________________________________________

Work address of presenter:  ______________________________________________________________________

_________________________________________________________________________________ ____________

Phone No. presenter:__________________________  email_____________________________________________

Please include names and contact information for additional presenters on back.
ACUBE 45th Annual Meeting
Oct. 11-13, 2001
University of Nebraska at Kearney

Biology in the Light of Evolution

Participant photos taken during the Fall 2001 ACUBE meeting by Alida Hartwell, a biology major at the University of Nebraska - Kearney.

ACUBE
46th Annual Meeting
Columbia College
Chicago, IL

September 12-14, 2002
Travel Preview
46th Annual ACUBE Fall Meeting
Columbia College Chicago
September 12-14, 2002

BY CAR
From I-55 (Stevenson) Proceed to the end of the expressway and take Lake Shore Drive north to Balbo Street. Take Balbo to Wabash; turn right to Harrison.

From I-57 to I-94 (Dan Ryan) or I-90/94 (Kennedy/Edens) Exit on Congress Parkway. Drive east to Wabash; turn right to Harrison Street.

From I-290 (Eisenhower) Follow signs for Congress Parkway. Drive east to Wabash; turn right to Harrison Street.

Parking Parking is available on Wabash between Harrison and Balbo and on the corner of Wabash and Harrison. Walk east on Harrison to Columbia College Chicago. Get your ticket stamped at any of our security guard stations for a discount rate.

BY METRA/AMTRAK
Northwest Station & Union Station
Take the Indiana/Hyde Park #1 bus from Adams and Canal Street south to Michigan and Harrison.

LaSalle Station
Walk five blocks east on Harrison to Michigan Avenue.

Randolph Station
Take the #3 bus from Randolph and Michigan south to Harrison.

BY CTA
Toll Free 1-888-968-7282

Red Line
Monday thru Friday -- Harrison and State stop. Walk two blocks east to Michigan Ave. Weekends and Holidays -- Jackson and State stop. Walk two blocks east to Michigan Ave., turn right and walk three blocks south to Harrison.

BY PLANE
Midway Airport Subway "EL" -- Take Orange Line to Library/Van Buren stop. Walk east to Michigan Avenue. Take right to Harrison. Taxi -- Expect to pay around $15 from Midway to Columbia College.

O'Hare Airport Subway "EL" -- Take Blue Line to LaSalle stop. Walk east on Congress to Michigan Avenue. Take right to Harrison. Taxi -- Expect to pay around $25 from O'Hare to Columbia College.
Manuscript Guidelines for

Bioscene: Journal of College Science Teaching

A publication of the Association of College and University Biology Educators

Manuscripts submitted to the Bioscene should primarily focus on the teaching of undergraduate biology or the activities of the ACUBE organization. Short articles (500-1000 words) such as introducing educational resources provided by another organization, reviews of new evolution software, suggestions for improving sampling methods in a field activity, and other topics are welcome as well as longer articles (1000-5000 words) providing more in depth description, analyses, and conclusions for topics such as introducing case-based learning in large lectures, integrating history and philosophy of science perspectives into courses or initiating student problem solving in bioinformatics.

Please submit all manuscripts to editor(s):

**Ethel Stanley**
Department of Biology
Beloit College
700 College St.
Beloit, WI 53511
stanleye@beloit.edu
FAX: (608)363-2052

**Timothy Mulkey**
Department of Life Sciences
Indiana State University
Terre Haute, IN 47809
mulkey@biology.indstate.edu
FAX: (812) 237-2418

We prefer receiving manuscripts as Rich Text Format or RTF files to facilitate distribution of your manuscript to reviewers and to work on revisions. You can mail us a disk or attach your file to an email message with the subject line as BIOSCENE. All submissions should be double-spaced and may follow the style manual for publication you are currently using such as APA. You will also need to include:

- title
- author(s) information:
  - full names
  - name of your institution with the address
  - email address, phone number, and/or fax number
- brief abstract (200 words or less)
- keywords
- references in an appropriate format

Please refer to issues of the Bioscene from 1998 or later for examples of these items. You can access these issues at: [http://acube.org/bioscene.html](http://acube.org/bioscene.html)

**Graphics are desirable!** Lengthy sections of text unaccompanied by tables, graphs or images may be modified during layout of the issue by adding ACUBE announcements or other graphics. While tables and graphs may be included in the manuscript file, images should be submitted as individual electronic files. If you are unable to provide an image in an electronic format such as TIFF for Macintosh or BMP for Windows, please include a clear, sharp paper copy for our use. At this time, graphics will be printed as grayscale images with a minimum resolution of 300 dpi and a maximum resolution of 1200 dpi. Cover art relating to an article is actively solicited from manuscript contributors.

Upon receipt of your manuscript, an email or fax will be sent to the author(s). The editor will forward your manuscript to the chair of the editorial board. Within the next two weeks or so, your manuscript will be sent to two reviewers. You should receive comments when changes are recommended from the reviewers prior to publication of the article. Manuscript format is usually retained as accepted; however, limits of publishing the issue may affect the length of an article. Graphics may be added by the editors when lengthy sections of text are unaccompanied by tables, graphs or images. Previously published work should be identified as such and will be reviewed on a case-by-case basis. Your article will appear in the Bioscene and then on the ACUBE website: [http://www.acube.org](http://www.acube.org) shortly after the issue date.
NAME: ___________________________________________ DATE: ____________________

TITLE: __________________________________________________________________________

DEPARTMENT: ______________________________________________________________________

INSTITUTION: _____________________________________________________________________

STREET ADDRESS: __________________________________________________________________

CITY: __________________________________  STATE: ______________ ZIP CODE: ____________

ADDRESS PREFERRED FOR MAILING: ________________________________________________

CITY: __________________________________  STATE: _____________ ZIP CODE: ______________

WORK PHONE: ___________________ FAX NUMBER:  __________________________________

HOME PHONE: ___________________ EMAIL ADDRESS: __________________________________

**MAJOR INTERESTS**

- Biology
- Botany
- Zoology
- Microbiology
- Teacher Education
- Other

**SUB DISCIPLINES:** (Mark as many as apply)

- A. Ecology
- B. Evolution
- C. Physiology
- D. Anatomy
- E. History
- F. Philosophy
- G. Systematics
- H. Molecular
- I. Developmental
- J. Cellular
- K. Genetics
- L. Ethology
- M. Neuroscience
- N. Other

 RESOURCE AREAS (Areas of teaching and training): ________________________________

 RESEARCH AREAS: ______________________________

How did you find out about ACUBE? ________________________________________________

Have you been a member before: ______________ If so, when? __________________________

**DUES (Jan-Dec 2002)**

- Regular Membership $30
- Student Membership $15
- Retired Membership $5

Return to: Association of College and University Biology Educators, Attn: Pres Martin, Executive Secretary, Department of Biology, Hamline University, 1536 Hewitt Avenue, Saint Paul, MN 55104
The BioQUEST Curriculum Consortium is an open community of bioscience educators and researchers interested in undergraduate science curricular reform. The projects of the Consortium are designed to help teachers develop tools and resources to provide their students with opportunities to solve complex, research-like problems in the classroom.

We invite you to become involved in BioQUEST - attend a workshop, collaborate on a project, or explore a computer simulation!

Bioquest Library VI
The BioQUEST Library VI is a peer-reviewed publication of computer-based curricular materials for biology education. Volume VI includes more than 75 software simulations, tools, datasets, and other support materials for many areas within bioscience.

Bioquest Project: Evolution Education
Investigate evolution by making a wide range of data available to students with BRIO, try out a simulation for selection against a recessive allele with Evolve, or add inquiry activities.

Bioquest Project: BEDROCK
Join us at one of several planned workshops, such as the Chautauqua Short Course at Clark Atlanta University, May 8 - 10, to develop and field test new learning materials for implementing bioinformatics in your bioscience curricula.

Bioquest Project: Unseen Life on Earth
Designed to accompany the video series Unseen Life on Earth, this collection of multimedia resources for problem solving in microbiology will be published in 2002 by ASM Press.

Bioquest Project: Biocomplexity
A new curricular initiative in BioQUEST addresses the development of teaching strategies for integrating biocomplexity and its multidisciplinary approaches to problem solving in undergraduate education.

Bioquest Curriculum Consortium
Beloit College
700 College Street
Beloit, WI 53511

For more information on these and other BioQUEST Projects:
Email: bioquest@beloit.edu
Phone: 608-363-2743
bioquest.org
BioQUEST Curriculum Consortium

Beloit College
700 College Street
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bioquest.org