From Cookbook to Collaborative: Transforming a University Biology Laboratory Course

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Title: From Cook-book to Collaborative: Transforming a University Biology Laboratory Course

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Abstract: This article describes the transformation of a biology laboratory course at an urban university from one based on a traditional, cook-book curriculum to one incorporating inquiry-based methodologies. In this article, the instructor compares the two approaches and provides the new syllabus, assessments, and course evaluation results. (46 words)
As described in *How People Learn* (NRC, 2000), *Developing Biological Literacy* (BSCS, 1993), and much earlier by the Commission on Undergraduate Education in the Biological Sciences during the 1960’s and early 1970’s (Sundberg, Kormondy, Carter, Moore, Postlewait, & Thornton, 1992), laboratories should promote guided-inquiries or investigations, and not simply consist of cookbook or verification activities. However, the only words that could describe the curriculum followed in the laboratory course that I was soon scheduled to teach were “cook-book”.

This article describes the transformation of this biology laboratory course at an urban university from one based on a traditional, cook-book style curriculum to one incorporating inquiry-based methodologies. In the words of Uno (1990), “Inquiry (is) a pedagogical method that combines hands-on activities with student-centered discussion and discovery of concepts… The teacher acts as a catalyst, directing student interaction, activities, and discussion rather than bearing all information” (p. 841).

Biology majors enroll in this particular general biology laboratory course during the second semester of their sophomore year, after having completed two semesters of general chemistry and one semester of organic chemistry. A prerequisite for pre-professional schools, many post-baccalaureate students also enroll in the course. The university has a reputation for high admittance rates to medical and dental schools. The average percentage from 2002 through 2007 was 62% (J. Scott Wright, personal communication, July 21, 2008).

From the inception of the course, the curriculum consisted of a collection of kits purchased from a well-known university-based supplier. Each kit, designed to verify a biological concept, consisted of a pre-packaged experiment, content information, and “cook-book” instructions for the student.

The former instructor provided a hard copy of the content information from the kit to students during a Friday afternoon, one-hour lecture session. This instructor administered a fill-in-the-blank quiz (taken directly from the content information) at the beginning of each three-hour laboratory session the following Monday or Tuesday. Students were allowed to bring an 8x10 inch “cheat sheet” with them to take their multiple-choice midterm and final exams. Thus, students memorized the reading material and spent hours hand-writing terms and definitions in extremely tiny print or typing and printing them in the tiniest font size visible. Grading was strictly
norm-referenced, thus contributing to a highly competitive, decidedly unfriendly atmosphere.

**Methods**

With a background in high school and college teaching, and having experienced inquiry-based teaching and learning for many years, I sought to revise the curriculum to move the focus of the course from strict memorization to a framework that supported more conceptual understanding. According to *How People Learn* (NRC, 2000) “students must: a) have a deep foundation of factual knowledge, b) understand facts and ideas in the context of a conceptual framework, and c) organize knowledge in ways that facilitate retrieval and application in order to develop competence in an area of inquiry (p 16).” I set out to organize a course and present investigations that facilitated the scaffolding of skills and understanding in a collaborative laboratory environment.

The basic laboratory schedule and biological concepts covered could not be changed. Oversight was intense as departmental faculty members demanded a high-caliber course. Even though cost-cutting was not a concern (and the number of sections offered more than doubled), changes resulted in a cost-savings approaching $20,000.00 per semester.

General transformations to the course curriculum included the addition of several investigative, open-ended laboratories. Often, skills learned in one laboratory were used for a more open investigation during the next lab. Several experiments were customized to make explicit connections to current or prior research by biology faculty members, and made use of in-house strains, plasmids, and proteins, thus increasing interest level and relevance. Rather than presenting a smorgasbord of topics, laboratory exercises were based on one theme prior to midterm and another after midterm. In addition, several wet-lab experiments were paired with computer-lab experiments.

Student laboratory activities changed dramatically. Rather than working in an individualized, competitive atmosphere, students were encouraged to work in pairs or groups of four for various experiments. Each experiment required individual effort as well as collaborative and/or cooperative efforts. Student interest drove several investigations. Students weighed, pipetted, melted, and poured reagents themselves. (Previously, everything had been prepared for them, and they weren’t allowed to use the
Because the instructor acted as a facilitator during the laboratory session, students interacted with, rather than feared, the instructor. (Previously, the instructor behaved as an unfriendly, demanding overseer.)

Transformations in assessment strategies included changing from strictly objective, low-cognitive level test items to providing a set of writing-intensive test questions from which students could select a specified number to answer. Answers were graded by teaching assistants and the instructor using a common scoring rubric developed in collaboration with each other. Several performance-based assessments were added, including an oral communication component.

**Results: The New Curriculum**

According to BSCS (1993), biology education should attempt to meet students’ personal needs. Many undergraduates at this university are given the opportunity to work in professor’s research laboratories. Therefore, considerable effort was made to connect the curriculum to research topics conducted at the university. Research interests at the university included yeast as a research model and the genetic diseases sickle cell and ataxia telangiectasia.

One researcher worked with yeast, and a former dean at the university had conducted seminal research on light-activated DNA repair systems in yeast. Therefore, the new curriculum incorporated several yeast laboratories developed by The Gene Project (Manney, [http://www.phys.ksu.edu/gene](http://www.phys.ksu.edu/gene)). These resources, developed at Kansas State with funding from the National Science Foundation and the Howard Hughes Medical Institute, provide extensive investigative laboratories that utilize various strains of yeast. Complete background information, diagrams, and teaching tips are provided. The UV sensitive yeast strain, available from Carolina Biological Supply, lacks the ability to repair DNA damage caused by UV light and provides an excellent source for student-designed investigations. Adenine-requiring mutants are also available and lend themselves to dramatic (and therefore, effective) genetic investigations. The author set the selected investigations into a 5E learning cycle (BSCS, 1993). Rather than following step-by-step directions, students designed their own experiments within certain parameters using a common set of materials made available to them, as well as unique materials they contributed. For example, after learning
microscopy and microbiology skills, students utilized these skills in conducting several yeast investigations that they designed themselves.

As a nonpathogenic organism, yeast lends itself well to a teaching laboratory. The teaching laboratory facility at the university was accessible to students only during their laboratory sessions. Therefore, observation of cultures outside of the laboratory did not present a major safety concern. The Friday lecture session provided an opportunity for students to observe their cultures before and after the lecture in an area just outside of the laboratory facility. Students were also encouraged to carry their plates with them in order to transfer cultures, incubate, and make observations at home.

Another researcher at the university had received funding from the AT Children’s Foundation, thus providing a direct link to the module Bioinformatics and the Human Genome Project (BSCS, 2003). The module, developed by BSCS with funding from the Department of Energy as an ELSI (Ethical, Legal, and Social Implications) component of the Human Genome Project, follows the discovery of the AT (ataxia telangetasia) gene in a guided-inquiry format. Students engage in both print-based and web-based activities using authentic data. Students assume various roles of a fictional company as they proceed through the module. The work of this company and its patents are based on an actual biotech company.

Several researchers work with sickle cell disease, and therefore hemoglobin became a focus. With their assistance, blood from local blood banks was used for analysis, and one kit was purchased from Modern Biology, Inc. for the separation of proteins.

The new course was designed to begin and end with web-based exercises and experiments. As everyone who has ever coordinated laboratory courses knows, the first and last labs have their own special concerns. The first lecture was devoted to bioinformatics, but the bulk of the first laboratory session was spent in the library during which time students learned how to access journal articles at the NCBI website, from online journals at the university, and from those not available online in preparation for midterm and final reports. Students completed an abridged version of the module Bioinformatics and the Human Genome Project on their own time and submitted their reports during the second laboratory session. During the last laboratory session, students compared their own
mtDNA sequence to others in the *Sequence Service* database following the protocols established at *Genetic Origins*. The excitement of seeing students compare their own DNA sequences to those of many other extinct and living humans cannot be understated. Even the most serious-minded, pre-med students laughed and expressed shock, delight, and amazement during this session.

The ability for students to submit their own samples for sequencing and analysis continues to be provided by The DNA Dolan Learning Center at Cold Spring Harbor Laboratory through *The Gene Almanac* ([www.dnaftb.org/home](http://www.dnaftb.org/home)). Contained within this vast resource are two programs that provide teachers the resources to bring the timeliest topics in biology and the most innovative laboratory experiences to their students. *The Gene Almanac* includes the following programs: *Genetic Origins, Bioservers, Eugenic Archive, Your Genes - Your Health, Inside Cancer, DNA from the Beginning, DNA Interactive, Greenomes, Silencing Genes, Dynamic Gene, and My DNAi*. *Genetic Origins* ([http://www.geneticorigins.org/](http://www.geneticorigins.org/)) provides the background information and laboratory protocols for two experiments, *Alu* and mtDNA, and enables students to compare a small portion of their own DNA with sequences from others in the *Bioservers* database. *Bioservers* ([http://www.bioservers.org/bioserver/](http://www.bioservers.org/bioserver/)) is a set of statistical tools that allows students to access full-featured databases and manipulate specific sequence collections. Educators have the Howard Hughes Medical Institute, the National Science foundation, the Department of Energy, Roche Molecular Systems, and Applied Biosystems to thank for their support for these programs.

Even though these programs may have been designed for high school students, the content may be even more relevant to post-secondary students. They may be better prepared to understand these concepts, more mature in conducting the investigations, can move through the information at a faster pace, and can make more informed predictions. It is this educator’s opinion; based on more than 25 years of interaction with high school teachers (and teaching high school), that a higher percentage of college faculty utilize the service than high school teachers. A review of the *Sequence Service* database in June 2007 revealed that DNA from 877 high school groups and 581 colleges and universities had been sequenced. Given the fact that there are many more high schools in the nation than institutions of higher learning, the author’s observations seem to be accurate.
Both *The Gene Project* and the *DNA Dolan Learning Center* have partnered with Carolina Biological Supply Company to provide the reagents and materials needed for these experiments. Established in 1927 by a college professor, this company caters to educators and provides everything needed for a teaching laboratory. The only special materials required for the laboratories in the new curriculum, however, are specific yeast strains and restriction enzymes.

As discussed in *Developing Biological Literacy: A Guide for Developing Secondary and Postsecondary Biology Curricula* (BSCS, 1993), positioning a curriculum within a theme helps organize and deliver relevant information, and thus provides a frame of reference for each concept or activity. Two themes, reflecting departmental emphases, formed the framework for the course: cellular and molecular biology. Cellular biology with a focus on yeast set the stage for the first half of the semester. Molecular biology with a focus on protein (hemoglobin specifically) and DNA (mtDNA specifically) set the stage for the second half of the semester. Thus, students use both prokaryotic and eukaryotic organisms, and learn laboratory skills one week that are utilized during the next throughout the semester.

The laboratory manuals by Bloom, Freyer, and Micklos (1995) and Micklos and Freyer (2002) served as reference for the DNA lectures and laboratory procedures. Protein synthesis and recombinant DNA models and manipulatives purchased from Carolina Biological Supply Co. provided interactive resources for the lecture component of the course. Table 1 gives a brief description of the laboratory topics and activities for the semester-long course.

**Results: Student Assessment**

A laboratory report of each experiment, due at the beginning of the following laboratory section, collectively contributed 44% of students’ grades. The instructor provided a digital camera and encouraged students to take photographs of their plates, gels, and activities. For a specified length of time, TAs posted the photographs on a website for downloading. Students downloaded their own photographs for use in weekly reports and poster presentations, and many started using their own cameras and cell phone cameras more extensively.
Consisting of several discussion questions from which a specified number could be selected, weekly quizzes constituted 26% of the final grade. During the first two planning sessions, the instructor reviewed students’ answers with the course graduate students who served as teaching assistants (TAs). Criteria were discussed and a common scoring rubric was developed collaboratively.

For the midterm report, the instructor and TAs independently graded reports from three individuals who could be categorized as high, medium, and low-achieving students from the laboratory population. The team discussed our ratings to informally determine inter-rater reliability. Surprisingly, the team consistently assigned similar scores. Over three semesters, only one TA (who had just entered the U.S.) assigned scores inconsistent from the others, thus warranting another iteration of discussion before arriving at a consensus for inter-rater reliability. Afterward, each TA scored and recorded all of the reports from his or her laboratory sections and recorded their scores. The author reviewed each report and awarded the final grade.

Thirty percent (30%) of students’ grades came from the midterm and final reports. Specifications and scoring rubrics for the midterm and final were included in the syllabus and explained the first day of class. In summary, students were assigned a midterm report, specifically a five-page “review of the literature” (plus title page and bibliography) on any human disease or condition of interest with a genetic component and incorporating summaries of research related to the topic that had been conducted with yeast. The final, a revision and expansion of the midterm report, incorporated one of the laboratory investigations conducted during the semester that related to the yeast research described or the disease.

Yeast served as the model organism for the laboratories conducted during the first half of the semester, and students approached each lab with their midterm in mind. Even though students were provided a customized presentation from a librarian during the first laboratory session, many students expressed a great deal of apprehension about this report during the first semester of implementation. They were required to cite and discuss research from five scientific articles. Instructions and scoring rubrics were provided to students in the syllabus and discussed weekly. Some students were surprised to discover that this assignment was not like a typical book report: that simply typing in yeast and the name of a disease into a search engine was not sufficient; that a description of a
genetic disease was not sufficient; and that reading scientific research can be extremely difficult. Personal communication with students was often necessary in order to help them fully understand the task. The effort was more than repaid when reading their reports. No two reports were ever the same, in part, because reports had to be submitted directly to Turnitin.com and accessed from this site by the instructional team.

Turnitin.com (http://turnitin.com/static/home.html), a service subscribed to by many educational institutions, provided a report of the percentage of words taken directly from other sources and names the source. Taking the burden of proof and policing from the professor, Turnitin.com allowed the professor to spend time on process and content, not policing. Knowing up front that their papers would be analyzed in this manner seemed to deter students from blatant plagiarism and enforced the concept of developing an original and unique body of work. Given the level of student choice in conducting the research, the assignment itself demanded a high degree of originality. During the period of this study, no one was assessed higher than a 32% plagiarism on the midterm, and that incidence was due to the large number of quotations.

For the second component of the final, the group presentation, students were encouraged to work with others who selected the same laboratory exercise as themselves. Many students did, but some elected to work with their friends and a few developed their posters and gave presentations independently. Posters were displayed on the walls of the main hallways of the biology department. Students dressed professionally and enjoyed refreshments provided by the instructor. Some groups arrived for their presentations in color-coordinated outfits that matched their posters (see figure 1). All students listened to each group give its presentation and were encouraged to ask questions. Faculty and graduate students often came by to listen and interact.

The diversity of topics and unique combinations of laboratory investigations incorporated into the reports, made grading them pleasurable experiences. The instructor felt a great sense of satisfaction when seeing the improvement students made from their midterm reports to their final reports. Students selected topics related to skin cancer and sickle cell disease most often, but reported on numerous diseases including Adrenoleukodystrophy, Neurofibromatosis, Parkinson’s Disease, and Celiac Disease.
Results: Course Evaluation

Students were asked to complete a Likert-style survey at the end of the poster presentations during 2003-2004 fall and spring semesters. For each of three statements about each exercise, students could select from one of the following responses: strongly agree (assigned 5 points), agree (4 points), undecided (3 points), disagree (2 points), strongly disagree (1 point). With a mean of 4.0 (n=174), students agreed that the laboratories increased their biological knowledge, understanding of biological research, and laboratory skills. No significant differences were seen among the exercises. The UV sensitive yeast lab (during which students designed and conducted their own experiments) tied with yeast genetics for the highest mean (4.2). The exercise with the lowest mean was the mtDNA web-based activity on human origins (3.8). A lower scoring of this exercise may be explained by the fact that it was the last laboratory exercise and students may not have had sufficient time to fully comprehend it while completing their reports and posters.

Conclusion

By all accounts, the transformed biology laboratory course provided rigorous content and also promoted students’ critical thinking, experimental, scientific writing, and speaking skills. Even those laboratories that promoted the acquisition of laboratory skills fostered inquiry by providing students the space to draw or record their predictions prior to actual observations. The course sought to combine hands-on activities with student-centered discussion and discovery of concepts by fostering collaborative rather than competitive learning environment. To those ends, the transformation involved curriculum, instruction, and assessment practices. Departmental faculty members expressed approval in numerous ways, and the fact that the course continues to follow this design even though the author now teaches at another university provides evidence that inquiry-based teaching techniques can be successfully employed at the university setting and in a department that prides itself on high academic standards.

Acknowledgements

The author wishes to thank the undergraduate students who received elective course credit as teaching assistants for helping me make this course a student-centered, active learning experience.
**References**

**Table 1.** Laboratory Topics and Activities of the Transformed Biology Laboratory Course.

<table>
<thead>
<tr>
<th>Lab</th>
<th>Topic</th>
<th>Student activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab 1</td>
<td>Bioinformatics (computer-based experiments)</td>
<td>Completing the guided-inquiry curriculum supplement, <em>Bioinformatics and the Human Genome Project</em></td>
</tr>
<tr>
<td>Lab 2</td>
<td>Microscopy techniques</td>
<td>Making wet mounts (with and without stains) of various materials with special emphasis on yeast</td>
</tr>
<tr>
<td>Lab 3</td>
<td>Microbial techniques</td>
<td>Preparing media, pouring plates, performing serial dilutions of yeast, using a spectrophotometer, spreading and streaking plates</td>
</tr>
<tr>
<td>Lab 4</td>
<td>Experimental techniques</td>
<td>Designing, conducting, and analyzing student-designed experiment using UV sensitive yeast</td>
</tr>
<tr>
<td>Lab 5</td>
<td>Yeast genetics</td>
<td>Crossing 4 haploid yeast auxotrophs of different mating types and patching to MV plates.</td>
</tr>
<tr>
<td>Lab 6</td>
<td>Yeast transformation</td>
<td>Transforming mutant yeast cells to wild type cells using low copy and high copy plasmids</td>
</tr>
<tr>
<td>Midterm</td>
<td>5-page report</td>
<td>Researching a genetic disease and linking to yeast</td>
</tr>
<tr>
<td>Lab</td>
<td>Description</td>
<td>Details</td>
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<td>---------------------------------------------------------------------------------------------</td>
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<tr>
<td>Lab 7</td>
<td>Proteins</td>
<td>Identifying models of amino acids and separating proteins with gel electrophoresis</td>
</tr>
<tr>
<td>Lab 8</td>
<td>Detection of a Genetic Disease</td>
<td>Separating four versions of hemoglobin (AA, SS, AS, HbF) through gel electrophoresis.</td>
</tr>
<tr>
<td>Lab 9</td>
<td>DNA Extraction and Modeling</td>
<td>Extracting DNA from materials brought by students and their own cheek cells. Manipulating and analyzing a DNA model.</td>
</tr>
<tr>
<td>Lab 10</td>
<td>Restriction Enzyme Digest, Plasmid Mapping, PCR</td>
<td>Digesting a yeast plasmid and mapping with banding analysis. Amplifying students’ cheek cell DNA with PCR.</td>
</tr>
<tr>
<td>Lab 11</td>
<td>Computer-based evolution experiments</td>
<td>Calculating Molecular Clocks by comparing their own DNA to prehistoric humans. Comparing their DNA to other modern humans and creating phylogenetic trees.</td>
</tr>
<tr>
<td>Final exam</td>
<td>10-page research paper and presentation</td>
<td>Submitting a final research paper that connects a genetic disease to yeast research and to an experiment conducted during the course. Giving a poster presentation as a group on an experiment conducted during the course.</td>
</tr>
</tbody>
</table>

Figure 1. A group of students at their final poster presentation.