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Cover images: A hissing cockroach (*Gromphadorhina portentosa*) is on display with a penny and human hand. Photograph provided by Melissa Daggett.

Laboratory Exercises

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Bioscene: Journal of College Biology Teaching

Guidelines for Submissions

I. Submissions to *Bioscene*

Bioscene: Journal of College Biology Teaching is a refereed quarterly publication of the Association of College and University Biology Educators (ACUBE). Submissions should reflect the interests of the membership of ACUBE. Appropriate submissions include:

- Articles: Laboratory and field studies that work, course and curriculum development, innovative and workable teaching strategies that include some type of evaluation of the approaches, and approaches to teaching some of the ethical, cultural, and historical impacts of biology.
- Reviews: Web site, software, and book reviews
- Information: Technological advice, professional school advice, and funding sources
- Letters to the Editor: Letters should deal with pedagogical issues facing college and university biology educators

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II. Preparation of Articles

Submissions can vary in length, but articles should be between 1500 and 4000 words in length. This includes references, but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. A complete submission will consist of the following:

A. Cover letter: All submissions should come with a cover letter (cover letter could simply be an email with accompanying attachments) indicating that the manuscript is being submitted exclusively to *Bioscene* and why it is appropriate for this journal. Authors may also offer graphics from the article as possible cover art.

B. Cover Sheet: Submissions should include a cover sheet that includes the title of the article, the number of words in the manuscript, the corresponding author's name, and all co-authors. Each author's name should be accompanied by complete postal and email addresses, as well as telephone and FAX numbers. Even with hardcopy submissions, email will be the primary method of communication with the editor of *Bioscene*.

C. Abstract: The first page of the manuscript should contain the title of the manuscript, the names of the authors and institutional addresses, a brief abstract (200 words or less) or important points in the manuscript, and keywords in that order.

D. Manuscript Text: The introduction to the manuscript begins on the second page. No subheading is needed for this section. This supply sufficient background for readers to appreciate the work without referring to previously published references dealing with the subject. Citations should be reports of credible scientific or pedagogical research.

The body follows the introduction. It is recommended that it be broken into sections with appropriate subheadings including Materials and Methods, Results, and Discussion. Some flexibility is permitted here depending upon the type of article being submitted.

Acknowledgment of any financial support or personal contributions should be made at the end of the body in an Acknowledgement section, with financial acknowledgements preceding personal acknowledgements. Disclaimers and endorsements (government, corporate, etc.) will be deleted by the editor.

A variety of writing styles can be used depending upon the type of article. Active voice is encouraged whenever possible. Past tense is recommended for descriptions of events that occurred in the past such as methods, observations, and data collection. Present tense can be used for your conclusions and accepted facts. Because *Bioscene* has readers from a variety of biological specialties, authors should avoid extremely technical language and define all specialized terms. Also, gimmicks such as capitalization, underlining, italics, or boldface are discouraged. All weights and measures should be recorded in the SI (metric) system.

In- text citations should be done in the following manner:

"…rates varied when fruit flies were reared on media of sugar, tomatoes, and grapes" (Jaenike, 1986).

or

" Ulack (1978) presents alternative conceptual schemes for observations made…"

E. References: References cited within the text should be included alphabetically by the author's last name at the end of the manuscript text with an appropriate subheading All listed references must be cited in the text and come from published materials in the literature or the Internet. The following examples indicate *Bioscene*'s style format for articles, books, book chapters, and web sites:

Articles-
Single author:
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Multi-authored:
GREEN, H., GOLDBERG, B., SHWARTZ, M., AND D. BROWN. 1968. The synthesis of collagen during the development of *Xenopus laevis*. *Dev. Biol*. 18: 391-400.

Books-
BOSSEL, H. 1994. *Modeling and Simulation*. A.K. Peters, London. 504p.

Book chapters-
GLASE, J.C. AND M. ZIMMERMAN. 1991. Population ecology: experiments with Protistans. In Beiwenger, J.M. 1993. *Experiments to Teach Ecology*. Ecological Society of America, Washington, D.C. 170p.

Web sites-
MCKELVEY, S. 1995. Malthusian Growth Model. Accessed from http://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html on 25 Nov 2005.

Note that for references with more than five authors, note the first five authors followed by *et al*.

F. Tables
Tables should be submitted as individual electronic files. Placement of tables should be indicated within the body of the manuscript. All tables should be accompanied by a descriptive legend using the following format:

Table 1. A comparison of student pre-test and post-test scores in a non-majors' biology class.

G. Figures
Figures should be submitted as individual electronic files, either TIFF or BMP. Placement of figures should be indicated within the body of the manuscript. Figures include both graphs and images. All figures should be accompanied by a descriptive legend using the following format:

Figure. 1. Polytene chromosomes of *Drosophila melanogaster*.

III. Letters to the Editor

Letters should be brief (400 words or less) and direct. Letters may be edited for length, clarity, and style. Authors must include institution address, contact phone number, and a signature.

IV. Other Submissions

Reviews and informational submissions may be edited for clarity, length, general interest, and timeliness. Guidelines for citations and references are the same for articles described above.

V. Manuscript Submissions

Article manuscripts may be sent to the current editor either electronically or by hard copy, accompanied by a disc copy. Electronic submissions are preferable. All authors will receive confirmation of the submission within three weeks. Manuscripts should be submitted either as a Microsoft Word or RTF (Rich Text File) to facilitate distribution of the manuscript to reviewers and for revisions. A single-email is required to submit electronically, as the review process is not blind unless requested by an author. If the article has a number of high resolution graphics, separate emails or separate discs mailed to the editor may be required.

If hard copy is sent it must be accompanied by a disc containing the complete submission. Three copies of the manuscript, as well as the original, should be submitted. Standard paper should be used with lines of sections of the manuscripts numbered and enough margin to permit reviewer comments. Two self-addressed stamped envelopes must be included if the authors wish to receive reviews and responses by methods other than email.

VI. Editorial Review and Acceptance

Manuscripts will be sent out for review, once the author has either joined ACUBE or agreed to page charges. Charges will be the membership fee at the time of submission per page. Once the authors' membership or page charge status has been cleared, the manuscripts will be sent to two anonymous reviewers as coordinated through the Editorial Board. Reviewers will examine the submission for:

- **Suitability:** The manuscript relates to teaching biology at the college and university level.
- **Coherence:** The manuscript is well-written with a minimum of typographical errors, spelling and grammatical errors, with the information presented in an organized and thoughtful manner.
- **Novelty:** The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

Once the article has been reviewed, the corresponding author will receive a notification of whether the article has been accepted for publication in *Bioscene*. All notices will be accompanied by suggestions and comments from the reviewers. Acknowledgement of the reviewers' comments and suggestions must be made for resubmission and acceptance. Upon acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website. The review process can take 4-5 months. Upon final acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website within six months of publication. Depending upon volume, time from acceptance to publication may take up to a year.

VII. Editorial Policy and Copyright

It is the policy of *Bioscene* that authors retain copyright of their published material.

Hairy Root as a Model System for Undergraduate Laboratory Curriculum and Research

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Abstract: Hairy root transformation has been widely adapted in plant laboratories to rapidly generate transgenic roots for biochemical and molecular analysis. We present hairy root transformations as a versatile and adaptable model system for a wide variety of undergraduate laboratory courses and research. This technique is easy, efficient, and fast making it an ideal tool for undergraduate teaching. Students in a biotechnology course successfully transformed soybean cotyledons with *Agrobacterium rhizogenes* strain K599 during laboratory sessions. The students introduced the green fluorescent protein (GFP) gene into soybean and observed hairy roots regeneration. After two weeks, 45% of the cotyledons developed roots. Of the roots that appeared after transformation, 55% expressed the GFP protein.

Keywords*:* hairy root, *Agrobacterium rhizogenes,* transformation, cotyledons

Introduction

Currently in undergraduate teaching laboratories, plant transformation experiments are demonstrated mostly with *Arabidopsis,* using the floral dip method (Clough and Bent, 1998), or tobacco leaf disc transformation (Fraley et. al., 1983). However, both transformations suffer one major limitation. These techniques are time consuming. Both experiments take at least 6 weeks to prepare, which is needed to bring the plants to maturity. After the transformation, both experiments take another 5 or 6 weeks to harvest the transgenic material. The considerable waiting time reduces student interest in the subject significantly. For trimester universities, the entire term is only 10 weeks long, making *Arabidopsis* and tobacco transformation experiments difficult to set up. In this article, we present the classroom use of a unique, rapid, and reliable method to genetically modify the roots of a wide variety of plant species. This study relies on the hairy root plant transformation system.

Hairy roots originate from a plant disease caused by the Gram-negative soil bacterium *Agrobacterium rhizogenes*. Hairy root tumors are characterized by a proliferation of adventitious roots at the bacterial infection site. The genetic determinant of hairy root disease is a large plasmid called the root-inducing (Ri)-plasmid which is carried by virulent strains of *A. rhizogenes* (Chilton et. al., 1982). The Ri plasmid is similar to the tumor-inducing (Ti) plasmid found in *Agrobacterium tumefaciens*, which is the causative agent of Crown Gall tumors in many dicotyledonous plants. Both the Ri and Ti plasmids transfer a segment of the plasmid called transfer DNA or T-DNA to the plant genome during infection. Transfer of the T-DNA to the plant genome is directed by a different region of the plasmid called the virulence (*vir*) region. The T-DNA contains genes that encode enzymes responsible for the biosynthesis of plant hormones, such as auxin and cytokinin. Upon transformation, these genes are expressed resulting in tumor-like growth. In addition, the T-DNA has genes controlling the production of various opines which serve as carbon, nitrogen, and energy sources for the infecting bacterium.

The Ti and Ri plasmids can be engineered to insert novel genes into the T-DNA for the introduction of genes-of-interest in various plant species. A more common approach is the use of a binary vector system where the *vir* genes reside in one plasmid (i.e. Ti or Ri plasmid) and the T-DNA in a second plasmid. The use of disarmed strains of *A. tumefaciens,* where the tumor causing genes have been removed from the Ti plasmid, results in non-tumorous transgenic tissue. These strains are commonly used for plant transformation. Reporter gene(s) to detect the transformation event may include antibiotic resistance genes, Beta-

Glucuronidase [GUS] (Li and Leung, 2003) or the Green Fluorescent Protein (GFP) (Hughes et al., 2002). The GFP gene was originally isolated from fluorescent jelly fish. It emits green light when activated by UV irradiation. Various forms of GFP have been widely used as non-destructive visible markers in biological research.

While *A. tumefaciens* produces transgenic tumors, *A. rhizogenes* produces transgenic roots. This provides a major advantage for root-related studies since it eliminates the lengthy and expensive process of regenerating whole transgenic plants. As an additional advantage, these roots have the ability to grow in culture when exogenous sugar is supplied. This system has been broadly utilized by biologists to genetically modify roots of a wide range of plant species for basic and applied research. Originally, hairy roots were thought to be a disease limited to dicotyledonous plants (De Cleene and De Ley, 1981). After further research, *A. rhizogenes* root induction was demonstrated on monocots (Porter, 1991) and in gymnosperms such as radiata pine [*Pinus radiata*] and larch [*Larix*] (McAfee, et. al., 1993; Li and Leung, 2003). The hairy root transformation system is adaptable to a very broad range of plant species, which is important for teaching different subjects to suit various curricula.

Hairy root cultures are potentially useful for the production of a large number of foreign proteins and secondary metabolites. The transformed roots are genetically stable and exhibit faster growth rates than normal roots (Hu and Du, 2006). For example, hairy root cultures of red beet (Beta vulgaris) have shown promise for the commercial production of peroxidase (Rudrappa et al., 2005). Brigham et al. (1999) demonstrated that hairy root cultures of *Lithospermum erythrorhizon*, a member of the Boraginaceae plant family, manufacture shikonins at an elevated level. Shikonins exhibit varying degrees of antimicrobial activity against a wide range of bacteria and fungi. Hakkinen et. al. (2005) showed that hairy root cultures of *Nicotiana tabacum* expressing the *h6h* gene from *Hyoscyamus niger* had an enhanced secretion of the alkaloid scopolamine. This alkaloid compound has pharmaceutical significance as an anticholinergic agent.

In addition to metabolic engineering, hairy root cultures have proved to be a powerful tool for gene expression and gene silencing studies. Kumagai and Kouchi (2003) used hairy root cultures to introduce hairpin RNA (hpRNA) sequences complementary to the GUS gene in *Lotus japonicus*. They were successful in silencing GUS gene activity in the hairy roots and on symbiotic nodules formed on the hairy roots. Subramanian et al. (2005) silenced isoflavone synthase (IFS) genes in soybean cotyledons by introducing hairy root cultures containing RNAi silencing constructs. Hairy root cultures exhibiting IFS silencing were more susceptible to the plant pathogen *Phytophthora sojae* than control cultures suggesting a protective role for isoflavones. The above study used a non-tissue culture based method to generate hairy roots.

In this study, eight undergraduate students representing an entire biotechnology class started hairy root cultures for research projects. This biotechnology course is offered at a sophomore level and was an elective for the majority of the students. A diverse cross-section of students were involved in this study and included the following majors: Pre-Medical, Clinical Laboratory Science, and Biology. Hairy root cultures were used to demonstrate plant genetic transformation and expression of the GFP protein. The short and engaging experiences of hairy root transformation improved the teaching results significantly.

Materials and Methods

Students were prepared for the exercise by reading assignments of literature on hairy root cultures. The literature included three research journal articles and an overview of the process in their lab manual. The instructor gave a short lecture on *A. rhizogenes* and plant root transformation. Reading, lectures, and student discussion on the hairy root transformation system occurred prior to the laboratory exercise. Due to time limitations, the instructor planted the soybean seed and prepared bacterial cultures for the class.

<u>Materials that are needed for transformation:</u>

Soybean seedlings—one 6” pot can supply enough cotyledons for an entire lab section.
24 hour *A. rhizogenes* cultures (containing a binary plasmid of interest)
Sterile Whatman filter paper
Sterile Paper towels
Sterile 1/4 strength Murashige and Skoog (MS) salts (no sucrose) or 10mM $MgSO_4$.
Micropipettes
70% ethanol
Sterile surgical steel blades

<u>Equipment:</u>

Clean bench (optional)
Centrifuge to pellet bacterial cells
Spectrophotometer (optional)

Protocol for Transforming Soybean cotyledons using *A. rhizogenes*
(Subramanian et al., 2005)

The soybean seeds (variety Williams 82) were planted in an artificial soil mix (Superfine germinating mix, Fafard, New Jersey) and placed in a mist chamber. If a mist chamber is not available, the seedlings need to be sprayed on a daily basis with a mist-sprayer. This helps dislodge the seed coat and results in high quality cotyledons. The cotyledons were ready to harvest 5 days after planting. Younger or older cotyledons may not yield good results.

Overnight cultures of *A. rhizogenes* strain K599 were prepared the day before inoculation. The K599 strain that was used contains the GFP gene as a visible marker. This gene is located in a binary vector (pCAM-sUbi:GFP) published previously (Subramanian et al, 2005, 2006). Cultures were started in 10 mL of Luria Broth with 50 µg mL^{-1} kanamycin added. *A. rhizogenes* can be maintained in 25% glycerol at –80°C for several years. Fresh cultures were spun down at 8°C for 10 minutes at 5,000 rpm. Pellets appeared pinkish-brown as expected. The pellets were drained and resuspended in the original volume (10 ml) of 1/4 strength MS medium. Cells were diluted to an OD_{600} of approximately 0.3 for the inoculation of cotyledons. If a spectrophotometer is not available, overnight (16h) cultures can be diluted five times in 1/4 strength MS medium.

Solutions and materials were gathered while the cells were being centrifuged. Optimally, the transformation procedure should be finished within 2 hours after the cell resuspension. It took our class approximately 2 hours to finish the transformation process. Although a laminar flow hood or clean bench is optional, we performed the transformation steps and transfer in a clean box. Sterile 9 cm Whatman filter paper was added to the sterile Petri dishes. The filter papers were moistened with sterile 1/4 strength MS salts. Excess fluid was poured off the plates.

Cotyledons were carefully inspected by the students. As instructed, they used only cotyledons that were disease-free and have fully opened, exposing the first true leaves (fig. 1A). Cotyledons were gently twisted off the plant and surface sterilized in 70% ethanol. After surface sterilization, the cotyledons were promptly blotted in sterile paper towels to remove the excess ethanol. Cotyledons were placed on sterile filter papers soaked in 1/4 strength MS medium until the students were ready for wounding infection. Students wiped their hands with 70% ethanol prior to the wounding process. Cotyledons were wiped on both sides with 70% ethanol using a cotton swab.

A sterile surgical steel blade was used to cut a diamond shaped wound on the abaxial side of the cotyledon close to the petiole end. Students were instructed to make the slice deep enough to expose the midrib, but not slice through it. The wounded cotyledon was transferred to the filter paper lined Petri dish. Six cotyledons were placed on each plate. Plates were labeled with the date and student initials. Students added 20 µl of the *A. rhizogenes* suspension to each wound (fig. 1B). The Petri plates were promptly covered with aluminum foil as darkness provides better results. Plates were placed in a 22°C growth chamber.

The plates were checked weekly. Sterile water was added as necessary to maintain moisture on the filter paper. Every other week, the plates were watered with 1/4 strength MS medium. Plates were kept moist, but not excessively wet. Hairy root cultures were viewed under the fluorescent microscope. Other constructs and reporter genes (e.g. GUS) can be used if a fluorescent microscope is not available. The experiment was duplicated during the semester.

Results and Discussion

Students were successful in obtaining hairy root cultures. After 4 weeks, only 25% of the plates produced hairy roots in the first trial. Most of the plates were contaminated and disposed of. Of the plates that produced callus and roots, 75% of the cotyledons produced roots and 57% of the roots were transgenic (GFP positive). The experiment progressed more rapidly in the second trial and 100% of the plates produced callus and hairy roots. After two days, the area that was inoculated appeared necrotic. Callus tissue appeared in 6-7 days (fig. 1C). After 2 weeks, roots appeared from the callus site (fig. 1D). Of the cotyledons that were inoculated, 45% produced roots. After transgenic roots appeared, the GFP protein was expressed in the transgenic tissue when viewed under a fluorescent microscope. Of the roots that were induced, 55% were transgenic roots expressing the GFP protein (fig. 1 F, G). This procedure was concluded in five weeks, but could easily be adapted for a semester project depending upon the goals of the research. As shown in fig. 1E, the cultures will continue to grow and produce additional roots for 4-5 weeks.

This system is very adaptable, but conditions for the hairy root culture system may vary depending upon the plant species that will be studied. One must determine the appropriate bacterial strain of *A. rhizogenes*, the proper antibiotic to control bacterial growth after inoculation, the best plant tissue to use, and a suitable culture medium. Protocols are published in the literature for such model plants as *Medicago truncatula* (Chabaud et al. 2006) and *Lycopersicon esculentum* (Collier et. al., 2005). Due to the high rate of transformation, hairy root transformation does not use antibiotic resistance genes for selection. This might be an advantage in a classroom setting since it minimizes biosafety issues for disposal.

Soybean cotyledons are easy to work with, but a great variety of plant materials can be used. Hypocotyl, leaf, stem, stalk, petiole, shoot tip, protoplast, storage root, tuber, and cotyledons have been used successfully (Hu and Du, 2006). When adapting this protocol, the proper explant material may vary by species. Typically, juvenile material will give the best results.

Figure 1. The outline of hairy root transformation procedures(see p 84).

a) 5 day old soybean seedlings ready for hairy root inoculation
b) A student inoculating cotyledons with *A. rhizogenes*
c) 6 day old cultures showing browning and callus
d) 15 day old cultures showing callus formation
e) 30 day old cultures showing root development
f) Transgenic root using visible light
g) expression of GFP in adventitious hairy roots

Conclusions

A written report including an abstract, review of literature, objectives, materials and methods, results, discussion, and conclusions were required of all students in the course. The written report required interpretation of the data obtained by the entire class. Assessments of the written reports were based on the student's ability to demonstrate an understanding of the technique and root transformation process through their writing. All of the papers were well written and indicated that students gained valuable insights from the project. Students were further asked to evaluate this experiment by completing the following survey and commenting on the value of the exercise. Responses were strong for all of the questions (Table 1). One student commented that this lab exercise was "the most interesting lab exercise that I have done". Another student suggested that this experiment "made us feel like real scientists and was both a fascinating and highly rewarding experiment". Other students in the course stated that the contaminated plates and slow callus growth in the first trial were actually a plus demonstrating some of the realities of conducting laboratory research.

Hairy root culture systems can easily be adapted for use in classroom laboratories or for undergraduate research. Historically, root systems have been very difficult to study. Hairy root culture systems offer an extremely versatile tool that can be used on a wide variety of plant species to answer a range of biological questions. Classroom studies could be designed for secondary plant metabolism in biochemistry, plant transformation studies in biotechnology, root morphology in botany, symbiosis between plant and bacteria, fungi, or parasitic plants in ecology, genetic knockouts of genes involved in root development for genetics, gene silencing of transcription factors involved in root development for gene expression, antimicrobial activity of plant compounds in microbiology, potential for drug development in pharmacology, study of pest resistance genes in plant pathology, or auxin insensitivity in hairy roots for plant physiology courses. Students could be asked to design their own experiments and large scale screening would be possible with this system. This system ideally lends itself to investigative teaching in the laboratory.

Classroom laboratory exercises utilizing hairy roots could be very simple as in this situation or very sophisticated. We have demonstrated that this system can be used in small universities or colleges with limited resources. All of the work in this paper, with the exception of the fluorescent microscopy, was conducted at Maryville University. Maryville's biology department is located in a small, liberal arts college which has very limited laboratory resources. The fluorescent microscopy was conducted as a part of a field trip to the Donald Danforth Plant Science Center. Other reporter genes are available (e.g. GUS) that would not require specialized techniques or equipment to detect transformation/ gene expression, making the hairy root system useful for small institutions with limited resources.

Table 1 –Student survey on hairy root transformation study.

5= Strongly agree
4= Agree
3= Neutral
2=Disagree
1=Strongly disagree

1. This laboratory exercise increased my appreciation for sterile technique.

1 2 3 4 5—Average response = 5; SD=0

2. This laboratory exercise increased my curiousity concerning genetic transformation systems.

1 2 2 4 5—Average response = 5; SD=0

3. This laboratory exercise increased my understanding of genetic transformation systems.

1 2 3 4 5—Average response = 5; SD=0

4. This laboratory exercise increased my understanding of the use of marker genes in genetics transformation systems.

1 2 3 4 5—Average response = 4.8; SD= 0.35

5. This laboratory exercise increased my confidence in my ability to undertake independent research.

1 2 3 4 5—Average response = 4.6; SD= 0.5

6. I think that this exercise is a useful supplement to a biotechnology laboratory experience.

1 2 3 4 5—Average response = 5; SD=0

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NOTE: Figure 1 of this article is displayed in its entirety on page 84 of this issue. Our apologies to the authors for this omission.

Teaching Outside the Can: A New Approach to Introductory Biology

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Abstract: We describe a new approach to teaching introductory biology. Our introductory experience for undergraduates is a laboratory course that is entirely inquiry and discovery based. We introduce our students to fundamental concepts in biology in the framework of three multi-week laboratory modules, each of which is an open-ended investigation of a current area of biological study. Students read the primary literature about the research question, learn techniques and statistical approaches, and conduct student-designed experiments. We focus on the process of doing biology, rather than on acquiring a particular body of facts. Students are actively engaged in integrative thinking about biology, and they emerge from the laboratory experience with a strong grasp of quantitative and experimental approaches and skills. Our assessments indicate that this process-based approach is an effective way to approach introductory biology.

Keywords: introductory biology, process, inquiry-based learning, laboratory

Introduction

The pace of progress in biological research is accelerating at an unprecedented rate. Greatly improved information technology, along with the rapid development of public databases housing biological data, have dramatically enhanced access by faculty and students to current advances in all biological fields. College-level textbooks for introductory biology are veritable encyclopedias of information that rapidly become dated. College faculty, as well as teachers at all other levels of education, are faced with the dilemma of how to handle all this information, while at the same time emphasizing the processes of biological investigation, quantitative reasoning and critical thinking.

We recognized the need a number of years ago to fundamentally restructure our introductory curriculum to address these issues. In addition, we noted that, as more introductory students enter our curriculum having taken an Advanced Placement (AP) Biology course in high school, there was an increased need to focus on the process of doing biology, as well as a need to emphasize more explicitly how concepts are integrated across areas of biology. Our traditional introductory sequence did not allow a fully integrated approach to biology, and seemed to give students the impression that there were clear distinctions between the sub-disciplines of biology, an impression that did not represent current practice in biology. In response to these varied challenges, we dramatically restructured our introductory sequence.

Our new introductory curriculum seeks to accomplish a number of objectives:

- Coverage of the most fundamental concepts in biology using an integrative, cross-disciplinary, topic-centered approach, focusing on the relationship between genes and function and the evolution and inheritance of traits;

- Construction of a tool kit for biology, consisting of skills and concepts essential for every biologist, including experimental design, hypothesis testing, data collection, statistical analysis, scientific communication and writing;

- Infusion of an enthusiasm for biology by introducing students to current questions in biology from the start of the first course; and

- An emphasis on process rather than content, in order to allow for and respond to the rapid pace of progress across biological disciplines.

To accomplish these goals, we designed two courses, *Biology 105: Introduction to Biological Processes*, and *Biology 106: Introduction to Biological*

Investigation. Biology 105, *Processes*, while not our focus here, is a course without a laboratory component that introduces students to major concepts in biology in the context of a current topic of biological interest and emphasizes critical thinking and writing skills. *Processes*, usually taken by first-year students whose background prior to college might not have been strong or who might not have had biology since the ninth or tenth grade in high school, provides some background content and introduction to fundamental concepts in biology. Key concepts are reviewed and reinforced. Emphasis is placed on integration across concepts and helps to provide students with adequate preparation for the *Investigations* course. Our focus here is Biology 106, the *Investigations* course. *Investigations* is an introduction to the process of biological inquiry, and is designed to provide students with many investigative skills, including observation in the lab and in the field, experimental design and hypothesis testing, data collection, statistical analysis, visual representation of biological data, and scientific communication.

Active, inquiry-driven approaches to biology have been found by us and others to be very effective at encouraging integrative learning and better retention of fundamental concepts (Wilke and Straits, 2001; Flannery, 2007). Other recent curricular changes have demonstrated increased learning with more interactive approaches in introductory biology (Wilke and Straits, 2001; McDaniel et al, 2007). Further, the Bio2010 Report underscores the need for training in experimental design, communication skills and quantitative approaches. *Investigations* is a course that addresses these issues.

The course has three laboratory modules, each lasting 4-5 weeks, that focus on a current area of investigation. Each module pursues a research question from multiple levels of analysis and is based on primary literature and current approaches to open-ended questions in biology. The modules are designed to be modified easily to build upon the data and results discovered by previous semesters' students and to incorporate individual faculty members' expertise and interest. All of the modules have the flexibility to incorporate new directions and lines of inquiry to keep pace with the progress of scientific discovery. In the next sections, we describe the overall structure and format of *Investigations*, along with a description of each module and the particular goals addressed by each. We provide more complete resources in the supplemental materials.

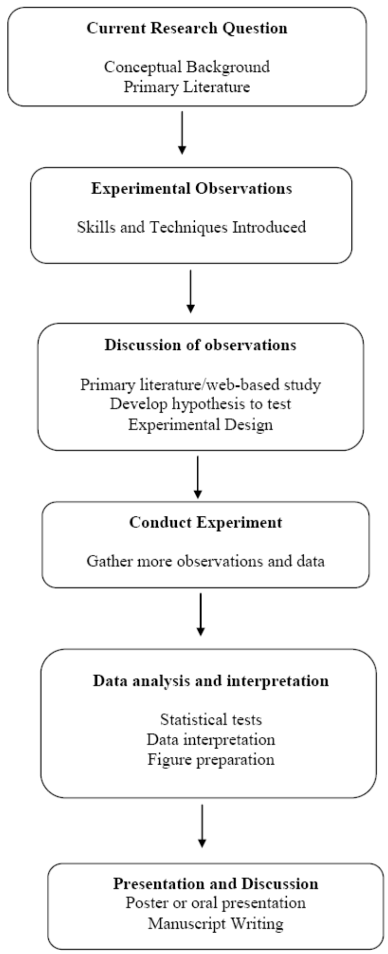
Overall structure and implementation of "Investigations"

Investigations serves as the introductory lab course for 90-120 students each term. Students have a range of backgrounds upon entering the course, from not having had a biology course for a number of years, to having just taken the *Processes* course the previous term, to having just had a high school AP Biology course and received a 4 or 5 on the AP Exam. The department typically offers four or five separate sections of the course each semester. Each section is taught by a faculty member, with one 75 minute period of classroom-based work and one 4 hour laboratory period each week. Instructors meet weekly to discuss the implementation of the course. In addition, the outgoing and incoming instructors meet at the end of each semester to discuss avenues for improvement for the upcoming semester. Finally, the department maintains a course website (Blackboard Academic Suite v. 7.1, Blackboard, Inc), where electronic copies of syllabi, assignments, class data, images and lecture notes, as well as copies of the departmentally-written laboratory manual are maintained. The textbook for the course is *Biological Science,* 2nd Edition, by Scott Freeman. The selection of the textbook is reviewed by the faculty to ensure that it is current and appropriate for the course. The text is used by both the *Processes* and the *Investigations* courses. Students are assigned readings for which they are held responsible with homework and other graded assignments. In addition, students purchase "Soil Biology Primer," a publication produced by the Soil and Water Conservation Society (Tugel et al, 2000). Other readings, particularly primary literature articles, are placed on electronic reserve or on restricted access websites.

In each module, students learn the major concepts associated with a current question in biology in the classroom period with a mixture of lecture and discussion and then conduct initial observations in the laboratory in order to become familiar with the system being studied (Figure 1). Initial observations introduce both the research question and the particular skills and techniques used to address the question. Students learn the fundamental aspects of each technique, or experimental approach, not just how to operate the equipment. With specific guidance from the faculty instructors, students then read and discuss the primary literature to gain some background into the research question and, combined with the initial observations, develop specific hypotheses and conduct experiments to test them. The results are analyzed and interpreted within the framework of the initial primary literature that motivated the study. Finally, students present their findings in different written and oral formats.

The overall design of this course allows instructors to modify the particular research question being addressed from semester to semester. Each module need only address a biological question from an integrated perspective. Further, the questions chosen for study are current, and still unresolved, areas of exploration and, as such, do not lead students through a “canned” experience. Rather, students generate testable hypotheses that yield data that could contribute to a resolution. The results can be (and are being) used as a springboard by students who wish to pursue independent research as a result of their experiences in *Investigations*.

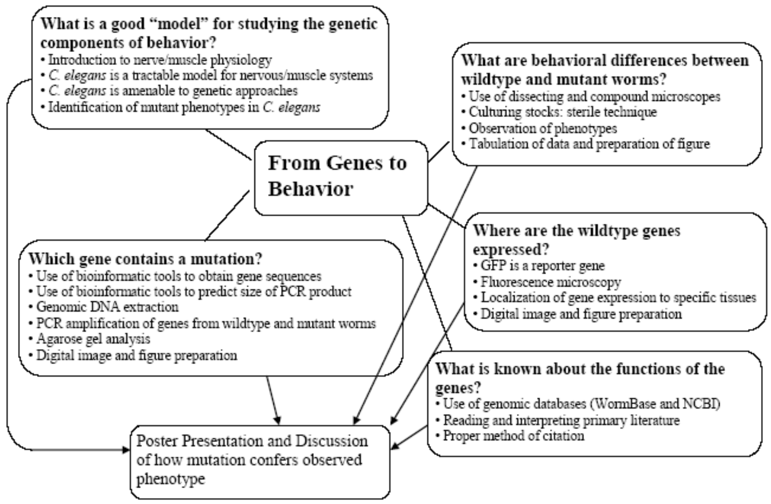
Figure. 1. Overall organization of laboratory modules



Module 1: <u>C. elegans</u>: From Genes to Behavior

While immersed in this laboratory module, students explore the connection between genes and behavior and become familiar with the concept of model organisms in biological research, focusing on *Caenorhabditis elegans* anatomy, behavior and use in the laboratory. The overall organization of this laboratory module is described in Figure 2. We explore fundamental concepts about nerve and muscle physiology while studying two different locomotion mutants, *unc-54* or *unc-119*. The students are given one of the two mutants but are not told which mutant they have been given. The goals for this module are to characterize the phenotypes of wildtype and mutant worms, observe where the wildtype gene is expressed in the worms, determine which gene is mutated, and then use that knowledge of the gene’s functions to develop a hypothesis about why a mutation in this gene would confer the particular phenotype observed.

Figure 2. Organization of *C. elegans* behavior module



In the laboratory, students, working in pairs, learn how to use the dissecting and compound microscopes, as well as how to observe worm behavior and manipulate worms grown on nutrient medium in Petri dishes. They are introduced to sterile technique so that they can transfer worms to a new culture plate to propagate worms that they will use later for DNA extraction and PCR (polymerase chain reaction).

We next review the central dogma of molecular biology. We consider types of mutations, how mutations arise in DNA and the effects of mutations on protein function. Students learn about PCR and compare this technique with cellular replication of DNA. In the laboratory, students extract DNA from wildtype and their mutant worms and perform PCR using primers to amplify the *unc-54* and *unc-119* genes. The students read primary literature articles (Manning et al, 2004) about both gene mutations and discuss what is known and what is not yet known about the genes and their protein products.

To gain additional access to what is known about the genes, students explore two very powerful websites, WormBase (http://www.wormbase.org) and NCBI (http://www.ncbi.nlm.nih.gov). They learn how to use tools like "Sequence Extractor" (http://www.bioinformatics.org/seqext/) to predict the size of their PCR products based on the sequence of the primers. In the laboratory, students perform gel electrophoresis to compare the sizes of the PCR products from the wildtype and the mutant worm DNA. It is their task to determine which genes have which mutations and the size of the insertion or deletion in each. Students also consider the use of GFP (green fluorescent protein) as a cell biological tool. Using fluorescence microscopy, they identify cells and tissues in which the wildtype versions of the mutant genes are expressed by observing transcriptional fusion constructs of the promoters of the genes linked to GFP. Students learn how to capture a digital image and create publishable figures that capture accurately what they have observed with the microscope. The student pairs present their data in the form of a poster and an accompanying abstract. In so doing, they learn how to prepare figures and figure legends, and to organize written information into a standard scientific format.

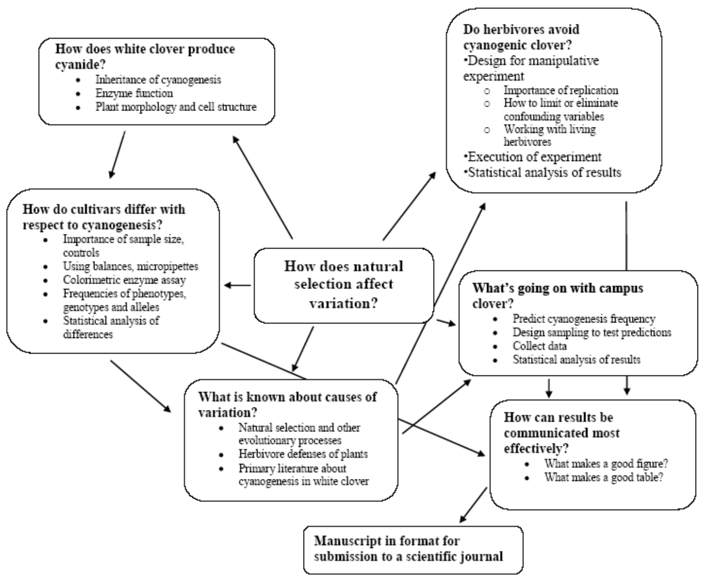
This module can be modified to explore different genes and phenotypes. In addition, the module can be designed to allow students to pursue an independent experiment, testing the effects of an experimental condition on mutant and wildtype worm behavior. Alternatively, students could compare two different mutations in the same gene to explore more fully the effects of various mutations on protein function. For example, students could look at mutations that affect the ability to express the protein (null mutations) and compare the effects with mutations that affect the folding of the protein. The combination of behavioral, microscopic, molecular and bioinformatics approaches provides a rich array of possible ways to explore fundamental biological concepts using the *C. elegans* model system.

Module 2: Cyanogenic clover: Genetic variation and natural selection

In this module, students use cyanogenesis in white clover (*Trifolium repens*) to examine natural selection as an evolutionary force affecting variation within and among populations. Many plants, including many white clover strains, are cyanogenic, and there is substantial evidence that defense against herbivores is an adaptive function of this trait. When the plant cells are damaged, the enzyme linamarase, sequestered in cell walls, comes in contact with a non-toxic cyanogenic glycoside, linamarin. Linamarase, a β-galactosidase, catalyses the removal of glucose from linamarin. The resulting acetone cyanohydrin can spontaneously break down to acetone and cyanide. Cyanogenesis is largely determined by two Mendelian loci, one affecting the production of linamarase, the other affecting the production of linamarin. Plants with at least one dominant allele at each locus are cyanogenic.

The overall organization of this module is shown in Figure 3. Students learn about the inheritance of cyanogenesis and become familiar with the enzymatic system of cyanogenesis and of the variation of cyanogenesis within and among populations of clover. In the laboratory, students examine variation among cultivars from an international seed bank using a colorimetric assay (Kakes, 1991) that allows them to determine whether and to what extent a given plant is cyanogenic. For each cultivar, they determine the frequencies of the two phenotypes (cyanogenic or not) and the frequencies of the four distinguishable genotypes. Goodness-of-fit tests are used to determine whether differences among cultivars in phenotype and genotype frequencies are statistically significant.

Figure 3. Organization of cyanogenesis module



Next, we focus on microevolutionary processes (selection, mutation, gene flow, and drift) that affect variation within and among populations. Students read and discuss research reports describing broad-scale latitudinal and altitudinal variation in cyanogenesis among populations of white clover in Europe and North America (Daday, 1958; Ganders, 1990). Based on the findings reported in those papers, students generate testable hypotheses and design experiments to be carried out over the subsequent weeks. The student-designed experiments focus on the importance of proper experimental controls, adequate sample size and appropriate statistical analyses.

Students test the hypothesis that the frequency of cyanogenic clover varies with local winter soil temperature. For this experiment, we take advantage of a system of underground steam heat tunnels that produces strips of warmer ground where snow thaws more rapidly. We have buried retrievable temperature probes in clover patches for several months to show that the soil is warmer over the steam lines. Using the colorimetric assay, students test the specific hypothesis that clover growing over the steam lines is more likely to be cyanogenic than that growing away from the steam lines. They analyze their data statistically and relate their findings back to the primary literature.

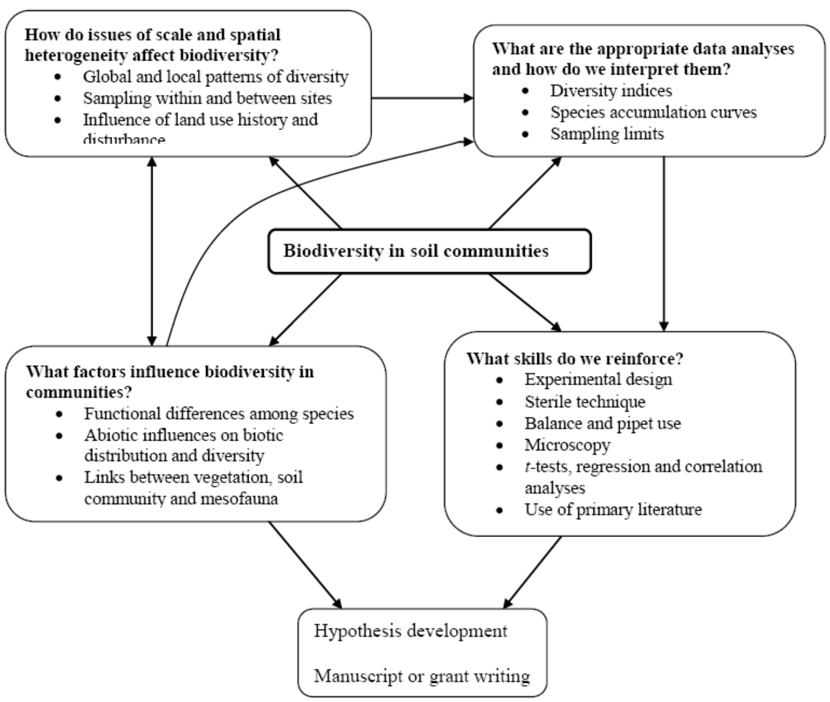
Because generalist herbivore density tends to be lower at higher elevations (Horrill and Richards, 1986), students also test the hypothesis that herbivores exhibit a preference for acyanogenic clover. Students determine the cyanogenesis profile for particular clover leaves of a variably cyanogenic cultivar of clover from the international seed bank which they assessed at the beginning of the module. Students then introduce herbivores such as locally harvested land snails (*Cepaea nemoralis*) or commercially available beetle larvae (*Zophobas morio*) to clover leaflets of known genotype. Students determine the amount of clover eaten by measuring leaflet surface areas before and after the feeding trial, then they conduct paired, one-tailed *t*-tests to assess whether the herbivores have eaten significantly more acyanogenic clover. The final assignment for this module is a manuscript prepared in the format for submission to a peer-reviewed journal.

This laboratory module is also amenable to modification in a number of ways. Students can test other hypotheses that might explain the results of the primary literature they read, including effects of soil water content or other factors that might exhibit a similar latitudinal or altitudinal cline. Alternatively, they can examine developmental aspects of cyanogenesis, where young plants exhibit less cyanogenesis than do adult plants (Hayden and Parker, 2002).

Module 3: Biodiversity and Soil microbial ecology

In this module we investigate how variation in the local environment affects the biodiversity of soil communities. The overall organization of this module is shown in Figure 4. We introduce this module with a discussion of biomes, ecological communities and global patterns of biodiversity. We consider several current hypotheses explaining those patterns. This allows us to discuss how biologists develop and test hypotheses, as well as to introduce important concepts in ecology and conservation biology. We then narrow our focus to local soil communities and the effect of soil properties on different types of organisms. The students read and discuss a recent research article (Fierer and Jackson, 2006) that provides background material and motivation for the study of soil properties and microorganismal diversity.

Figure. 4. Organization of soil microbial diversity module



After gaining insight into the relationships between diversity and soil properties, the students move to an experimental field-based approach to test specific hypotheses about patterns of biodiversity in soil communities. They learn how sampling techniques are integrated into experimental design and discuss the limitations of sampling. Student pairs use a stratified random sampling method to collect soil and leaf litter samples from two local sites. They make observations about vegetation types, topography, and current disturbance patterns at each location. In the laboratory students examine soil and topographic maps of the sites, giving them a good sense of the underlying geology of the area. They measure several soil properties for each of their soil samples, including pH, soil water content, and soil organic matter content.

To investigate the mesofaunal diversity in their leaf litter and soil samples, students set up Berlese funnels and then identify the mesofauna at the level of Order using dichotomous keys. Students learn serial dilution plating techniques to assess bacterial and fungal diversity for each of their soil samples. They examine their plates and describe all the morphospecies they see, constructing a class "morphospecies library." The students determine both the total morphospecies richness as well as which morphospecies are present for each sample. The data on the morphospecies found per sample are used to create a species accumulation curve, allowing us to revisit issues of experimental design and sampling.

In the final section of this module, students reinforce and extend their understanding of statistics by using Student's *t*-tests to analyze their data for differences in soil properties, bacterial and fungal morphospecies richness and abundance, and overall mesofauna diversity between sites. We also contrast the use of regression and correlation analyses when they test their hypotheses about how the various soil properties might affect patterns of diversity in the soil. They use the number of colonies of each morphospecies to calculate a Shannon-Wiener index as an overall measure of diversity for different types of organisms at each site. Finally, they calculate Jaccard indices for the bacteria, fungi and mesofauna to examine community similarity between the sites. The culminating assignment for this module is an individually written manuscript. This assignment builds on the scientific writing skills of the previous module and allows students to focus more on aspects of interpretation and presentation of results.

This module, like the others, can be modified to accommodate different interests and expertise. Different soil properties can be measured. For example, in one semester, the study sites differed in levels of soil arsenic (because one site was an old orchard). Alternatively, the module could include an experimental angle, by culturing the soil microbes under different environmental conditions to test hypotheses about what factors control biodiversity. Another intriguing direction, described in a number of research articles (eg. Pace, 1997), would be to incorporate a molecular assessment of bacterial diversity, using PCR and either sequencing or RFLP analysis to identify 16S rRNA variants. This last approach would build on skills developed in the first module.

Assessment and Discussion

Prior to 2004, we offered a two-semester introductory sequence. Each course was formatted as a lecture period three days each week bundled with a four-hour laboratory, one focusing on cellular biology and the other concentrating on ecology, transmission genetics and evolution. During this period, we found that 40-60% of our faculty teaching effort was devoted to the 100-level curriculum, constraining the development of new intermediate and advanced courses. Another consequence of our former introductory curriculum was that students identified themselves as either "cell biologists" or "ecological biologists," and most were resistant to taking intermediate and advanced courses that ran counter to that identity. We also found that the content and memorization-focused lecture/laboratory format was dampening many students' enthusiasm for biology.

The new introductory curriculum has reduced the teaching effort at this level to 25-30%, which has increased our flexibility and ability to offer new courses at other levels of the curriculum. Perhaps the most striking improvement is that our students approach biology with a much more integrative perspective while still addressing substantial content and concepts, no longer distinguishing based on field or level of approach. We have also seen a recent impressive increase in the number of biology majors, which we attribute, at least in part, to our changes at the introductory level.

Graded assessment of student learning

In order to assess how well students mastered the skills and concepts of *Investigations*, each module has a number of short, graded assignments that take the form of homework, problem sets or other short written assignments. These assignments focus on content and concepts covered in class and in the textbook-assigned reading. In addition, each module has a culminating assignment that stresses a major form of scientific communication. The cumulative final exam consists of a conceptual essay-style section and a skills-based practicum. The instructor of each course section poses essay style questions designed to examine how well students mastered particular integrative concepts covered in each individual course section. The skills practicum portion of the final exam is a 45 minute-long exercise in which those being examined move among approximately 20 stations. The stations contain questions that examine particular skills emphasized throughout the term (see Table 1 for examples). Some stations have microscopes, others have balances, and still others have other small equipment used throughout the semester. Quantitative and statistical skills requiring computer-based software or a calculator are also included in the skills practicum. Several questions examine critical thinking skills pertaining to experimental design, data interpretation and hypothesis testing.

Overall course assessment

In order to gauge the effectiveness of *Investigations* at achieving its goals, we administered a skills questionnaire to all students at the beginning of the semester and again at the end of the semester. This skills assessment tool gauged student learning, as perceived by them, of laboratory skills as well as quantitative skills like statistical measures, experimental design and data analysis. We queried 114 students, distributed among six separate sections of the course, taught by five different faculty members in 2007. Students were asked to indicate their level of familiarity with a given skill, from "fluent", meaning considerable exposure to the use of the skill, to "tried once or twice" to "never before encountered."

The skills questionnaire includes a variety of skills taught in *Investigations*, including some that students might well have encountered before coming to college (eg. using graduated cylinders, Fig. 5A). The responses of the students to the survey at the beginning of the semester reflect perceived skill familiarity prior to taking the course. These responses were tallied across the six sections surveyed. As is evident from Figure 5A ("Before"), at the beginning of the semester, 79% of the students felt "fluent" in the use of graduated cylinders. In contrast, only 5% of the students felt highly skilled in PCR (Fig. 5B). Only six percent of the students felt "fluent" in the use of a model organism for biological research, with 58% of the students having never encountered a model organism prior to the course. Eighty-three percent of the students had never encountered bioinformatics approaches to biological questions.

Table 1. Examples of skills practicum questions on the final exam

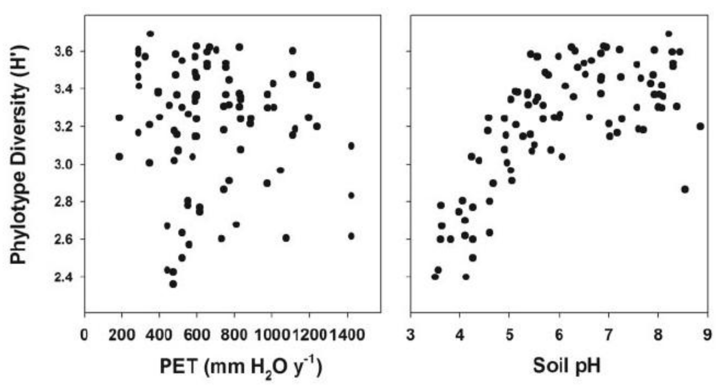
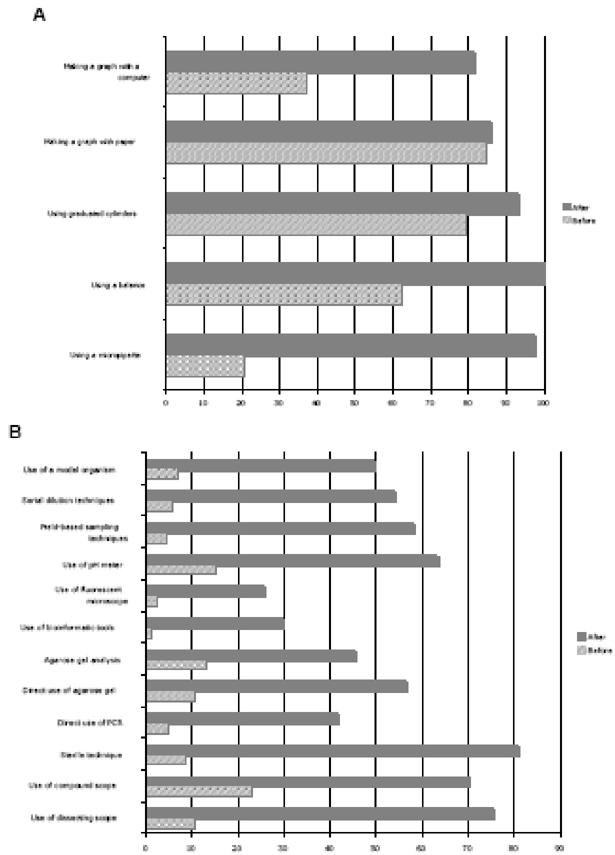
1. Pipet 170 µl of distilled water into the next preweighed, empty tube from the yellow rack. Close the tube and put it in the white rack. Write the # of your tube and the micropipette you used on your answer sheet, and write your name on the list next to the # of your tube. TUBE# ___________ MICROPIPET USED:-----
2. Use the provided mesofauna data table to answer the following questions: a. Calculate Jaccard's index comparing the two sites [re: Cj= a/a+b+c) b. Which index (richness, H', Cj) or combination of indices gives you the most complete picture of biodiversity at these two sites?
3. Shown below are two scatterplots from the Fierer and Jackson 2006 paper. Correlation analysis was performed, and the correlation coefficients (*r*) are shown below each graph. The critical *r* value (to determine statistical significance) is **0.195**.  ***r* = 0.14** ***r* = 0.83** **a)** Is **PET** correlated with biodiversity? Yes No **b)** Describe how you made this conclusion. **c)** Is this correlation positive, negative, or no correlation? Circle correct answer **d)** Is **pH** correlated with level of biodiversity? Yes No **e)** Describe how you made this conclusion. **f)** Is this correlation positive, negative, or no correlation? Circle correct answer
4. Please identify the *C. elegans* on the plate as either wildtype or a mutant strain.
5. You need to make serial dilutions to perform a plate dilution assay on a soil sample. You begin with 10 g of soil and add it to 95 ml water for your first dilution (10^{-1}). For tubes with a final volume of 10 ml, how much of your 10^{-1} dilution and how much water do you need to make a 10^{-2} dilution? How would you create a 10^{-4} dilution sample?

Figure. 5. Skills assessment questionnaire: The percentage of students rating each skill as "fluent" was determined the first day of the semester (Before) and again at the end of the semester (After). A) Skills students might have encountered before taking *Investigations*. B) Laboratory techniques specific to *Investigations*. C) Conceptual and integrative skills involving scientific communication, experimental design and statistical analysis.



The responses were tallied in the same way at the end of the semester and the difference in percent of students feeling fluent for each skill was determined ("After", Figure 5). These responses indicate the change in the familiarity or exposure to a skill, as perceived by the students. While it is possible that some of the skills were also developed in other science courses that were being taken concurrently, many of them are covered only in *Investigations* and not in introductory chemistry, physics or math. Thus, changes in the perception of mastery of a skill most likely reflect learning (or perceived learning) on the part of the student as a result of taking this course. The change in level of perceived mastery of skills specific to introductory biology was quite dramatic. The percentage of students feeling "fluent" in the use of a dissecting microscope changed from 10% at the beginning of the semester to 75% at the end of the semester. Similarly, the percentage of students feeling skilled in the use of bioinformatics approaches increased from 1% at the beginning of the semester to 30% at the end. Thus, from the students' perspective, the course format led to an increase in skill level in virtually all of the skills addressed by the course. We are in the process of conducting follow-up questionnaires with this cohort of students to address longer-term retention of skills and concepts.

Conclusions

Our new introductory curriculum has contributed to an increased interest in the biology major. The curriculum introduces our students to fundamental concepts in biology in a topical, integrative, discovery based manner that seems to accomplish the stated goals. Faculty teaching *Investigations* are excited about being able to teach open-ended, discovery-based laboratory projects and find the relevance of the projects to the primary literature to be an important and positive element of the course. One challenge we face with the course is our own comfort levels with a process-focused approach to introductory biology concepts as opposed to the traditional content-focused march through a list of concepts. While a few faculty feel that students seem to be less-prepared for work at the intermediate level of the biology curriculum, most faculty report a greater ability of students to engage the primary literature and no noticeable deficiencies in preparedness for intermediate level course work, as compared with the traditional two-semester lecture/lab courses that preceded *Investigations*. After four years with this new curriculum in place, we find our students engage intermediate and advanced courses with confidence and enthusiasm, with no notably apparent gaps in their basic knowledge and with substantially greater sophistication in their abilities to read the primary literature and approach topics integratively and experimentally. They also approach their intermediate and advanced laboratory work with skill and confidence. We continue to monitor and evaluate our student preparedness for advanced level work in biology. Perhaps the most notable change since we implemented the new introductory curriculum is that students no longer identify themselves as "cell people" or "ecology people."

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GOOSE CAM: The Development of a Practical Underwater Exploration Platform

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Abstract: We challenged an Aquatic Biology class to find a way to access, observe, and record aquatic habitats and organisms without causing disruption. Using off the shelf components the class was guided in the design and assembly of a remote controlled, video broadcasting, data collecting, floating vehicle based on a molded goose decoy. GOOSE-CAM or Guided Object Observatory for Scientific Experiments-Camera Afloat Module is now used to observe, count, and record aquatic invertebrates, fish, and plants. Recent additions have expanded GOOSE-CAM to record temperature, light (turbidity), and depth. The project fulfilled the dual educational goals of (1) integrating student biological knowledge with engineering, physics, and chemistry and (2) providing a context in which students develop problem-solving skills. The project required active participation, research, teamwork, and application learning in a realistic context to be able to support the collection of ecological data. With a bit of imagination, the concept could be adapted to other courses and environments.

Keywords: Remote Sensing, Underwater Video, Environmental Measurement, Undergraduate Research.

Introduction

Nature television and the World Wide Web provide a glimpse into worlds that most people seldom see. Today audiences watch remote vehicles explore the Titanic or the surface of Mars and with a few mouse clicks students in China can observe osprey chicks being fed in Florida. However, as interesting and engaging as these experiences are, they are essentially vicarious as there is an obvious gap between seeing and doing science.

Yet, inquiry is the basis of scientific research whether or not it is shown on TV. Inquiry is "a multifaceted activity that involves making observations; posing questions; ... planning investigations; … using tools to gather, analyze, and interpret data …" (NSES, 2004). Science education should involve inquiry (Windschit and Buttemer, 2000) while stimulating critical thinking and decision making skills in the context of scientific principles (BSCS, 2004). "The intention is to improve the quality of student learning by enabling them to acquire the abilities of inquiry, develop knowledge of scientific ideas and understand the work of scientists" (NSES, 2004). The process of thoughtful inquiry "encourage students to view science as an ongoing, relevant process of learning, as well as a body of knowledge" (BSCS, 2004). In short, students become engaged in science by doing science.

Today, much of the practice of scientific inquiry is closely linked to technology. The development of machinery, instruments, and methods necessary to answer scientific questions is an integral part of scientific investigation. Woods Hole built ALVIN to investigate the deep ocean and found the Titanic. NASA built the rovers to explore Mars and found evidence of water. Bringing scientific technology and investigation into the classroom is challenging; to do so we must add a mixture of structured inquiry and cooperative learning to our more traditional techniques to encourage and guide students to ask questions, evaluate information, and make decisions.

Goals

The learning objectives of our Aquatic Biology course were to introduce students to the biology of stream and lake organisms and to the methods used to study their ecology. To the basic course we added two additional educational goals: to integrate knowledge from related disciplines (e.g. engineering, physics, and chemistry), and to provide a context in which students develop problem-solving skills. The first two goals were addressed with lectures, laboratory exercises, and field trips. The new goals were addressed with a semester long laboratory project that required active participation, teamwork, and research to design and build a vehicle to collect ecological data. The project was presented to the class in the form of a challenge.

The Challenge

The Aquatic Biology class at Chestnut Hill College was challenged to discover and document the diversity of fish species living in the Wissahickon Creek, which runs through their suburban Philadelphia campus, without disrupting the population(s) or the habitat. In order to address the challenge students had to think both creatively and scientifically about the problems of assessing the stream ecosystem. They had to work as a team to develop an analysis strategy, assess methods that did not disturb the stream ecosystem, and develop a workable solution.

Process

After being presented with the problem, general criteria, and limitations the students developed a four step process in a brain storming session. First, they would identify and evaluate options for solving the problem. Second, they would design, construct and test equipment. Third, they would use the equipment to address the challenge. Fourth, they would review, evaluate, and enhance the solution to the problem. Each step was allotted a three hour lab period spaced through the semester. The eight students independently researched questions, assembled equipment, conducted experiments, and solved problems as a study group. The resulting GOOSE-CAM was used not only to identify fish but it became a tool to collect data on other laboratory field trips. The instructor served as mentor and consultant during the process.

Step 1: Identify and Evaluate Options

Initially students thought they could use the internet to answer the challenge but the information they found was too general to produce a list of species that actually lived in the Wissahickon Creek just a few yards from our class room. For example, they found a list of fish of eastern Pennsylvania from the Pennsylvania Fish and Boat Commission (PAFGC, 2005); however, there was no information about smaller drainages. They followed other links to university courses; again, although useful, these did not provide direct answers. Some websites were informative on aquatic sampling methods and guided students back to published references (books and articles).

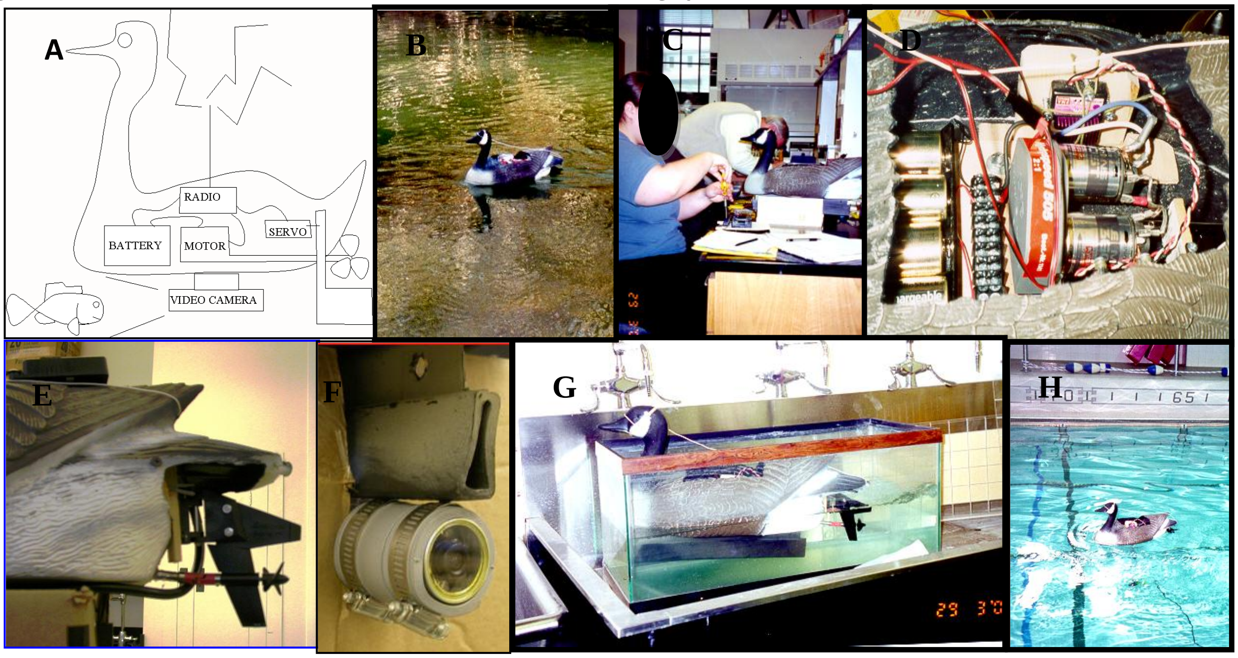
During this step, students read and evaluated material of varying quality from a variety of sources ranging from superficial websites through scientific papers. They evaluated the material both for the application to the project and the biological, practical, and ethical ramifications. They discovered that many of the options would necessitate obtaining permits from one or more regulatory agencies. Students prepared synoptic reports of several options and we discussed the merits of the methods during laboratory class.

Option one was to stretch a net across the stream, poison the water, and collect all the dead fish for identification in the laboratory. This option was rejected for biological, safety and criteria reasons: because it required a permit for the poison, killed the fish, and caused changes in the structure and composition of the aquatic community down stream. The second option was to electroshock the fish; this option was rejected because we did not have the permits, equipment, or appropriate training to ensure safety during field work. The students also voiced the same conservation concerns of killing so many fish and other organisms for a small learning reward. We discussed the appropriate use of these research tools and decided they were outside the design intent of the challenge. The third option was to conduct a survey of fishermen to determine what they were catching; this was rejected because of the built in bias in sampling. A creel count would be limited by the number of fishermen and the few larger species they seek. Our fourth idea was to SCUBA dive to examine the aquatic community; this was rejected for three reasons. First, no one had the training and certification for diving; second, bias would result from the presence of a diver in water only 3-6 feet deep; and third, in the spring semester (January-May) the water temperature is quite cold and uncomfortable.

Finally, the class felt the method that caused the least disturbance and had the greatest possibility of success in identifying the actual diversity of fish was to put a camera into the stream and take pictures of the inhabitants. However, this option posed its own challenges. A camera had to be (1) water proof, (2) small enough not to be disruptive to the fish, and (3) the image had to be of a quality sufficient to facilitate identification. Further, the unit had to be (1) portable, (2) maneuverable, and (3) affordable.

Our discussion considered building a Remote Submergible Vehicle (RSV) similar to the one used to find the Titanic but it was quickly realized that this was beyond our resources. Our discussion settled on the idea of suspending a waterproof video camera under a model boat, that we could motor around and observe the aquatic wildlife. The class also felt that if a Canada goose hunter's decoy was chosen for our boat, it might have less impact on the behavior of the aquatic fauna. We developed a design concept (Fig. 1A) and named the idea GOOSE-CAM for Guided Object Observatory for Scientific Experiments, Camera Afloat Module.

Figure 1. A. Original design and concept drawing; B. GOOSE-CAM on the Wissahickon Creek; C. Building GOOSE-CAM; D. Internal compartment showing wooden platform supporting the motor, batteries, and radio controls; E. Rudder / propeller mechanism on transom; F. Underwater camera on keel; G. GOOSE-CAM in aquarium for first water tests; H. GOOSE-CAM in pool during maneuvering tests; I. Model radio-controller used to guide GOOSE-CAM; J. Video receiver & camcorder recording system.



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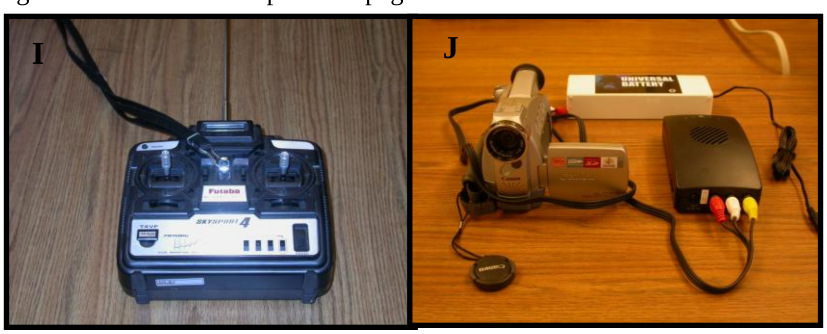

Step 2: Design, Construct and Test Equipment

The selection of components was restricted by the availability, the cost, the weight and the time allotted within the class to complete the project. We have listed the parts, descriptions, where we found them, and approximate prices in Table 1, brand names have been omitted because several different companies make similar items; a search of the internet will display alternatives. Minor components such as screws, bolts, scrap wood etc are lumped together.

The use of off-the-shelf components kept the focus on the goals of the project. Each component was selected for its contribution to the total; however, the assembly presented unique problems in getting the different parts to work together inside the goose decoy. This served as an allegory for the cooperative learning situation imposed on the students. Each student contributed their own unique skills and knowledge to the team effort. Some knew about sealants, adhesives, and fasteners. Others calculated buoyancy, matched voltage, and wired circuitry. One student had flown model airplanes and another was into video editing. Some searched the internet for components while some sought out experts (fathers, teachers, and friends) to answer questions. As individual components were acquired they were bench tested and pre-assembled for fit and function. Faced with practical problems of designing, constructing and testing GOOSE-CAM, students developed problem solving skills, improved communications, and learned from each other.

Assembly. A 4x5 inch opening was cut in the top (dorsal) surface of the goose decoy with a jig saw (Fig. 1D). The hatch piece was hinged back to the body with hook and loop material and could be sealed with duct tape when in the water. Two 3/8 inch bolts were inserted into body cavity through holes drilled in the bottom of the decoy and sealed in place with silicone bath tub caulk. The bolts served as positioning guides for the wooden platform to which the motor, batteries, and radio control modules had been attached with small wood screws (Fig. 1D). A second opening was cut in the posterior (caudal) end of the goose under the tail. This hole was fitted with a wooden plug, attached with screws through the sides of the decoy and the seams sealed with silicone to make a transom. The plug was waterproofed with urethane finish, a hole was drilled through which the propeller shaft extended, and the rudder assembly attached (Fig. 1E). The waterproof video camera was mounted on the keel of the decoy with wood screws and band clamps (Fig. 1F). Note: for safety reasons the cutting and drilling was preformed by the instructor at home.

Testing. The assembled system was first tested in a large fish tank (Fig. 1G) and then in a swimming pool (Fig. 1H). These steps provided project milestones, ensured the assembled unit would function, and allowed the adjustment of the position of the batteries to avoid capsizing. The pool test gave us training and practice in the operation of GOOSE-CAM.

The GOOSE-CAM was maneuvered with a radio control (R/C) model controller (Fig. 1I) but was tethered to the shore by the cable between the video camera and its TV monitor and battery. The cable was buoyed with small fishing floats, but the drag hindered GOOSE-CAMs movement and it became entangled in floating debris and vegetation during field trials.

We found a wireless video transmitter designed for a home security system that did not require a license (Fig. 1J). It gave a line-of-site video signal up to 700 feet even though GOOSE-CAM has seldom been deployed more than 150 feet from the operators. Video observation became portable and recordable by replacing the TV monitor with a camcorder, borrowed from our Audio-Visual department (Fig. 1J). But putting the video transmitter onboard GOOSE-CAM presented new challenges because the camera system, motor, and radio controls each required different voltages.

Field trials of GOOSE-CAM demonstrated that the motor was sufficient to propel the decoy against the mild current and that it could be maneuvered easily with the R/C controller. Fish could be seen clearly on the side screen of the camcorder when the turbidity was low. We quickly learned that vertical visibility translated into horizontal fish visibility.

Step 3: Using the Equipment

GOOSE-CAM allowed us to observe fish with little disturbance. Bigger fish did not mind the moving decoy but smaller fish only came around while it was still. Students checked GOOSE-CAM out of the lab on non class days to explore different habitats in the stream and recorded and identified 12 species of fish and five different aquatic plants. Our applications expanded beyond viewing the fish in the Wissahickon as GOOSE-CAM quickly became part of our field trip equipment. We it to a lake in a state park and were able to watch the fish under docks and we followed a big bass as it swam between lily pads in a marsh. The transmitted video improved our understanding of three dimensional spaces even in shallow water. The observation of invertebrates was more difficult because of distance, magnification, and lighting limitations but we did observe a few crayfish and one large dragonfly larva. Once, we tried to get close to a beaver but it swam too fast. Another time, a large male Canada goose landed next to GOOSE-CAM and followed it around the stream honking loudly; eventually, he lost interest and left.

Step 4: Enhancing the Unit

Having demonstrated that GOOSE-CAM actually provided a window under the water, it allowed us to answer the challenge of identifying what fish lived in our stream. As a tool, GOOSE-CAM introduced the class to questions of double counting, estimating populations, and spatial and temporal differences.

As we started to discuss other applications, the class decided that by adding instruments to GOOSE-CAM, we could take measurements in places we could not reach. We decided to measure location, water depth, turbidity, and air and water temperature. The students selected instruments based on function, size, weight, and cost (Table 1). A small data logger was suspended in a clear plastic case from the keel behind the camera, this recorded water temperature and light (turbidity). A similar unit on the back of the decoy recorded air temperature, light and relative humidity. A fisherman's depth gage was found that could be towed behind the decoy.

But data is meaningless unless it can be spatially oriented, thus location on the water was determined to be a critical element. A small, light weight (6 oz) GPS unit capable of recording waypoints was found and with one of the free channels on the R/C controller we were able to construct a simple lever to activate the waypoint button. We later downloaded the data from the data loggers and the GPS into a spreadsheet and matched the times at a specific waypoint. Thus GOOSE-CAM was enhanced to a remote sensing instrument in space and time.

Table 1. Components used in GOOSE-CAM.

ITEM	Description	Approximate Cost (2004)
Goose Decoy Fig. 1B	A plastic, Canada goose decoy was hollow and water tight. It had a flat bottom with a small keel. Sporting Goods Store.	$20
Radio Control Fig. 1D, 1I	A four channel radio control (R/C) system of the type used in models. One channel to control forward, reverse and speed of the propeller; second channel to control the rudder for steerage; the third & fourth channels were free. One was later used to mark location (waypoints) on the GPS. Hobby shop.	$150
Propulsion Fig. 1D, 1E	A model boat electric motor with propeller, shaft, and rudder mechanism. Hobby shop.	$80
Video Camera Fig. 1F	An off-the-shelf underwater video camera designed for exploring sewer pipes, it had a built-in LED illuminator and included a 7" TV monitor for viewing. Internet / mail order	B/W $150 or Color $350
Video Transmitter / Receiver Fig. 1J	2.4 GHZ technology which requires no license to operate allowed line-of-sight video transmission up to 700 feet. Included transmitter and receiver. Internet / mail order	$100
Supplies	Miscellaneous hardware, batteries, wires, connectors, tape, Velcro, screws, bolts, sealant, etc.	$50
Total	Basic GOOSE-CAM w/o instruments or camcorder	B/W $550 or Color $750
	Options: Instruments	
Location	Small, light weight (6 oz) GPS capable of recording waypoints when activated by R/C controller. Included unit, cables & software. Down loadable to a computer spread sheet. Sports Retail Store.	$100
Depth	A small digital depth sounder and wristwatch receiver. Sports Retail Store.	$85
Environmental Sensors	Temperature and light (turbidity) data loggers. Internet / mail order or Science Catalogues.	$100 ea
Totals	Basic GOOSE-CAM with instruments, w/o camcorder	$835 - $1135
	Options: Recording	
Images Fig. 1J	A camcorder that accepts external analog A/V input can capture images for later use. Digital recording allows image analysis and editing. Borrowed from AV Dept.	$300 - $1,000

Discussion

The making of GOOSE-CAM was not an end in-itself. The goal was to engage students in a project that would further their knowledge of biology and improve their problem-solving skills. Throughout the GOOSE-CAM project students were encouraged to think critically, incorporate their existing knowledge, test ideas, interact to find solutions, and to achieve the goal: to access, observe, and record aquatic organisms and habitats without causing disruption.

Based on our experience, we agree with Lord (2001) that the application of cooperative learning in the teaching of biology encourages critical thinking and improves students' practical problem-solving skills. We chose the GOOSE-CAM class project as a structured, inquiry-based learning project (Windschit and Buttemer, 2000) because of the availability of laboratory time. This approach proved useful because our class size was small (8 students) and because we emphasized student learning with a mixture of inquiry and classical classroom experience. Based on our students' active participation, we believe we achieved the goals of integrating biological and related knowledge while developing problem solving skills.

Because we can not afford to build a new GOOSE-CAM every year, the challenge for the next Aquatic Biology class will be to develop quantitative and qualitative applications for GOOSE-CAM. Students will be challenged to design experiments that will provide data of our stream and lake communities as an undergraduate research tool. Our class has envisioned mapping the depths and developing thermal profiles of small ponds. They suggested deploying dissolved oxygen and pH meters on GOOSE-CAM to record the diurnal chemical cycles. They also want to document fish behavior relative to structures (tree stumps, rocks, and docks).

Since this project was conducted, several students have continued to experiment with variations of the technology. One student mounted the underwater camera system on the bottom of a pole and used it for reef walking on the Great Barrier Reef. She observed and recorded shrimp, feather worms, an octopus and a small shark. When we took a class to the Amazon we used the camera to observe piranha feeding in a black water lagoon. Another student mounted a wireless camera on an R/C toy truck and monitored the behavior of geese on our soccer field. Still another student carried the video camera aloft with a helium balloon for a low level aerial measurement of invasive plants encroaching into a wetland. For now GOOSE-CAM motors through the shallows and broadcasts images of the animals and vegetation that are in front of it.

Acknowledgements

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Teaching Stress Physiology Using Zebrafish (*Danio rerio*)

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Abstract: A straightforward and inexpensive laboratory experiment is presented that investigates the physiological stress response of zebrafish after a 5 °C increase in water temperature. This experiment is designed for an undergraduate physiology lab and allows students to learn the scientific method and relevant laboratory techniques without causing significant stress to animals. An additional experimental design and a set of additional questions for lab report are also included.

***Keywords*:** zebrafish, temperature, stress, physiology lab

Introduction

The use of hands-on experiments with animals is an important method of teaching undergraduate biology students about physiology. However, there has been a recent trend of using computer-simulated experiments to teach physiology to students. Although there are numerous benefits to using computer technology, simulated experiments cannot replace the experience of working with animals such as mice, frogs, and zebrafish. Zebrafish have been used to study vertebrate development and genetics, and as a model for studying human disease, aging, oxidative stress etc. (see review by Gerhard and Chang, 2002). Zebrafish have also been used in studying developmental physiology (Barrionuevo and Bufggren, 1999) and there are studies on the effects of heat shock at the molecular level (Krone *et al.*, 1997; Yabu *et al*., 2001). However, the studies related to normal basic physiology of zebrafish are limited. Given that zebrafish are inexpensive and easy to maintain we wanted to explore the possibility of using them to teach physiology in an undergraduate lab. This paper describes an experiment using zebrafish as a model to teach students about the stress response in vertebrates.

Background

The stress response in fish has many similarities to that of terrestrial vertebrates (Wendelaar Bonga, 1997). By studying the stress response in zebrafish, students can apply what they learn to other vertebrates. According to Hans Selye, a renowned physician, a stressed organism passes through three stages that make up the General Adaptation Syndrome (GAS). The first stage is an alarm reaction in which the neuroendocrine system is activated and stress hormones are produced. The second stage, adaptation, which generally occurs within 24-48 hours, involves the organism's return to the pre-stress state or an altered resting state through physiological changes (i.e., increased respiration, decreased metabolism, and decreased immune response). If the stress is too severe or chronic, adaptation may not be possible and the organism enters the third stage, exhaustion, which affects the entire organism. During the third stage, consequences such as poor growth, poor reproduction, and increased susceptibility to diseases may be observed (Barton and Iwama, 1991).

There are many parameters that can be used as indicators of stress in fish (Barton and Iwama, 1991; Wedemeyer et. al. 1990). In this experiment, five parameters including opercular beats (ventilation frequency), oxygen consumption, blood glucose, spleen somatic index (SSI), and condition factor (K) were used to study the effects of temperature stress. Ventilation frequency is an indirect measure of the metabolic rate of fish. Fish initially adapt to stress by increasing their ventilation frequency. If this adaptation is successful, other physiological changes may not occur. Stressed organisms usually require more oxygen to carry out their metabolic processes. In order to compensate for the increased oxygen requirement during stress, hyperventilation may occur. Blood glucose is another indicator of metabolic stress, and functions to provide the caloric energy needed for a fight-or-flight response. Blood glucose levels become elevated due to the action of the stress hormone, cortisol. The spleen stores red blood cells and releases them for circulation, and can decrease in size during stress. The condition factor indicates the overall health of fish. Stress can affect the condition factor of fish by causing them to have a smaller than usual weight at a particular length. As such, the condition factor reflects the growth or wellbeing of an individual fish. Typically, the condition factor is one of the last parameters to change when a fish is under stress, and the change usually occurs in the exhaustion stage.

It is well known that a significant increase or decrease in water temperature can cause physiological changes in vertebrate animals that may lead to the exhaustion stage of the stress response. However, various experiments have shown that a 2-5 °C increase in water temperature does not result in any significant physiological changes (Burka et al., 1998). Hence, we wanted to use a fish model system and temperature stress to teach physiology.

Hypothesis

The present study was used to investigate the effects of a 5 °C temperature increase on zebrafish with the hypothesis that no significant changes would occur in the following physiological parameters: opercular beats (ventilation rate), oxygen consumption, blood glucose, spleen somatic index, and condition factor.

Goals

Our goals for conducting the experiment described in this paper were to make sure that zebrafish are not stressed to exhaustion under the experimental conditions and to ascertain the feasibility of using such an experiment in an undergraduate physiology lab by allowing undergraduate students to conduct the experiment, collect and analyze data and present their finding in a professional setting.

Learning objectives/ outcomes

After completing the exercises presented and suggested in this paper the students should: (1) understand basic concepts and principles related to stress physiology, (2) be able to define common physiological terms and describe the parameters used to evaluate stress, (3) formulate and test the hypothesis, (4) gain experience in the laboratory techniques used during the experiment, (5) demonstrate an ability to collect, analyze and interpret data, and (6) be able to describe experimental design and present their results and analyses in a written or an oral form.
Instructors might want to use Bloom's taxonomy or Revised Bloom's Taxonomy to assess student learning as described by Forehand (2001).

Materials and Methods

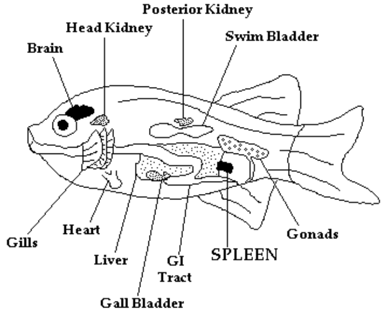
Sixty zebrafish were purchased from Aquarium 33 in Fort Wayne, IN, divided into two groups (control and experimental, each with 2 replicates), and placed randomly into four 20 gallon glass aquaria which contained dechlorinated water. The dechlorination process involved filling large bins with city water, which remained uncovered and aerated for 2-3 days. This process enabled the slow evaporation of chlorine from the water sources. The aquaria water was filtered and oxygenated by the use of Millennium 2000 filters (Aquarium Systems, Mentor, OH). Water within the aquaria was heated to an optimum temperature of 28 °C by the use of Visi-Therm Deluxe 100W heaters (Aquarium Systems, Mentor, OH) and fish were acclimated for 2 weeks. After the acclimation, water temperature in the experimental aquaria was raised to 33 °C. The fish were fed TetraMin: Large Tropical Flakes (The Rich Mix) (Tetra, Melle, Germany) twice daily to satiation and cared for according to the guidelines of the appropriate animal care committee.

Stress parameters were measured from randomly sampled fish (6 fish per group: 3 from each replicate) on days 0 (before the water in the experimental aquaria was heated), and on days 2, 4, 6, and 8. For measuring the rates of opercular beats and oxygen consumption, each sample fish was placed in a glass beaker with pre-measured water, each beaker was equipped with an YSI Oxygen Probe (YSI Incorporated, Yellow Springs, OH) to measure the oxygen levels, and sealed with Parafilm to minimize any addition or loss of oxygen. Because parafilm does not totally prevent exchange of gases, the measurements were taken for a very short time (3 minutes) and averaged. Also, the conditions used for oxygen measurement were identical for both control and experimental groups hence the relative values are still valid. The reason for the simple set up is to make it possible to perform it in an average undergraduate laboratory where sophisticated apparatus may not be available. The opercular beats were then recorded using a digital video camera, and the levels of oxygen were measured using the oxygen probe over 1 minute. The video was later used to count the number of times the operculum opened and closed per minute. The oxygen consumption rate was calculated by subtracting the final O_2 concentration from the initial O_2 concentration per minute. After these 2 parameters were measured, the zebrafish were euthanized by qualified personnel using a lethal dose of MS-222 (greater than 200 mg/L) (Wedemyar et al., 1990).

Condition factor (K), was measured by taking the length (L) and weight (W) of each zebrafish and using the following formula: $K = (W \times 100) / L^3$ (Ibrahim et al., 2000). A drop of blood from each fish, from the severed caudal peduncle, was then obtained and placed on a glucose strip in a standard glucometer (Prestige Smart System, Home Diagnostics, Deer Field, IL) to determine the levels of blood glucose. Directions from the manufacturer were followed when operating the glucometer. This method has been validated for use in glucose analysis for fish (Wedemyar et al., 1990). After blood determinations were concluded, each fish was carefully dissected to obtain the spleen (Figure 1). The spleen somatic index (SSI) was calculated using the formula: ((spleen weight

(g) / body weight (g)) x 100 (Garcia-Abiado et al., 2004).

Figure 1. Zebrafish anatomy



After the sampling period ended, statistical analysis of the data was performed. The means and their standard deviations were calculated for each parameter. Analyses were carried out using Student's t-test with Minitab (Minitab ® Release 14 2006). Differences were considered significant when $p < 0.05$.

Results and Discussion

Data for opercular beats is presented in Figure 2 which shows that at days 2, 4, 6, and 8 there was a significant increase in the number of opercular beats. The results for oxygen consumption, blood glucose levels, spleen somatic index, and condition factor are presented in Table 1. There were no significant differences between the control and experimental groups of fish except for glucose at day 4. The difference in blood glucose at day 4 was due to an outlier or anomaly in the data and hence we conclude that the difference was not related to the stress response.

Figure 2. Number of opercular beats for control and experimental zebrafish. * Significantly different from control (p <0.05).

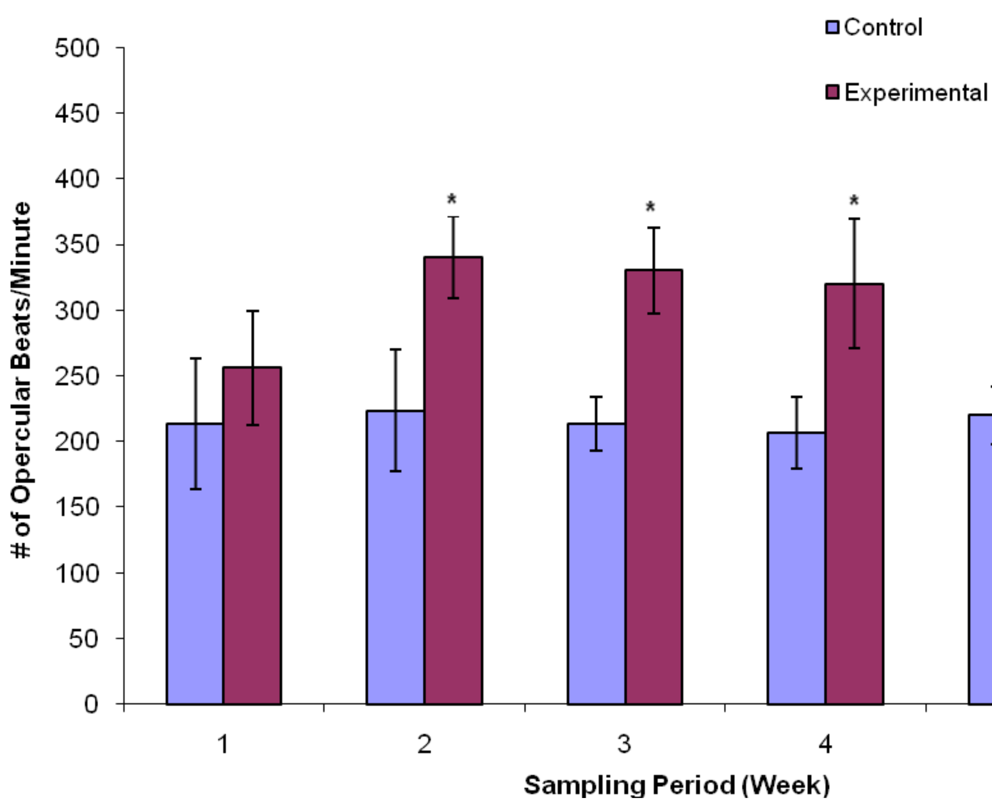


Table 1. Comparison of stress parameters between two groups (control and experimental)

Fish Group (n = 6)	Sampling Period (Days)	Oxygen Consumption (mg/L /min)	Blood Glucose (mmol/dL)	Spleen Somatic Index (SSI)	Condition Factor (K)
Control (28 °C)	0	0.86±0.27	28.00±9.66	0.07±0.03	0.90±0.25
Experimental (33 °C)	0	0.71±0.16	44.00±18.01	0.10±0.06	0.82±0.19
Control (28 °C)	2	1.30±0.74	58.75±31.68	0.11±0.07	0.86±0.11
Experimental (33 °C)	2	1.61±0.33	59.66±28.51	0.10±0.05	0.89±0.10
Control (28 °C)	4	0.89±0.16	25.25±9.91	0.15±0.10	0.99±0.10
Experimental (33 °C)	4	0.94±0.16	61.60±22.91*	0.10±0.04	0.94±0.12
Control (28 °C)	6	1.34±0.17	15.75±5.73	0.14±0.03	0.96±0.18
Experimental (33 °C)	6	1.24±0.30	25.66±11.02	0.14±0.04	0.93±0.06
Control (28 °C)	8	1.00±0.19	34.50±25.09	0.15±0.05	0.90±0.10
Experimental (33 °C)	8	1.03±0.19	42.66±24.68	0.16±0.10	0.90±0.22

* Significantly different ($p < 0.05$); means ± standard deviation

A significant part of stress adaptation involves the redistribution of metabolic energy away from activities such as growth and reproduction and towards activities such as respiration that will help to restore homeostasis. The data presented in Table 1 and Figure 2suggest that in order for the zebrafish to successfully adapt to the 5^0C temperature increase from the optimal temperature (28^0C), they reallocated some metabolic energy to increase their ventilation frequency. Some increase in oxygen consumption was also observed but it was not statistically significant. Hence, we suggest that because the zebrafish were able to adapt by increasing their opercular beats (Figure 2), more significant physiological changes such as an increase in blood glucose or reduction in spleen size did not occur and movement into the exhaustion stage was prevented. Thus, there was no change in the condition factor which is affected only in the third stage of the stress response. Since no significant physiological stress occurred when the temperature was increased by 5^0C (above optimal temperature 28^0C), concerns about exposing animals to stress were eliminated.

Given that this experiment was performed by three undergraduate students, we feel that it is well-suited for undergraduate physiology labs and will enable students to develop and test hypotheses, describe an experimental design, learn lab techniques, collect and analyze data, draw conclusions, and present results as they relate to the stress response. Before students perform the experiment the instructor may divide students into five groups and provide them with the references for five parameters to be tested (the references are given in this manuscript) and instruct students to develop a hypothesis and an experimental design to test the hypothesis. It is likely that their design will be different from what we have proposed below. This will provide an opportunity for the instructor to discuss pros and cons of their design. The instructor may use their design (if practical and appropriate). After the experiment is completed the students can be asked to give an oral presentation or write a report in a scientific format. In either case, assessment can be based on content, synthesis, data interpretation, sequence and organization of material, clarity. For oral presentation additional criteria such as addressing audience well and handling questions can be added. The instructor might want to use the Likert scale of 1-5 with 5 being excellent.

Although this experiment was conducted over an eight day period in the classroom setting, the experiment may be performed over a different period of time (i.e., five weeks) at the instructor's discretion. Also, if an instructor wishes to devote only one laboratory session to this experiment, we suggest the following alternative experimental setup:

1) The instructor or lab personnel will have to set up 10 tanks 10 days prior to the day of actual experiment to be performed by the students. Out of these 10 tanks, use 5 tanks for the control group and 5 tanks for the experimental group. Raise the temperature in 1 experimental tank to 33 °C every 2 days. Therefore, at the end of 10 days, there will be 5 tanks each representing a time point (2, 4, 6, 8, and 10 days of exposure to increased temperature).

2) On the tenth day divide student into 5 groups and give each group one control and one experimental tank. Have each group collect data for all 5 parameters from their control and experimental tanks during the same lab period.

3) Pool the data from each group and distribute it to the class – thus each student will have data for all five time points.

4) Have each group perform data analysis using statistical software.

5) Require students to write a lab report and present results, interpretations, and conclusions in the desired format.

It is also important to keep in mind that the animal care protocol chosen should be approved by an animal care usage committee prior to beginning the experiment. If desired and time permits, students can be made aware of the regulations related to the use of animals in the laboratory. This is particularly relevant to the experiments that might be perceived as cruelty to animals by subjecting them to stress. It may also be used as an issue worth discussing in class.

Furthermore, students can be assigned to answer additional questions in their lab report such as:

1) Is it possible that genetics plays a role in the stress response of zebrafish? Would it be better to conduct this experiment with an isogenic pool of zebrafish or a wild population?

2) Would an instantaneous increase in water temperature yield different results?

3) Ventilation frequency (opercular beating) consumes energy. If stress increases the rate of ventilation, would this loss of energy begin affecting other parameters over time?

4) Does water temperature affect the amount of dissolved oxygen? If so, would an increase of 5 °C significantly impact the oxygen consumption results?

5) Can the same question be answered using an alternative experimental design?

6) What other hypotheses involving zebrafish and stress physiology could be investigated?

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Learning How to Learn: A Model for Teaching Students Learning Strategies

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Abstract: Incoming freshmen frequently struggle with the transition from high school to collegiate academics. This appears to be particularly evident in the sciences. Students often lack the self assessment skills and metacognition skills required to self-identify problems with their academic learning strategy. This does not allow them to diagnose and modify their learning strategies to allow them to be successful. Instructors often have little experience with such learning challenges and therefore may not be able to offer students appropriate learning strategy modifications. I present and assess a model for teaching learning strategies to students in an introductory biology course. This model presents specific techniques to assist students in accurate self assessment which then leads to recommendations for modifying their learning strategies. This model was used in an introductory biology course and students who attended these learning strategy workshops performed significantly better in the subsequent exam than students who did not attend a workshop. I present an outline of the workshop and learning strategy modifications and discuss the ramifications of incorporating learning strategy workshops on a broad scale for freshmen.

Keywords: learning strategy, freshman, introductory biology, metacognition, self assessment, study skills

Introduction

Many colleges have programs designed to prepare and guide incoming freshman students as they transition from high school to the college experience. Many of these programs (almost 60% according to the National Survey on First Year Seminars (http://www.sc.edu/fye/index.html) focus on the social aspects of this transition (e.g. creating new social networks, adjusting to the new independence of college living, etc.) which is an important component contributing to the successful college transition . However, the transition from high school to higher education academic expectations is often not addressed at all or, at best, only superficially even though the successful use of study skills and learning strategies is strongly correlated with academic achievement (Zimmerman 1998). Time management skill workshops are often the only academic skill presented at these college transition sessions to help students prepare for their new academic life and less than a quarter of the First Year Seminar programs offer basic study skills seminars (http://www.sc.edu/fye/index.html).

Incoming students (especially freshmen) often were moderately or even highly successful in high school and their expectation is that the skills that produced success in high school will transfer successfully to college academics. However, the expectations and learning model in high school is often very different than they are in college. The high school learning model often requires students to attend class five days a week for a whole semester or year and students are in class for 30 hours per week. Class time in this model is not just about presenting material but is also the place where students learn the class material. Topics may be repeated and discussed with a fairly small number of students numerous times. In this model, students often spend the majority of their learning time in class and there is frequent testing on more focused knowledge than students are presented with in college.

The higher education model differs in that material is often presented at a brisk pace once during lecture and the majority of learning is expected to occur out of class (students are in class only 12-16 hours per week). The quantity of knowledge learned, the pace of academic learning and the ability to synthesize and utilize knowledge at the college level is usually at a much higher pace or level than students have previously experienced. Therefore, it can be very challenging for new college students to understand and be successful using this different model of higher education learning.

In college, students are expected to be self-motivated, able to self-assess their learning strategies, self-diagnose and then modify any learning hindrances. Metacognition, being able to self assess understanding and decide whether or not it is adequate (Bransford et al 2000), is critical for students to accept any modifications to their learning strategies. However, given their success in the high school learning environment and the many years of ingraining those high school learning strategies, it is often difficult for incoming college students to even self-identify that there is a problem with their academic learning strategy much less self-diagnose and modify those ingrained learning strategies. Several studies have found that students often fail to adapt and implement new study strategies when needed (e.g. Broekkamp and Van Hout-Wolters 2007). College students often report that "looking over their notes" before the exam has served them well in the past (Ruban and Reis 2006). Low achieving students, in particular, often report that "they felt that they knew the material well going into the exam but then were shocked at their exam grade." Compounding the problem is the fact that most higher education faculty have little or no training in study skills or learning strategies. Also, given that many faculty were exceptional students (hence their academic success) they may have no experience with such learning challenges. So when a student approaches an instructor on "how to do well in their course" many faculty truly have little to offer to the student other than "study harder". This can be extremely frustrating for both the student and the faculty member.

The purpose of this paper is to present and assess a model for teaching study skills strategies to help students self assess and diagnose their studying strategies and then develop new successful studying strategies. This model presents techniques to help students assess and modify their studying strategies for all levels of questions ranging from simple knowledge, to conceptual to critical thinking.

Methods

Students from two lecture sections of a large introductory majors level biology course (n = 348 students) were offered a one hour Advanced Study Skills workshop during the Fall 2006 semester shortly after the first lecture exam. The term "advanced" was added to indicate that this was not a remedial workshop and to encourage more students to attend. The workshop was interactive and developed to present self assessment tools, study skills strategies and student learning styles information to students. A PowerPoint presentation accompanied the workshop. Four identical workshop sessions were offered immediately after the first lecture exam. Almost all of these students in the course are traditional first year freshmen students and a majority of them self describe as being preprofessional health students who aspire to enter professional schools such as medicine, dentistry, optometry, podiatry and veterinary sciences.

The difference between the first and second exam score was examined using a t-test for unequal variances (Sokal and Rohlf 1995). By examining the difference between the two exams this eliminated the need for standardizing the scores for each exam. Each exam was made up of three types of multiple choice questions, recall, conceptual and application. The majority of questions were recall or conceptual based questions. Exam 1 had 44 multiple choice questions covering four chapters and Exam 2 had 46 questions covering five chapters. Both exams covered material on cell and molecular biology and were held during a 50 minute period.

At the end of the semester students were assessed on their perceptions of the effectiveness of each of the study skills strategies.

Workshop Contents

1) Self-Assessment of Learning Techniques

The workshop begins with a series of three interactive exercises that allow students to self evaluate their current study techniques: 1) assessment of Mona Lisa recall ; 2) multiplication table analogy, 3) current knowledge assessment.

As discussed previously, most low achieving students are not able to self diagnose problems with their studying strategies. The most basic issue of self diagnosis is having students identify when they actually "know" something. Memory or knowledge is the basis for learning and problem solving (Tulving 1983). For instructors, it often seems needless even to discuss this first step of acquiring a knowledge base with students because our expectation is that students must know how to learn this information. Many students report that their study skills often entail "looking over" their notes numerous times and feeling confident that they understood the material using this strategy. However, there is a large chasm between understanding information and actually knowing information without the use of any external information (e.g. notes). The three exercises presented here demonstrate this difference for students.

Assessment of Recall Knowledge - Mona Lisa Example - In order to help students self assess their levels of learning, I have developed an exercise which allows them to demonstrate their recall knowledge to describe a familiar object. At the beginning of my study skills workshops, students are asked to describe in detail an object that they could all identify easily, the painting the Mona Lisa by Leonardo da Vinci. Even though most students have never seen this portrait in person almost all acknowledge prior to the exercise that they are aware of and can recognize this painting (e.g. it is often considered the most easily identifiable painting in the world) . Numerous other examples that might be more relevant to students such as describing the White House or describing an object (such as a school mascot) or building on their campus could be used. The key is that the object must be familiar enough to students that their prior self assessment is that they can easily identify this object and feel that they "know" it.

The students are given a short time limit of 3-4 minutes to write down every detail they can remember of the painting (or object) as if they were describing it in detail to someone who had never seen the painting. Giving students a well defined and short time limit impels them to focus on the task.

After the assigned time, students are asked to share the details that they remembered of the object. For the Mona Lisa, students can almost always identify that it is a woman, the painting is overall dark in color, she has an odd smile/ smirk on her face and that her hands are showing but they are not sure how they are shown. Students responses on hair length, its nature (curly or straight), her clothing, and the background, etc. vary widely. In other words, students remember the very superficial or most rudimentary aspects of the painting but little of the details or nuances. This is analogous to many students studying/ learning strategies. Students overwhelmingly report that they look at the information in their notes or in their textbook and understand the basic information but have not learned the more specific aspects of the knowledge or how to analyze this knowledge. They might be able to identify a concept when it is presented to them as they saw it in the textbook or notes but they have not absorbed and synthesized this information in order to be able to use this knowledge in other contexts.

After the students share their responses of their recollection of the Mona Lisa, a slide is shown of the painting and I discuss the contradictory aspects they reported. The analogy to their learning of their notes is then discussed with the students. The students are asked to compare how this experience relates to their current learning experience. The students overwhelmingly report that they can identify "where" a concept is located in their notes but they can not remember the details. This is analogous to being able to identify the Mona Lisa but not being able to carefully describe her appearance.

<u>Recall Learning Example - Multiplication Tables</u> - In order to emphasize this point, students are next asked to recall how they learned their multiplication tables while in elementary school. Most students report that they spent a great deal of time repeatedly going through each multiplication example where they would recite the example without looking at their notes or the multiplication table. Students are asked if they felt that they could have learned how to multiply numbers if they had only "looked at" their multiplication table and did not repeatedly go through each example without their notes. Overwhelmingly they report that they could not. I stress that this is again analogous to their usual learning procedure where they look over their notes rather than actually learn the material.

<u>Course Knowledge Recall Example</u> - The next technique allows students to self assess their memory and their ability to organize and understand the main concepts from a recent course lecture. I select a chapter or topic that has been discussed in lecture recently that students have read and/or studied. Students are asked to write down the two or three most important main concepts on that recent chapter/ topic. Again, the students are given a short, limited amount of time (2-3 minutes) to complete this task. Students are then asked to share their understanding of the main concepts. Overwhelmingly, the students cannot remember or report the main concepts of a chapter that they heard for an hour in lecture and then may have spent several hours reading the textbook or going over their notes. Most students have no responses at all or at best may remember a key word or phrase. I emphasize that they reported spending considerable time and effort studying this material but do not appear to have learned that material. I stress that this indicates that their current studying strategies do not appear to be effective or this would be a fairly simple recall task.

<u>2) Study Skills Strategies</u>

Next, a series of study skills strategies are presented to help students prepare for class, take effective class notes, actively read their textbook, and prepare for exams. These strategies prepare students for learning in and out of the classroom.

<u>Preparing for Lecture - Keywords or Terms</u>

Biology is a discipline that is full of discipline-specific terms. In lecture, students may not have time to fully recognize and learn these new terms and as such, their ability to follow and comprehend the lecture topic is hindered. In courses such as introductory biology, each chapter is often a self contained mini-course in a new sub-discipline each replete with its own set of terms and keywords. For the student who is not familiar with these, listening to the lecture can sometime be analogous to listening to a foreign language. It does not allow for adequate retention and comprehension of lecture material. To remedy this, I recommend that students go through each chapter prior to lecture and make a list of new keywords and their definitions. By doing this the student is already engaged in the material and will have a better opportunity to follow the lecture topic. During the study skills workshop, students are asked to go through the textbook reading for the next chapter and look for words in bold font and section headings. Many textbooks use a different font to identify these key terms and definitions or use these as headers for each section. Students are encouraged to create a list of key terms and definitions for each chapter that they can refer to during the class time if needed to remind them of the meaning of the terms being discussed.

Preparing for Lecture - Passive vs Active Reading

Students reading each and every sentence of a new chapter prior to class may find the information to be a bewildering array of facts and terms. It is often useful for instructors to give students specific pages or figures for them to preview prior to class in order to focus their pre-class learning to a manageable amount and to emphasize the most important concepts on that topic. Students are asked to preview the text headings to use as a road map for the chapter. By asking what is the major concept illustrated in a figure they can begin to examine the conceptual underpinnings of the chapter. By having these concepts be familiar but not yet fully understood creates a greater learning potential during class. In addition, as students do not fully comprehend all concepts in this section they create internal questions (Walter et al. 2002) about the concepts that can drive their interest in the concept and this can lead to higher rates of retention of material.

Many students report that they spent numerous hours reading their textbook either before and/or after class and yet when quizzed on this knowledge have very little recall of this material. During the study skills workshop, I ask students to provide details of their most recent non-academic reading. In contrast to their academic reading, many students can provide elaborate plot and character details of this reading demonstrating that reading material once can allow for a large amount of comprehension and recall. This shows students that their ability to recall and retain knowledge is possible from their initial reading. However, in their non-academic reading they are usually actively making connections between characters and plotlines. Their inability to recall basic information from their textbook likely occurs because of the passive state of activity during their reading - they are reading the words but are retaining almost no information. Students were actively engaged in their non-academic reading which resulted in higher retention rates of information.

Another technique that students can use to be more actively involved during reading is to set up the relevance of the topic. If students ask themselves "why is this topic important" or "how might this topic relate to me" it creates relevance in their lives and this can increase student engagement and information retention. Another technique is for students to ask themselves "what do I already know about this topic" as this allows them to create connections with the topic and their previous learning. This creates an internal learning map to guide their learning for this topic.

During Lecture - Taking Thorough Notes

It may seem abundantly clear to instructors that all (or most) of the material discussed in lecture is important and relevant to the topic and as such students should be taking notes on this topic. However, students often are not effective at determining which information is important and many only take notes on what is on a PowerPoint slide, the chalk board or what the instructor writes down during class. In order to retain information it is important for students' to review these notes shortly after lecture. For some students learning styles recopying their notes can reinforce material. Students are also encouraged to create their own quiz questions of each day's lecture material. They can then share these with other students in the class or some students may form study groups to share their questions. Students are encouraged to create quiz questions that are in a format similar to the exam format (e.g. short answer, multiple choice, etc.) in order to best simulate this experience.

Actively Reading the Textbook After Class

Another strategy for reinforcing knowledge is to review the textbook on the pertinent course material. This can be used to fill in knowledge gaps and again create more quiz questions in the appropriate testing format. Almost all biology textbooks (as well as other disciplines) outline the main concepts of each chapter at the beginning of the chapter. Many often do this as a short bullet list of concepts. Students do not usually read these or find them relevant but I show students that these can be used as study tools to develop the connections between topics. In addition, asking student to use their notes to determine the two or three main concepts after a specific lecture allows the students to review their notes and identify the underlying themes or concepts for this topic.

Studying Lecture Material and Self Assessment of Knowledge

Students often report that they read through their notes and understood them fully but yet their test scores indicate that they had not mastered the knowledge. They do not seem to make the connection between reading and understanding their notes and knowing the material. One strategy that students can use to self identify their knowledge is to ask them to explain the terms and/or concepts of the material to a friend, dog, plant, etc. without using their lecture notes or textbook. Students may need to practice doing this first with their lecture notes but eventually must be able to do this without the aid of any lecture notes or textbook.

Flash cards can be useful for students to utilize during short study sessions throughout the day to learn specific terms. This allows students to quickly ascertain their level of knowledge. It is also important to stress that this may take many repetitions until they know all terms and can explain a complex concept without using any notes or course material at all. Another useful technique for learning concepts is to have students draw a complete figure of a concept from memory without using any course materials. This again allows students to self assess their level of knowledge.

Even in classes that involve problem sets, students often do not realize the difference between "going over" the problems numerous times while looking at their notes versus being able to explain a problem to someone else without looking at their notes. Students are advised to be able to "teach" a problem or concept to another student without using their notes at all. This very simple solution is usually not utilized by students prior to these study skills workshops.

<u>Using Concept Maps to Create a Hierarchical Construction of Knowledge</u>

Even if students have learned all the terms and can fully explain each concept they may not yet understand the connections between concepts. Often the organization of their knowledge is in a linear fashion of facts and terms and concepts. This linear organization does not enhance the development of critical thinking nor their understanding of the critical relationships between concepts.

Concept maps are an excellent way to have students create a hierarchical construction of knowledge that reinforces their understandings and allows them to see connections between concepts. This allows them to practice their critical thinking skills. A concept map is a flow diagram that links important concepts with the key terms that explain the relationship between these concepts or terms (Allen and Tanner 2003).

The steps to creating a concept map are:

1) **List** all the key words/ terms, concepts or phrases from that topic. Rank these from the most broad and inclusive to the most specific and least inclusive;
2) Cluster the key words/ concepts that interrelate closely;
3) Arrange the keywords/ concepts in a diagrammatic representation from the most specific key words to the broadest concepts;
4) **Link** each key word with a preposition or verb to indicate their relationship.

The concept map technique can be time consuming and may not appeal to students with aural learning strategies. So it may be best used as an assignment for students to use for particularly challenging chapters or topics. For example, the immunology chapter in most introductory biology is often perceived by students as a bewildering array of T-cells, B-cells, etc. However, for the past three years I have assigned a required concept map assignment of the immune system for all of my introductory biology students. The students have overwhelmingly approved of this assignment and the number of student questions involving this chapter has decreased.

<u>Preparing for the Exam</u>

Time management is a critical component for success in exams. In high school, many students only studied the evening before an exam and still were successful on these exams. However, given that the quantity, depth of knowledge and pace is often much higher in college than in high school, this technique does not usually work for most college students. Students need to be able to identify which topics will require more studying time than others and make a realistic plan for studying at least one week before the exam. To help students with time management I present them with a week long hourly time chart that is posted on their course website that allows students to clearly identify actual times available for studying for this exam.

The week prior to each exam students are first asked to post in the time chart all of their other course activities as well as work responsibilities, clubs, sports, committees, etc. They are also asked to post all social obligations (e.g. dinner with friends or family, etc). In addition, they are asked to post in any other school work time commitments (e.g. writing papers, homework or assignments, etc.). Then, they are asked to rank the topics that will be covered on the exam from more challenging to less challenging. Students are asked to put each topic into an available study time during that week and to chart more time for more challenging topics than less challenging topics. This also allows students to break up the studying into management chunks of time and having a concrete schedule allows them to understand how much time it will take to study each topic for the next exam.

Results

In the Fall 2006 I presented this study skills model in four identical workshops shortly after the first exam. The workshops were held in the late afternoon or early evening for students in a majors level introductory biology course shortly after their first lecture exam and lasted approximately one hour. Out of a total lecture enrollment of 343 students, 68 (almost 20% of the class) students attended the workshops. The students in the workshops represented 10 different majors with Biology, Biochemistry, and Exercise Science Physical Therapy compromising the majority of these majors (n= 42) (Table 1).

Table 1. The majors of the students attending the study skills workshop (n = 68 students)

Major	Number of Students Attending Workshop
Biochemistry	6
Biology	21
Biomedical Engineering	2
Business Administration	1
Chemistry	4
Deciding	9
Exercise Science Physical Therapy	15
Nutrition and Dietetics	3
Nuclear Medicine Technology	1
Occupational Sciences	2
Psychology	4

The majority of the students who attended a workshop received a B or better on their first exam (46 of 68). Students who scored a B or higher on Exam 1 had the highest participation rates while students who scored a C+ or lower had the very lowest participation rates (22 of 68). To examine the effectiveness of attending a study skills workshop I evaluated the performance of students on the second lecture exam for two groups of students: those that did attend a study skills workshop and those that did not attend a study skills workshop.

The mean of Exam 1 was higher than the mean of Exam 2, (mean exam 1= 83.3% +/- S.E. .61; mean exam 2 = 68.7% +/- S.E. = .008) therefore the difference between the two exams was examined (e.g. Exam 1% - 2%). Students who did not attend a study skills workshop had a larger decrease (mean decrease = 15.5% +/- S.E. .7) than students who did attend a study skills workshop (mean decrease = 10.6% +/- S.E. 1.2) from Exam 1 to Exam 2 (t-test, $p<.0008$). This represents a five percent difference in the performance between these two groups, equal to half of a letter grade.

Discussion

Students attending a study skills workshop performed significantly better on the second lecture exam than students who did not attend a study skills workshop indicating that these workshops can enhance student academic performance. Most of the students who attended the workshops were already high achieving students and yet their performance increased after attending a study skills workshop. Study skills strategies, such as the ones described here, are rarely taught within a course setting and are also even rarely taught in freshman seminar classes. These results indicate that the addition of study skills strategies may be an important component to student achievement.

There are numerous papers (e.g. Chaplin 2007; Solon 2007, Miri et al. 2007) presenting strategies for helping students develop critical thinking skills but few that present strategies to help students self identify and self diagnose problems with their basic learning strategy. These papers often emphasize the importance of critical thinking skills. However, in order for a student to utilize critical thinking skills they have to have knowledge of the facts, terms and processes involved with that concept (e.g. successful studying strategies). Students who are performing poorly in science courses almost always do not have the basic knowledge of a concept although they will repeatedly report that they felt that they did "know" the material.

Metacognition (Bransford et al 2000) is the ability to self-monitor your current level of knowledge and understanding and diagnose when it is or is not adequate. There are several studies that indicate that students are often poor gauges of their level of skill development (e.g. metacognition). Studies examining the relationship between self assessment and assessor assessment (graduate students or faculty) of students skills found that students self assessment ratings were much higher than that of the assessors ratings (Kirby and Downs 2007; McEnery and Blanchard 1999). Chaplin (2007) found that students with actual test scores of 60% or less in an introductory biology class tended to overestimate their exam performance by an average of 22%. This demonstrates that low achievers in particular are truly poor at self-identifying any studying problems. Students who come to me for class performance advice often self report that they felt like they had "done well" on an exam only to be startled by their actual exam score. They also report that they "felt well prepared" for an exam based on their studying. These students may well have spent considerable time studying but may have been using ineffective studying strategies. Nonis and Hudson (2006) found that there was no correlation between amount of time business students spent studying and academic performance which again may indicate the importance of using appropriate studying strategies for effective studying.

At the end of the semester student assessment surveys examined students perceptions of the study skill strategies. Students were asked what aspects of their studying they modified after attending a study skills workshop (Table 2). Students could choose more than one answer. Overwhelmingly students responded that they changed their lecture preparation and note taking in lecture the most (56.2%). The next highest response was changes in making and using flash cards as a study aid and using an exam studying schedule (32.5%). However, few students reported using concept maps or creating their own quizzes (11.2%). Both of the later exercises are the most time demanding and skill demanding and students lack of utilizing these may be due to constraints on either of these (e.g. time or skill). Given the importance of these strategies for developing critical thinking skills future research should examine this result.

Table 2. Results of assessment survey regarding utilization of the strategies presented in the study skills workshop. Students were asked to reply to the following question: After attending an Advanced Study Techniques Workshop what specific aspect(s) of your studying did you modify or add to your studying. You can choose more than one answer.

Preparing for lecture (e.g. looking for key words or concepts in the textbook or in PowerPoint)	31.9%
Taking more detailed notes during lecture	24.3%
Making and using flash cards	13.9%
Making and using an exam studying schedule	18.6%
Making and using concept maps	6.6%
Creating Quizzes	4.6%

An important finding of this study indicates that the students who need the help the most are the least likely to seek it out. Low achieving students were the least likely to attend a study skills workshop. It is unclear whether this is due to their inability to self assess their need for assistance or their reluctance to seek assistance as they may consider this a remedial or punitive experience. However, given that the higher achieving students were more likely to attend a workshop this may indicate that these low achieving students do not perceive a need for this assistance. Weinert and Luew (1987) found that skilled learners appear to adapt more easily to new learning situations than unskilled learners which further indicates the necessity of providing study skills workshops for incoming students to help them develop these important academic skills.

There are numerous possibilities to explain why students have poor metacognition abilities (Somers and Burnbaum 1991; Meyer 1980). However, Rohwer (1984) acknowledged that academic studying research was one of the most neglected topics. Clearly, poor self assessment is a widespread phenomenon in students and future research on strategies for helping students increase their metacognition skills is greatly needed.

Acknowledgements

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Evolving the Concept of Homology

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Abstract: Understanding homology is fundamental to learning about evolution. The present study shows an exercise that can be varied in complexity, for which students compile research illustrating the fate of homologous fish skull elements, and assemble a mural to serve as a learning aid. The skull of the most primitive living Actinopterygian (bony fish), the bowfin, *Amia calva,* is the starting point for tracing the evolutionary fate of homologous bones in other living and extinct vertebrates. By tracing bone fates through time and across lineages, students learn both their names and association patterns. Emphasizing bone group associations, structures and functions replaces memorization of names, while facilitating understanding of evolutionary processes that shaped complexes and the vertebrates in which they occur. Working in groups, students learn cranial ossification patterns from fish to amphibians, reptiles, mammals and birds that might otherwise seem unpredictable or unrelated to natural selection. Goals of this project include clarifying evolutionary processes, relating complex structures to functions, and assisting students in gaining a deeper understanding of features that define vertebrate anatomical relationships.

Keywords: Homology, evolution, vertebrates, fossils, comparative anatomy

Introduction

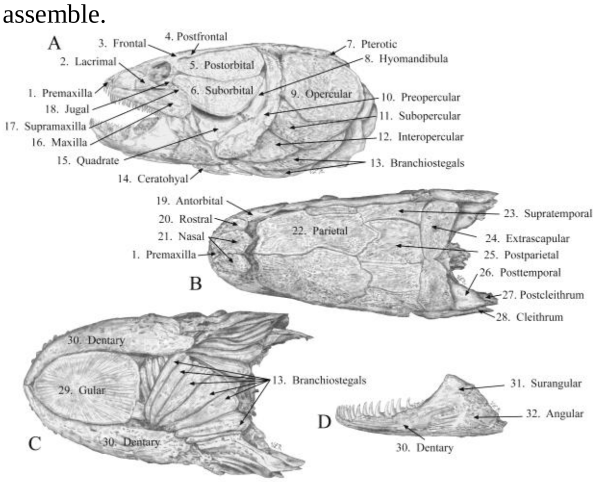
One of the most fundamental concepts underlying student understanding of the theory of evolution is homology, a term coined by Sir Richard Owen in 1848, which discusses the structure of the skeleton in vertebrates (Owen, 1848). Homology may be defined simply as organs or body parts that arose from a common origin, but may have diverged in appearance, function or both over time. Yet students often have difficulty in grasping the implications of this idea. An excellent means of illustrating complex concepts is to show examples that reveal their meaning. Such examples are even more instructive when students identify them using their own resources, by developing their own ideas while doing research on topics they have chosen.

In teaching organismal components of courses ranging from introductory biology and zoology and those for which the main focus is exposition of evolutionary processes, such as comparative vertebrate anatomy, evolution, vertebrate paleontology and natural history, it is essential to convey the role the theory of evolution plays in allowing scientists to predict and interpret the relationships between living and extinct taxa. Evolution serves as a way of explaining relationships of living organisms as they change through time (succinctly defined as descent with modification). It is essential for those engaged in teaching science, especially evolution, to ensure that students learn both the precise language of evolutionary theory, and how to interpret correctly the complexities inherent in the understanding of concepts such as homology, natural selection and phylogeny. Moreover, a true understanding of these important biological concepts requires a person to be able to apply them to examples from the fossil record and living organisms. This is one definition of critical thinking, a skill all students must master to enable them to evaluate the quality of information from all sources, and a main goal of education across all subjects and at all levels.

Therefore, this study proposes an innovative method of teaching homology, a fundamental concept inherent to an understanding of evolution. The exercises described here allow students to interact among their own groups to discover how patterns change through time, using a study of the skull bones of fishes. Many courses in organismal biology require students to learn about the skeletons of animals. This is often one of the first exercises that require students to learn a large amount of detailed anatomical information. This endeavor is often intimidating, and one of the reasons many students avoid progressing further into the study of science. If learning anatomical details can be combined with obtaining a deeper understanding of important concepts, students can gain a clearer perspective of evolution. The project described herein is designed to be flexible in the level of detail it requires as well as the number of participants that can be involved. It is aimed toward advanced placement biology classes in high schools, community college students or those taking a sophomore or junior level university course. The plan can be simplified for use at lower grade levels, or more complexity of research and presentation of information could be added to increase the level of effort required for more advanced class work.

The purpose of this project is to choose one of the 28 numbered ossification centers identified on the skull of *Amia calva* (Figure 1), and to trace its evolutionary fate from Actinopterygian fishes to other vertebrate groups. This fish has been chosen as the organism central to this project because the skulls of bony fishes have more bones represented as individual elements than do the skulls of other organisms. *A. calva* is the most primitive of the living forms, with the earliest fossils of related species found as early as the Devonian, over 400 million years ago, and therefore, shows one of the most primitive skull bone patterns that demonstrate skull element relationships.

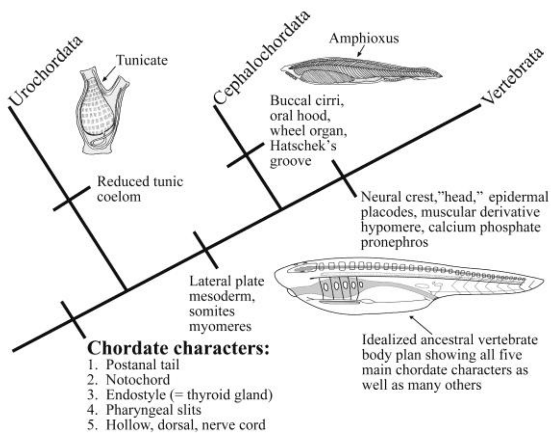
Figure 1. The skull and mandible of *Amia calva* are shown in lateral view (A) and ventral view (C). The skull only is shown in dorsal view (B). The mandible alone is shown in D. All bones are labeled and numbered in each view. This figure serves as the template around which students will assemble the collective table of bone homologies. Bone numbers correspond to spaces on the table students will assemble.



Background

Vertebrates differ from other living organisms, particularly in their degree of cephalization (i. e., evolution of a head), or the specializations of the anterior part of their bodies to concentrate and protect the organs of special sense, including the visual, olfactory and auditory systems. One early specialization prior to the evolution of vertebrates is the expansion of the anterior end of the hollow, dorsal nerve cord into a brain. The anterior aspect of the bodies of early protovertebrates also acquired specializations for feeding, such as ingesting and processing foods (Figure 2). Most of the early animals belonging to this lineage went extinct without leaving fossils for study; therefore, the characters that illustrate the evolutionary pathway leading to chordate and vertebrate origins have been reconstructed using comparisons to living organisms that show some of these traits. As living species are not necessarily adapted to the same ecological niches as ancestral protovertebrates, they may show only some of the chordate or early vertebrate characters, or in only a part of their life stages. For example, the Urochordata are represented by a group of organisms called tunicates, animals that exemplify some of the characters that were present in the lineage that evolved into the chordates and vertebrates. Because these characters are present in only the larval forms, these animals are not merely earlier versions of chordates or vertebrates. Another group, the Cephalochordata, show a greater number of characters of the Vertebrata, and are exemplified by *Amphioxus*, the lancet, a small, aquatic filter-feeding organism that shows the five main chordate characters as well as others that occur in vertebrates. However, *Amphioxus* also shows unique derived characters not present in vertebrates, indicating they are closely related, but not directly ancestral to this group. No fossil has yet been found that shows all of the characters that must have been present in early vertebrates, and none that preclude it from being the ancestor; therefore the "idealized" ancestral vertebrate body form is shown in the lower right side of Figure 2.

Figure 2. Cladogram of protovertebrates, chordates and early vertebrates that depict examples of a species of each group, or an idealized hypothetical ancestral body form. The cladogram nodes show where the diagnostic vertebrate characters appear for the first time.



The skull and mandible of *Amia calva* are shown in lateral view (A) and ventral view (C). The skull only is shown in dorsal view (B). The mandible alone is shown in D. All bones are labeled and numbered in each view. This figure serves as the template around which students will assemble the collective table of bone homologies. Bone numbers correspond to spaces on the table students will assemble.

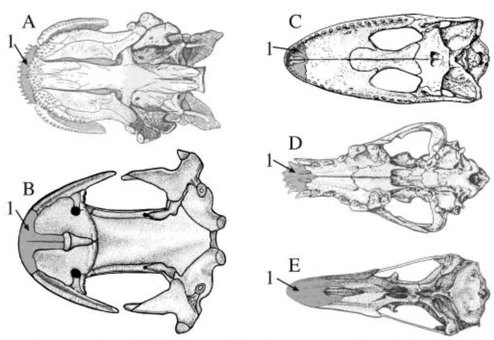
Only under unusual circumstances does the fossil record preserve impressions of soft tissue of long dead animals; more commonly skeletal and dental elements, i. e., the "hard parts" are the only evidence that an individual animal existed. Therefore, skeletal structures are foremost among those that must be studied by students of vertebrate biology. As early as the Cambrian, nearly 600 million years ago, organisms had skeletons to support and protect delicate internal structures, but also to serve as levers for muscles to pull against in performing locomotor and other life functions. Some animals had cartilaginous skeletons; ossified cartilage skeletal elements may be preserved, but most of the bones that make up bodies of fossils are bone, i. e., calcium carbonate ($CaCO_4$). Bony skeletal elements arise from two sources, dermal bones from layers of the skin, and endochondral bones from mesoderm that also gives rise to the skeletal or voluntary muscles. Both of these types of bony elements occur in the skull, although they often cannot be distinguished based on appearance of the adult bone. Nevertheless, the developmental history of these bones can provide clues as to their location and function in the skull. Bones arise at ossification centers, and the number of these determine how many bones form the skull of a vertebrate. Through time, and as cranial structures and functions evolve, ossification centers may change, which results in the loss or fusion of bones.

Procedure

1. For each bone, the student must identify:

A. The main function of the bone itself and those of any group to which it belongs, in *A. calva* as well as its function in representatives of all other vertebrate groups in which it occurs. Those functions must be demonstrated by making a chart or using bullet points for each taxon discussed. An example of the fate of one bone, the premaxilla, is illustrated in Figure 3.

Figure 3. An abbreviated discussion of the evolutionary fate of the premaxilla in (A) the fish *A. calva*, (B) an anuran, *Ambystoma maculatum*, (C) a reptile, *Alligator mississippiensis*, (D) a mammal, *Canis dirus* and (E) a bird, *Anas platyrhynchos*, is shown as an example of the kinds of information students can find and present in their posters. At the bottom is an explanation of the differing forms and functions of this bone in these animals.



The bone labeled 1 in A - E is the premaxilla. Although this bone does not change as drastically in shape and function as do some other bones of the skull, it bears teeth in A (*Amia calva*), C (*Alligator mississippiensis*) and D (*Canis dirus*) but not in B (*Ambystoma maculatum*) and E (*Anas platyrhynchos*).

B. All of the bones that abut the chosen bone, including those that may lie superficial or deep to it. A list of these bones, properly identified and labeled, or an image of the chosen bone and those surrounding it, must be included.

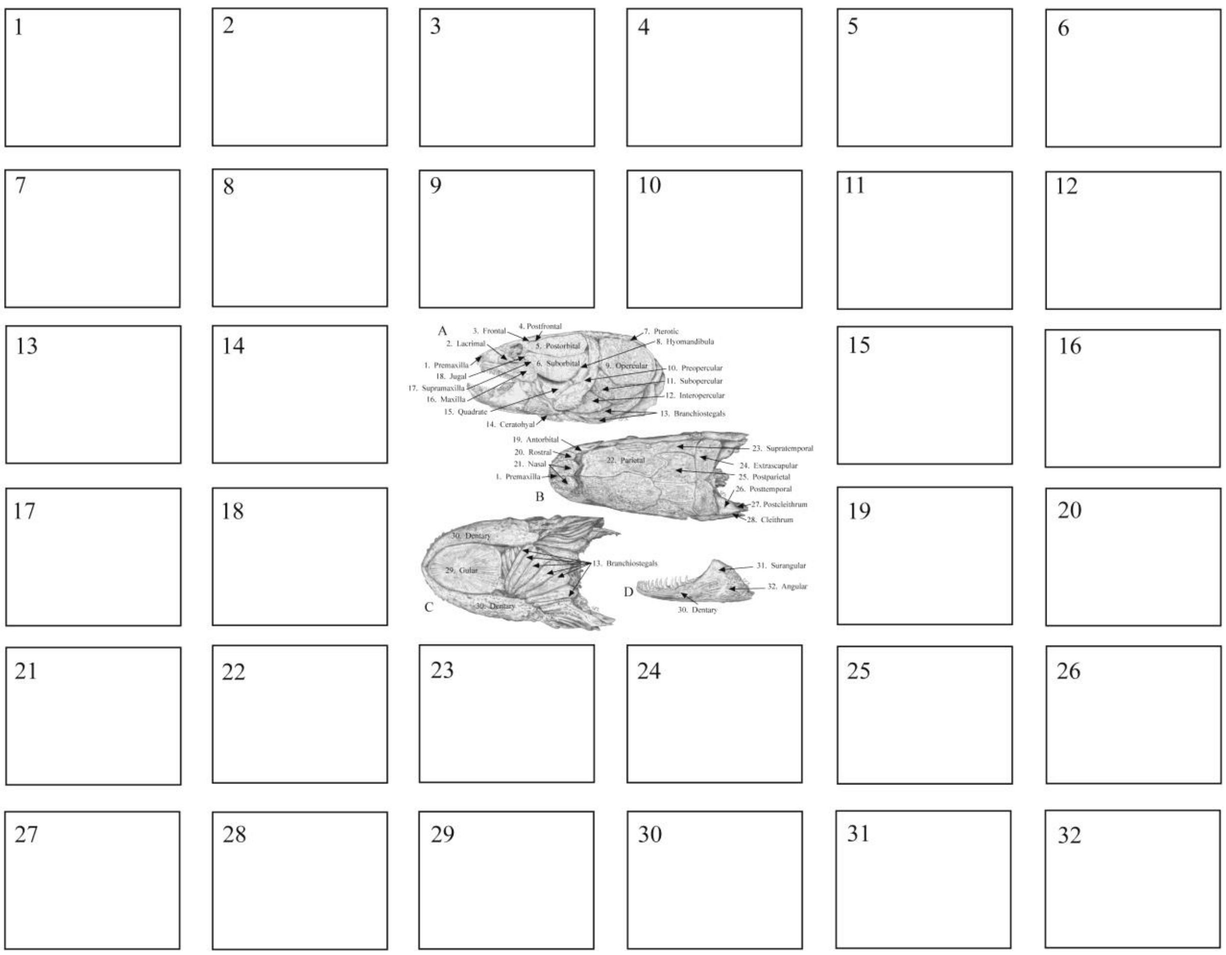
C. The function of the group to which the bone belongs, as well as the other bones that serve the same function within the group. It is important to note here, if the group, or one of the bones that belongs to it, changes function, and if so how that change occurs. In some cases, although a bone may be part of a complex, and to share in that group function, it may take on a unique function in other groups. All of these differences must be documented individually with labeled images and descriptions.

2. Note any bones that have been lost, or have coalesced with those of other ossification centers, and the groups in which this has occurred.

3. Prepare an 11" x 17" poster documenting the chosen bone(s). Specifically, the bone must be depicted in *A. calva* and its function in this organism explained, including the information from items 1-4. In the chart,

images of the other taxa in which the bone has been traced, accompanied by an explanation of the function(s) of each must be included. At the bottom of the poster, must be placed a chart summarizing the bone, any group(s) to which it belongs and the functions it assumes in vertebrate groups represented by *A. calvo* (bony fish), amphibian, reptile, mammal and bird (Figure 4).

Figure 4. A sample template for assembling the table of bone homologies among different vertebrate taxa with numbered spaces that correspond to the bones named in the central illustration of *Amia calva*. The sample entry, for the premaxilla (number 1) to be placed in the upper left was presented in Figure 3.



4. In class each student or group that worked together to determine the fate of a bone will present their results orally, explaining their findings concerning the fate of the bone or bones they have chosen. After each presentation the individual posters will be assembled into a large table with numbered spaces for each bone, which correspond to those on the central image of *A. calva* (Figure 4). The assembled table will serve as a review of skull bones in many vertebrates, as well as a means to illustrate the concept of homology, as a means of promoting student comprehension of the fundamental concepts that explain the theory of evolution.

Modifications of the project for middle school and introductory high school classes.

The project, as described, is aimed toward college level or university students in classes such as comparative vertebrate anatomy, vertebrate paleontology or evolution. To streamline the project for earlier level classes studying the concept of homology, students can be asked to limit the number of taxonomic groups they study in determining the fate of each bone, or the fates of only the more prominent bones in later groups can be traced. Descriptions of the function(s) of bones can be limited in length, and students can give short oral reports or omit this step entirely. To assist introductory students in preparing their posters, teachers can provide images or reference materials to limit the amount of research class members must undertake individually.

Modifications of the project for advanced high school, college or university classes.

Students could be asked to investigate the evolutionary fate of more than one bone or group of bones in the skull of *A. calvo* and other vertebrate groups. Students could also be required to write a paper that describes the changes in the evolutionary fate of the bone or bones among vertebrate taxa, to delve into the history of the development of information about each bone, and to provide the rest of the class with a detailed presentation on their findings. These students could also be asked to discuss the developmental origins of the bones, and structures that may be derived from them, such as the teeth that are rooted in many bones of the skull and mandible.

Conclusions

Regardless of mode, people learn best when they discover information for themselves, and therefore have invested more effort in its acquisition and can thus "claim" the knowledge as their own. This project will allow students to do that, as well as to understand the concept of homology, and to relate it to evolutionary interpretations of cranial bone structures and functions in different vertebrate taxa. This project allows students to work both singly and in groups, and to conduct individual and group research to create a chart collectively, that will serve as a learning tool for their class and subsequent classes. Instead of forcing students to memorize bone names, this project will allow them to make the association between bone structure, position and function within the skull and how each of those bones transforms in shape and function through time in different taxa as a means of meeting the selective pressures on different vertebrate groups.

Suggested Readings

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Acknowledgments

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An Experience Teaching an Undergraduate Level Course in Biophysics

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Abstract: The importance of including concepts, examples, and techniques from mathematics and the physical and information sciences in biology courses to fulfill the need of today's undergraduates has been the principle motivation for developing interdisciplinary biology-focused courses. Although this movement started many years ago, developing and offering courses like biophysics is still new in many liberal arts colleges. Taking advantage of the experiences gained by introducing an interdisciplinary course, simply titled Biophysics, this paper was developed to present the adapted structure, challenges, and useful factors to further develop such a course in order to heighten students' retention of the material.

Introduction

Traditional undergraduate science courses provide backgrounds in mathematics, biology, chemistry, physics, or computer science, often without demonstrating how these fields overlap. In contrast, interdisciplinary courses select and develop materials that promote student understanding of how different sciences and technologies integrate with one another. The importance of including concepts, examples, and techniques from mathematics and the physical and information sciences in biology courses in order to serve today's undergraduate biology students has received much attention recently (National Research Council, 2003; Goldestein, Nelson, 2005; Varmus, 1999; Mielczarek, 2006). At present, developing interdisciplinary courses is strongly encouraged and a variety of teaching methods exist (KANE, 2002; Biophysical Society, 2009; Physics Department, Haverford College, 2009; Biology Department, Beloit College, 2009; Physics Department, Simon Fraser University, 2009).

A biophysics course (PHY303) was developed at Canisius College with the support of a grant received from the Howard Hughes Medical Institute (HHMI) to establish an undergraduate interdisciplinary program. This course was developed by the physics department and approved by the departments of physics, biology and chemistry and taught in the fall of 2006. Two faculty members, one from the physics department and one from the biology department were scheduled to team-teach this course. However, the first round was taught by the author alone due to the sabbatical leave of the biology faculty member at the time that the course was offered. This paper describes the experience gained while teaching this interdisciplinary course in biophysics at a small liberal arts college.

Course Description

Textbook and Lectures Structure

There is a variety of different books and web resources available covering a broad range of topics for this class (Boal, 2002; Berg, 1993; Kane, 2003; Howard, 2001; Nelson, 2003; Tuszynski, & Kurznski, 2003). Since the course was designed to include a detailed quantitative and qualitative description of structures, functions and biochemical interactions to express the cellular mechanics, the three main books used were Jonathan Howard's *Mechanics of Motor Proteins and the Cytoskeleton* (Howard, 2001), Philip Nelson's *Biological Physics: Energy, Information, Life* (Nelson, 2003), and Jack Tuszynski's *Introduction to Biophysics* (Tuszynski, & Kurznski, 2003). These books include all the topics covered in this course; however, the level of mathematical usage was significantly adjusted to meet the students' background.

In order to address different teaching methods and provide more dynamic illustrations, lectures were presented via a combination of PowerPoint™ and chalkboard. Movies, animations and web links related to the topics introduced in the presentations were compiled to present the concepts of biophysics more effectively. The final evaluation of the students' performance was based on their grades in two written in-class examinations and their presentation of the assigned research project. The class met in a lecture format for fifty minutes, three times per week.

Lecture Outline

The main goal of this course was to study cellular biophysics with an emphasis on the investigation of the physical concepts behind the process of mitosis and the roles of biofilaments and other proteins in connection with it. To understand such a complex system, the topics covered included:

- Biofilament Structure: The nature, structure and functions of cytoskeleton filaments like microtubules and actins. To better understand the physics behind cell-mitosis, the nucleation of microtubules in microtubule organization centers was explained to express the ways in which they formed aster microtubules. This process presents a key component in mitosis (Boal, 2002; Kane, 2003; Howard, 2001).
- Biofilament Statics: filament deformation, bending energy, stiffness, and persistence length as well as single molecule manipulation techniques (Boal, 2002).

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- Biofilament Dynamics: polymerization and depolymerization of biological filaments, dynamic instability, and the steady state of biofilament assembly based on current experimental results and theoretical models (Physics Department, Simon Fraser University, 2009; Howard, 2001; Nelson, 2003; Tuszynski, & Kurznski, 2003; Walker et al., 1998; Dogtrom,. 1993).
- Biofilament Dynamics and Biological Significant: The effectiveness of dynamic instability by calculating the time required for a collection of microtubules growing from a centrosome to find a target (Holy, & Leibler. 1994).
- Force Generation: the physics involved in pushing or pulling chromosomes caused by polymerization and depolymerization of microtubules as well as Brownian motion (Howard, 2001; John Hopkins, The Cell Mechanics and Motility Lab, 2009).
- Motor Protein Motility: an introduction to different types of motor proteins including kinesin, myosin and dynein, and the structures and functions of motor proteins associated with their motilities (Boal, 2002; Howard, 2001; Nelson, 2003).
- Based on the concepts developed during the course, the various stages of mitosis were studied (Brust-Mascher, 2004).
- For the remainder of the course lectures, the biophysics of organs and their various roles in human biological systems were studied. The cardiovascular, respiratory, kidney and excretory systems were also discussed (Tuszynski, & Kurznski, 2003).

Along with the in-class lectures,, students were expected to research a specific topic relevant to the course in groups of two. A presentation was prepared and delivered during class using Microsoft PowerPoint™. Topics included the physics of laser tweezers (Ashkin, Dziedzic, 1987; Biophysical Society; Smith. et al., 1999; Sterba, Sheetz. 1998), the paradox of persistence length in microtubules (Pampaloni et al. 2006), the motility of taxol in microtubule bundles (Ross, Fygenson. 2003), the interaction of the motor proteins with microtubules as a ratchet mechanism (Brokaw. 2001), the stability of chromosomes (Campas, Sens. 2006), the immunotherapeutic effect on cancerous tumors (De Pillis, Gu, Radunskaya. 2006), and biological self-regulation and self- organization (Tuszynski, & Kurznski, 2003). In addition to the in-class PowerPoint presentations, all of the research topics were presented to the faculty members of the School of Science in the form of a poster presentation. This event, named "The Biophysics Research Day", was an excellent opportunity for students to experience the scientific presentation of their work. It also allowed them to receive feedback and grades from the faculty members and comprised ten percent of their final grades

Discussion

There is an extensive network of educators and professional societies working in the area of biophysics and curriculum reform (Mielczarek, 2006; Biophysical Society, 2009). However, teaching an interdisciplinary course,, such as biophysics, is exciting because of the novelty of such courses in undergraduate curricula. Having been the sole instructor in one of these courses, there are a number of thoughts and suggestions for future offerings.

One challenge in implementing an interdisciplinary science course at the undergraduate level is developing opportunities for students to apply new technology capable of solving interdisciplinary scientific questions. For example, many of the concepts presented in lectures of PHY303 referred to the use of laser tweezers to measure and analyze the static and dynamic properties of biofilaments and motor proteins.

For one group of students, the physics underlying the design of laser tweezers was grasped readily, while the application of the technology to cell biology questions was challenging. The opposite was true for another group of students, who struggled with the underlying physics of laser tweezers design. Thus, it appears that an important step in advancing their understanding and clarifying the concepts of biophysics would be to implement a biophysics laboratory in conjunction with the lecture.

The lab would allow students to be engaged in the hands-on application of experimental biophysics instead of being limited to just the abstract nature of theoretical biophysics. This new laboratory also reinforces the fact that theory and experiment are related to one another in the pursuit of a scientific explanation. Students are, therefore, provided with the opportunities to design experiments, find ways to test it, collecting and analyzing data and peer review each other's works.

Building an interdisciplinary laboratory as a complementary component of the lecture requires sufficient funding for basic essential equipment. However, developing a biophysics laboratory to support biology-focused interdisciplinary courses has, in fact, already been started in research institutions as well as liberal arts colleges (Biological Physics Laboratory, The University of Arizona, 2009; Department of Physics, Pomona College, 2009; Department of Physics, Brown University, 2009; Physics Department, Haverford, College, 2009).

Cross-institutional collaboration with research oriented institutions that have well-established interdisciplinary programs and well-equipped laboratories can also provide students with opportunities to be involved in a biophysics laboratory; especially if the research institution is in close proximity. Likewise, this allows for the exchange of ideas and perspectives during the resulting interactions. In our situation, following discussions with the Administration of the Center for Single Molecule Manipulation of University at Buffalo, there is hope that such a collaborative opportunity can be made a reality for our students when this course is next offered.

Canisius College students have expressed a great interest in interdisciplinary courses such as biophysics. However, they experienced a different structure in this biophysics course as compared with the structure of traditional courses which usually include practice of the material in terms of the regular use of homework and/or quizzes. In this course, however, different types of problems were assigned to students.

One group of assigned problems could be treated mathematically. For example, when the static properties of biofilaments were taught, a typical problem consisted of finding the energy required to bend a biofilament, such as a microtubule, into an arc when the persistence length (i.e., the length of the microtubule) and the radius of the arc were known. The source for these types of problems was chapter two of *Mechanics of the Cell* by David Boal (Boal, 2002). However, locating adequate problems that met the mathematical background of the students was challenging. Another problem set was mainly based on analyzing graphs and conceptual questions. Samples of such problems can be found in chapters nine and ten of *Mechanics of the Cell* (Boal, 2002).

In general, due to the limited number of problem-answer sets, students were restricted to fewer problem sets. Consequently, students experienced not a traditionally structured course with a good collection of "end of chapter" problem sets, but an interdisciplinary course with much greater emphasis on dealing with ideas and qualitative questions.

The syllabus outlined for this biophysics course may not be suitable for every institution. Depending upon the goals of the institution and the student requests, the course may emphasize differing topics. Students in this course who were pursuing medical careers, for example, expressed an interest in the study of a biophysics more closely linked to medicine and disease. This can be addressed by introducing another course, which emphasizes medical physics in particular and the design of medical equipment as a complementary component. This approach has also been taken in other undergraduate institutions (Physics Department, Haverford College, 2009).

Assesment

The main goal of offering this course was to expand the structure of interdisciplinary activities across the college. The "sub" goal of this course was to investigate biological systems that can be explained and clarified by employing concepts of physics and mathematics. This knowledge and experience will enable our students to be more competitive as they pursue advanced goals.

To facilitate the students' access to the material, all the lecture notes, prepared in PowerPoint™, were systematically posted on the internet via the Blackboard™ learning system. As evident from the Blackboard™ web server statistics, 652 hits from students showed this method to be a successful and effective in distributing the course material.

A survey prepared by the Canisius College HHMI Interdisciplinary Survey Committee was distributed at the end of the semester. The results are expressed below. In this survey the students rated each of the following questions on a scale of 1-5. For each question rating 1 or 2 were combined, 4 or 5 were combined, and 3 represented neutral. Also, the percentages in the tables are rounded off to one significant figure which is more appropriate for the number of responses.

1. Did the interdisciplinary nature of the course (i.e., combining Biology and Physics in one course) help your learning of the course material? Table 1

	Helped Very Little	Neutral	Helped Very Much
Frequency (n=14)	0	3	11
Percent of Students	0%	21%	79%

2. Do you agree or disagree with the following statement: "The nature of this course comes very close to what I think of as 'interdisciplinary science'"? Table 2

	Strongly Disagree	Neutral	Strongly Agree
Frequency (n=14)	1	4	9
Percent of Students	7%	29%	64%

3. Do you feel you were adequately prepared by previous Biology courses for the combination of Biology and Physics that you encountered in this course? Table 3

	Felt Poorly Prepared	Neutral	Felt Well Prepared
Frequency (n=14)	1	2	11
Percent of Students	7%	14%	79%

4. Do you feel you were adequately prepared by previous Physics courses for the combination of Biology and Physics that you encountered in this course? Table 4

	Felt Poorly Prepared	Neutral	Felt Well Prepared
Frequency (n=14)	0	5	9
Percent of Students	0%	36%	64%

5- Choosing and exploring a research topic enhanced my research skills in this field Table 5

	Strongly Disagree	Neutral	Strongly Agree
Frequency (n=14)	3	1	10
Percent of Students	21.4%	7.2%	71.4%

One of the main goals for interdisciplinary programs is rooted in research. Today, those who graduate with a background in interdisciplinary activities and were engaged in doing research in an interdisciplinary program can be productive in a shorter time if they choose to further their education in an interdisciplinary field. Applicability of assigning research projects at an undergraduate level as well as the positive response of students to this approach expressed above illustrates that this approach to offering the course was positive.

In conclusion, the different structures of the biophysics course offered to undergraduate students in liberal arts colleges and different approaches of assessing them complicates the comparison of the success of this particular course with similar courses offered at other schools. For the future growth of interdisciplinary programs in science, a consistent standard and a reliable assessment needs to be established. Therefore, offering such courses while continuously improving their quality should be a positive academic approach.

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Teaching the Broad, Interdisciplinary Impact of Evolution

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Abstract: As perhaps the most encompassing idea in biology, evolution has impacted not only science, but other academic disciplines as well. The broad, interdisciplinary impact of evolution was the theme of a course taught at Marian College, Indianapolis, Indiana in 2002, 2004, and 2006. Using a strategy that could be readily adopted at other institutions, professors from other, non-biological disciplines were asked to speak with the class regarding the impact of Darwin specifically or evolution more broadly on their field of study. A political scientist, literature expert, language professor, historian, theologian, art historian, and sociologist have all participated in this course. Student comments have been overwhelmingly positive and suggest the course format affected their thinking with respect to both the humanities and the science of evolution.

Keywords: art, Darwin, evolution, history, interdisciplinary, language, literature, sociology, theology

Introduction

Since the 19th century, evolutionary theory has had an enormous impact not only on science, but on Western society as a whole. The "honors evolution" course described here was designed as an educational tribute to the all-encompassing influence of evolution.

Recent studies indicate that although state standards for the teaching of evolution are improving (Lerner, 2000) college students are still not well grounded in evolutionary theory (Alters and Nelson, 2002). Many writers have proposed methods for teaching evolution in college that allow students to understand the process of science (DeSilva, 2004), discuss case studies (Farber, 2003), and gain experience in the field (Zervanos and McLaughlin, 2003). These methods offer important improvements to the teaching of evolution today. However, in today's interdisciplinary academic environment, while pedagogical changes are important, it is equally important to modify and enhance course content to benefit biology majors and non-majors alike. For example, evolutionary theory in biology also has far-reaching implications in the disciplinary studies of language, art, literature, political science, history, and theology.

One-hundred and fifty years after Darwin proposed a mechanism for evolution it has permeated all but the most blind corners of biology. That evolution and Darwin's mechanism have affected the study of biology may not be surprising to university students. However, the examination of how Darwin's idea has impacted disciplines outside of biology will open students' eyes to the broad, interdisciplinary impact of this biological theory. This, in turn, may help students understand the biology behind the theory more fully.

This was the premise for a course one of the authors (D. Benson) taught with the help of many of his colleagues (the other authors) in the fall 2002, 2004, and again in 2006. The class began as a typical, although short, introduction to the science of evolution. We covered the usual topics of natural selection and other mechanisms of evolution, Hardy-Weinberg, speciation, sexual selection, evidence, and human evolution. To give students a sense of the power of Darwin's argument, they read several chapters of *The Origin of Species*, (Darwin, 1859). The point of this portion of the course was to give students a good grounding in the biology behind the theory. Without this background, the diverse discussions that followed would have been uninformed.

The second half of the course involved colleagues from non-science disciplines explaining how Darwin, the ideas of common ancestry, evolution, and natural selection have impacted their disciplines. This allowed the students a chance to see the breadth of "Darwin's dangerous idea" and the profound impact it has had across the board. It also allowed the *students* to be the experts on evolutionary theory. By this point in the course, they knew as much or more about the science of evolution as the guests from other disciplines. This empowered the students to think critically and constructively about what was being presented.

We believe the basic idea behind this course could be adapted to any situation in which a science professor is surrounded by a reasonably engaged faculty and could be used in either a stand-alone course or as a unit within a larger course such as a first-year introduction to biology. In the section that follows, we describe our course as an example of what could be presented in a course of this design. The content of your own course will, of course, be guided by the willing faculty around you and their own areas of expertise. Most of the professors who contributed to this project did not have any special background in or knowledge of the intersection of evolution and their area of expertise. What they presented was a brief view of evolution from their perspective.

Language and Evolution, Patrick Kiley, French program. Dr. Kiley discussed and gave examples of some of the forces acting on language. For example, migration affects language by adding, and perhaps removing, certain words to a vocabulary by "borrowing." For instance, "boef," "porc," and "veau" in French were borrowed by English – "beef," "pork," and "veal." Social acceptability is another mechanism of language evolution that may, in fact, relate to the previous example. In 1066, the Normans (French speaking), conquered England and imposed their language upon the vanquished foe. Therefore, although English is a Germanic language and not closely related to French, it contains a lot of borrowings from French in a case of "social acceptability by force." Misunderstandings and metaphor are other forces acting on the evolution of language.

We also discussed cognates, like "hund" in German and "hound" in English – words that share a common origin. And, false cognates like "preservative" in English and "preservatif," meaning "condom" in French. Isoglosses are regional shifts within language such as the word "skillet" and "frying pan" used to mean the same kitchen item in southern and northern Indiana, respectively.

The students were then asked how all this relates to what we know about biological evolution? Are the forces acting on language similar to the mechanisms of evolution? How is linguistic variation injected into a population? Can it be selected for or against? Is it in some way, heritable? By exposing students to evolution from a different perspective, they were empowered to think critically about how their knowledge of evolution related to the ideas presented.

Art and Evolution, Jamie Higgs, Art History Program. Dr. Higgs discussed instances where Darwin's influence on specific subject matter is evident. For example, pre-Darwinian, flower art such as in Rachel Ruysch's *Flower Still-Life* (1700) was often quite contrived, showing beautiful, vase-bound arrangements. The flowers depicted did not bloom at the same time and could never have been assembled in one vase, but were simply meant to be aesthetically pleasing forms. Darwinian thinking, however, emphasizes the importance of environment including interactions among species. It also emphasizes the importance of form; flower form evolved for reasons other than simply for humans to find aesthetically pleasing. In the post-Darwinian flower art of artists such as Martin Johnson Heade (*Orchids and Hummingbirds*, late nineteenth century) and John La Farge (*Water Lily and Linden Leaves*, 1862), flowers are depicted as part of a natural setting including such aspects as pollinators and anatomically correct flower form (Foshay, 1980).

German graphic artist, Max Klinger was likewise influenced by Darwin as seen in his 1875 pen and ink drawing entitled *Darwinian Theory*. This work depicts an ape holding a human child in one arm with its other hand on a scientist's (Darwin's?) shoulder. The scientist's hands are resting on a large tome and an ape skull flanked by a human skull. In the background, a cleric is glaring at the three of them. The cleric's look is mirrored by the look on the scientist's face (Morton, 1992). The students had a great time analyzing the underlying meaning of this piece: the ape as an intimate relation of the human child, the skulls explaining how we know of this relationship, and the cleric's and the scientist's facial expressions as displays of animosity between science and the Church.

Finally, in *Sunday Afternoon on La Grande Jatte* (1884-1886), Georges Seurat depicts a scene on a famous island where the ladies and gentlemen are dressed in their Sunday finest and are behaving decorously. What the modern viewer does not realize, is that during the nineteenth century this island was famous for its wild and unruly Sunday afternoon crowd. Some interpretations of this work theorize that Seurat placed the small monkey in the foreground of this painting as an appeal for humans to act civilized, not like the apes from which they evolved (Stokstad, 1995).

Evolution and Literature, Jamey Norton, English program. For Dr. Norton's section of the course, the students read *War of the Worlds*, by H.G. Wells (1898). Wells, as a science prodigy and student of Thomas Huxley, is often considered the "grandfather" of the science fiction genre. In War of the Worlds and other novels, Wells used the paradigm of Darwinian evolution to push the reader to question what might be the result if evolutionary theory is pushed to the limits of our imagination.

War of the Worlds is Wells' well known story of the invasion of earth by Martians and is rife with allusions to evolutionary theory. For example, a common misconception at the time (and still!) is that humans are the "pinnacle of evolution." Wells plays with this idea in War of the Worlds by introducing the Martians, an obviously more advanced civilization. The narrator apparently does not grasp even the possibility that Martians could be more advanced and is dumbfounded by them until it is too late. Wells also uses the Martians to explore how evolution might have acted within an environment different from Earth. The Martians are very unhuman-like sacks of protoplasm that seemed to have evolved in tandem with the machinery in which they are confined. Cultural evolution has apparently proceeded along a different course on Mars, too, as seen by the fact that the wheel was never developed, something thought to be foundational to our advancement as a civilization.

Darwin's struggle for existence is played out on an interplanetary level in *War of the Worlds* between the Martians and humans, with humans destined to lose. By the end of the novel the humans have thrown all their military might at the Martians to no avail and their fate as food for the Martians seems secure, when, out of no where, Natural Selection comes to the rescue! The Martians succumb to an earthly disease and die; the conquest is ended.

Evolution and Political Science, Pierre Atlas, Political Science Program. Darwin had a profound effect on politics. For example, Social Darwinism grew out of attempts to apply Darwin's ideas of natural selection to human behavior. In the late 19th Century, Yale sociologist William Graham Sumner became America's most articulate advocate of social Darwinism (e.g. Sumner, 1963). He proposed that as long as everyone had equal liberty and therefore, equal opportunities, what people do with those opportunities is up to them. Sumner suggested that there will be a "struggle for existence" among people with winners and losers, and the winners are the heroes. He stated that the winners are the wealthy, the captains of industry, and they owe nothing to the unfit, the poor, because the wealthy used their own initiative and skills to acquire their wealth and become winners. Further, Sumner thought that, because the poor or "unfit" are a dead weight to society, any kind of altruism is a despicable act, blocking the advancement of society.

Sumner also felt that the marketplace is the arena where natural selection and survival of the fittest take place and where inequality (like variation in a population) is good, necessary, and natural for the advancement of society. Therefore, he thought there should be no government intervention or regulation of the marketplace at all, to allow the best competitors to survive and prosper.

But, what of the poor? Obviously, they will not do well in the struggle, but according to Social Darwinists, that is their own fault. They felt that the poor are responsible for their own status and fate. To Sumner, it is the duty of government to protect the opportunity of all to succeed, but there are no guarantees. He felt the equal liberty provided by the government provides for choices, but does not guarantee results. Results will be proportional to the merits of each individual.

Our students were at once intrigued and repulsed, but, also could see familiar pieces of contemporary thinking in these ideas. This section led to a discussion of social justice. They also were asked to relate social Darwinism to modern evolutionary theory. Should we really be cold, heartless, pawns in an evolutionary game?

Within the discipline of political science, evolutionary theory has informed contemporary debates over the process of institutional development. One point of contention among scholars of the state concerns explaining change: do institutions change gradually over time, or do they remain relatively stable for long periods, and then change rapidly and only in response to crises? Beginning in the mid-1980s, some political scientists introduced the concept of "punctuated equilibrium" into the literature (Krasner 1984), borrowed from evolutionary biologists, Stephen Jay Gould and Niles Eldredge (Eldredge and Gould, 1972). In the class, examples from American history were offered, including the New Deal expansion of government in response to the "punctuated" crisis of the Great Depression, and the post-9/11 reorganization of government agencies into the Department of Homeland Security. Such changes were not "gradualistic." They would have been inconceivable prior to the crises that sparked them. Here, the concept of punctuated equilibrium provides a compelling metaphor for institutional development.

Evolution and modern culture, Raymond Haberski, History program. Dr. Haberski used the "Scopes Monkey Trial" as a vehicle for discussing the intersection of science and religion. As the first televised trial in America (1925), the Monkey Trial was truly the trial of the century. Clarence Darrow, a famous criminal attorney, was brought in by the ACLU to defend John Scopes who was charged with teaching evolution in public school in Tennessee. Although the discussion of this well known trial and its aftermath was not related to particular evolutionary concepts, it was enlightening to contrast this trial with current controversies regarding the teaching of evolution over

80 years later, and provided an excellent segue into the discussion of evolution and theology.

Evolution and God, Michael Maxwell, Jr., Theology program. Dr. Maxwell began his discussion with the question: "Is there an irreconcilable conflict between the scientific theory of evolution and the notion of God as creator of the world?" There are reasons on both sides to answer "yes" to that question. On the one hand, fundamentalist Christians might say that the theory of evolution simply cannot be reconciled with the biblical account of creation as stated very plainly in *Genesis*. On the other hand, some scientists have argued that the theory of evolution is a complete explanation of the biological diversity we see on earth including humans, and therefore, there is neither room nor need for God as creator.

Dr. Maxwell proceeded in an attempt to resolve these conflicts by probing the fallacies of a "literalist" approach to reading the Genesis account of creation. Is it possible to read Genesis "literally" in English when it was written in Hebrew? Maxwell suggested that attempts to read Genesis in a completely literal way ends in self contradiction: what is a day, literally when there is no sun? Or, if humans are created in the image of God, would that mean, literally, that God is a relatively ugly, naked biped?

Fortunately, for most of the Christian tradition including St. Augustine, Thomas Aquinas, and St. Justin Martyr, a literalist approach to interpreting the meaning of scripture has not been considered the exclusive way of understanding scripture. Catholics (Marian is a Catholic College) interpret *Genesis* 1 symbolically as an explanation of humans' relationship with God. The question is not necessarily, "is *Genesis* chapter one true?" but "In what sense is it true?" Maxwell proceeded to explain the Catholic stance on Evolution.

Evolution and Society, William Mirola, Sociology program. As an excellent wrap-up for the semester, Dr. Mirola led the class in a more general discussion of the effect of the creation/evolution debates on society. He posed questions such as: "Why, 150 years later, are we still having this debate?" A partial answer to this lies in the continuing cultural conflicts over the appropriate role of faith in society. How do we as a society negotiate the places where scientific theory and discovery seem to contradict or challenge our faith traditions? Of course, how these conflicts play themselves out will have direct impacts on religious, scientific, and educational institutions. We must consider, for instance, how the creation/evolution debate will affect the science literacy of students in states without strong science standards. We might also consider the impact of these debates on environmentalism. By examining these issues, Dr. Mirola left students to ponder how their own prior educational experiences with the creation/evolution debate affected their views of the class and what they themselves might want their own children to one day be taught.

Conclusion

The students, both biology majors and other liberal arts majors, were fascinated by the wide ranging application of evolutionary theory to a broad range of human endeavors. They were intrigued by the history of reaction to evolution. Class sizes have been small, but student comments voluntarily given in response to the following question are revealing: Did the structure of the course affect your thinking about the science of evolution?

Several (5 out of 19) students felt the course structure affected their thinking about the relationship between science and faith. They had comments similar to the following: "I liked how each discipline was affected by evolution. The one that had a drastic effect on me was theology and evolution. I learned that there is room for God in evolution." And, "I did enjoy theology and evolution because they appealed more to reason than evidence that is observed. It helped me to think the deepest about what evolution means for me."

Seven students commented they found that the class format helped them understand the science of evolution more thoroughly and had comments such as: "I thought this class was structured really well. Seeing evolution in the other disciplines helped me to appreciate it that much more." Three other students thought the course helped them gain insights into the humanities and had comments like, "I like the fact that class gave the opportunity to think outside the scientific world and apply that knowledge to other disciplines. I think this idea helped me to both understand evolution and the other disciplines better."

The rest of the students were, overall, very positive in their comments about the course, "Hearing from other professors from other departments made this the best class I have taken in my 3.5 years at Marian."

Even more so than the students, the contributors loved participating in this course. Several have attended lectures led by their colleagues and all have found this course design to be an excellent way to encourage students to think across the lines of discipline.

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“Extreme Programming” in a Bioinformatics Class

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Abstract: The importance of Bioinformatics tools and methodology in modern biological research underscores the need for robust and effective courses at the college level. This paper describes such a course designed on the principles of cooperative learning based on a computer software industry production model called “Extreme Programming” (EP). The classroom version of EP included: working in pairs, switching roles between labs, partner interdependence and individual accountability. New pairings were created at random each week and at the completion of each lab, students (n=18) indicated their satisfaction and frustration levels with working with partners, the materials, and the technology. We used a Repeated Measures-ANOVA (RM-ANOVA) statistical design to provide statistical power with a modest number of subjects. Students consistently rated working with a pair highest in terms of both ease and satisfaction, regardless of prior programming and technology experience. We found no differences in reported ease or satisfaction between undergraduate and graduate students, or between students with prior experience with technology. Surprisingly, we found that students rated the more difficult computer programming part of the course higher than the web-based exercises. The Extreme Programming cooperative model appears to be very appropriate for Bioinformatics classes, and can be easily implemented in computational labs to enhance student satisfaction and potentially maximize the use of computer workstations.

Keywords: bioinformatics, Python, analysis of variance (ANOVA)

Introduction

Bioinformatics has become an integral facet of modern biological research. Academics and biotechnology companies rely heavily on a vast assortment of bioinformatics tools to analyze a virtual flood of biological data, from genome sequence to x-ray crystal structures, being dumped into computer databases (Kaminski, 2000). Bioinformatics tools are used to perform DNA and protein sequence searching (Altschul et al., 1997), sequence alignment (Chenna et al., 2003), molecular structure prediction (Akmaev et al., 1999; Chivian et al., 2005), evolutionary relationship analysis (Ronquist and Huelsenbeck, 2003), gene expression (Slonim, 2002), and many other applications to generate or test hypotheses. The recent development of simple, yet powerful, programming languages (e.g., Perl and Python) has also opened the door for biologists with little formal computer science education to develop functional bioinformatics software (Gentleman et al., 2004). Biotechnology companies have invested heavily in bioinformatics research, and scientists trained in bioinformatics software tools and/or programming are often hot commodities in the biotechnology industry.

The importance of bioinformatics tools and methodology in modern biological research underscores the need for robust and effective courses in college level bioinformatics. In our experience, however, the typical biology student has limited exposure to computational biology and little or no programming background. Indeed, we often find that both undergraduate and graduate biology students express some distaste for computer work. Given the increasing emphasis placed on bioinformatics and technology in biological research, it is therefore important to provide an educational experience that maximizes learning and fosters student motivation.

In computer labs at the college level, students typically work on their own computers to learn software or write programming code. This is true of all the biology computer lab courses (e.g., bio-statistics, conservation ecology, and population genetics) at San Diego State University where the study took place. However, numerous studies of cooperative learning have clearly shown the advantages of working in pairs or groups in terms of both learning outcomes and interest levels for science and mathematics courses. Slavin (1996) described cooperative learning as ‘one of the greatest success stories in the history of educational research’ (p. 1) because so much research has tied cooperative learning to achievement gains. Slavin’s review of 99 studies on cooperative learning and achievement in K-12 school environments found that

78% of the cooperative learning groups outperformed the control groups in terms of student achievement. In their meta-analysis of studies on cooperative learning in science, mathematics, engineering and technology (SMET) courses at the college level, Springer, Stanne, and Donovan (1999) found significant positive effects on achievement, persistence and attitude in students engaged in small learning groups compared to students who were not. They estimated that the effect of small group learning on achievement would increase a student's grade on a standardized (norm referenced) test from the 50^{th} to the 70^{th} percentile and the effect of group work on increased student persistence would reduce attrition from SMET courses and programs by 22%.

Given the clear potential benefits of cooperative learning, our aim was to develop and evaluate a novel cooperative learning approach for bioinformatics at the college level. In this study, we focused on the effectiveness of cooperative learning on student motivation, per se, rather than on learning. Motivation appeared to be a particular concern with biology students not naturally inclined towards computer work, and the students scored highly on all the course exams this semester and in previous years, indicating that they had mastered basic Bioinformatics concepts. We based our cooperative learning approach on a new software development model used in the computer industry called 'Extreme Programming' (EP). The EP model, described as a 'deliberate and disciplined approach to software development' (Wells, 2001), is characterized by a set of simple rules and practices associated with all phases of development from planning to execution. What makes this model different from others is that programmers work in pairs, with several pairs working to find solutions to the same project/problem or pieces of the problem. The process stresses communication and teamwork and appears ideally suited for a hands-on bioinformatics lab course, in which students could be paired at a single computer.

EP claims several key advantages to solo programming approaches: 1) increased problem-solving capacity; 2) higher likelihood and greater rapidity of error-catching; and 3) more engaging and productive work experience. These touted advantages in workplace productivity appear remarkably similar to the educational benefits observed in cooperative group learning approaches.

Many instructors assume that when students are working in groups or with partners that the students are engaging in cooperative group work. In fact, to reap the benefits of group work, attention to the structure of the group and the type of task required is critical. According to Johnson and Johnson (1994), cooperative learning has four basic elements: 1) group members work toward a common goal, resulting in interdependence; 2) students interact to solve problems; 3) a component of individual accountability is built in to the lesson or course to assure that all students master the content being taught; and 4) interpersonal and small group skills are developed. Cohen (1994) added two more necessary elements. First, all individuals must have opportunities to hold high status academic positions, such as facilitator. And secondly, for maximum learning to occur, the task assigned to groups should be open-ended, meaning that a variety of solutions are possible, and difficult enough so that students experience a 'healthy level of uncertainty'.

The structure of the bioinformatics class run by one of the authors (Kelley) was designed to encompass almost all of the requisite elements of effective group work. Interdependence was established by having both members of each pair earn the same grade for each lab. The success of one student was determined by the success of the partnership. The students were provided considerable opportunity to talk face-to-face to solve problems. In addition to group grades, each student took quizzes and wrote papers independently, creating individual accountability. Each pair worked together on two labs a week and they shared a computer to accomplish each task. One student worked at the computer while the other observed as they problem-solved. The students were required to switch roles for each lab. In the first half of the course, students learned how to use a series of complex, but highly useful, bioinformatics tools for analyzing biological data. In the second half of the course, the students were taught the fundamentals of computer science in the Python programming language and applied this language to the analysis of sequence data. These first labs were more 'cut and paste' as opposed to the labs in the second half of the semester, which were open-ended, and by the students' own admission, more difficult.

After designing the course based on best teaching practices, we developed a survey given after every lab to answer to the following questions:

1.) What was the satisfaction of working with a partner relative to lecture and technology?
2.) How effective was the paired learning approach under increasingly high levels of uncertainty?
3.) How did past experience with technology and student grade level (undergraduate or graduate) affect the learning experience?
4.) Did a decrease in comfort level with the material or the technology decrease satisfaction of working with a partner?

Due to the limited number of student respondents, we used a statistical design known as a

Repeated Measures ANOVA (RM-ANOVA; see Materials and Methods), a methods routinely used with studies including small sample sizes, such as clinical trials. Statistical analysis of survey responses answered all of the above questions in a straightforward manner and helped us determine the effectiveness of the EP cooperative learning model for Bioinformatics.

Materials and Methods

Data Collection and Participants

Data were collected using lab evaluation surveys (Table 1) during S. Kelley's bioinformatics course in the spring of 2005 at San Diego State University. The course participants included 8 female students and 10 male students (45% female). Of these, 11 out of 18 students (>60%) had non-European ancestry, and 7 were undergrads, while the rest were Master's students. The course was taught in a "lecture/lab" format. Prior to the lab, the teacher (Kelley) would teach a lecture on the algorithms or concepts underlying the particular exercise. For example, in the non-Python section the students might be taught a DNA sequence comparison algorithm and then use the algorithm to compare two novel sequences on pen-and-paper. In the Python section, the students might be taught a basic programming concept, such as the logic behind an "if/else" statement. Following this short lecture and exercise (usually lasting about 30-45 minutes) the students would then pair up at a computer and complete an exercise written by the instructor related to the lecture material. After the lecture on sequence comparison, the students would complete a lab exercise using web-based software implementing the algorithm for comparing two sequences, and after the "if/else" lecture, the students would write a Python program that used "if/else" statement.

Table 1. Sample survey completed by students after each lab.

Name or Red ID _____________ Partner Name ___________Lab # ____ Date _____
Place an X next to your student status: Undergraduate ___ Graduate ___ student.

I. On a scale of **1 (extremely frustrating)** to **10 (not frustrating at all)** rate your frustration level with elements of the lab. Please write the rating in the space provided.

Extremely Frustrating **Not Frustrating at all**
1 2 3 4 5 6 7 8 9 10
_____ material being studied _____ working with a partner _____ technology

II. On a scale of **1 (extremely dissatisfying)** to **10 (very satisfying)** rate your satisfaction with the lab experience. Please write the rating in the space provided.

Extremely Dissatisfying **Very Satisfying**
1 2 3 4 5 6 7 8 9 10
_____ material being studied _____ working with a partner _____ technology

III. Place an **X** next to the statement that best describes your familiarity with the software
_____ I am very familiar with the software used for this lab.
_____ I am not familiar with the software, but have successfully used similar software.
_____ I am not familiar with the software.

IV. Is there anything else you would like to communicate about your lab experience?

After each lab students were asked to complete a short survey indicating their level of ease and their level of satisfaction with the study material, the computer technology, and their partner. The "material" part referred to the written exercise the students worked on with the partner at the computer, while the "computer technology" referred to the web-based software or the Python programming environment. An example of the survey is shown in Table 1. The surveys were placed in an envelope which was stored unopened until the end of the semester after all the grades for the course had been assigned. Students were assured that no one would look at the survey results until after assignment of final grades.

Statistical Methods

We used one-way ANOVAs to test for significant difference in over all mean scores among labs, between undergraduate and graduate students, and between students with previous experience or no previous experience in overall mean scores. Survey scores were also analyzed using a 3-way RM-ANOVA. RM-ANOVA methods provide a powerful means of providing statistical power with a modest number of subjects. Many published RM-ANOVA designs use modest numbers of subjects. Case studies provided by Quinn and Keogh (2002) include samples sizes comparable to the present study: n=12, 20 and 24 subjects. According to Quinn and Keough, "The main aim of these [RM] designs is to reduce the unexplained variation (MS residual) …They offer more powerful tests of the null hypothesis of interest, with no increase in the overall resources needed for the experiment (p.262)." According to Munro (2004), "Each subject [serves] as his or her own control, and the within or error variance [is] decreased. This [results] in a more powerful test and [decreases] the number of subjects needed for the study (Page 214)." The proven ability of Repeated Measure approaches to provide statistical power in studies with modest samples sizes similar to our own, gave us confidence in interpreting our statistical results.

Lab exercises were highly variable in content and were treated as the repeated measures. Data normality and homogeneity of variances were tested and confirmed using graphical methods. We used an Expectation Maximization (EM) algorithm, based on the work of Little and Rubin (1987), to impute missing values in student survey responses. Missing values comprised approximately 15% of the dataset. The EM method used a maximum likelihood approach to estimate the expected values based on the observed data (i.e., student responses for other labs). The 3-factors in the RM-ANOVA included: (1) Lab Type (Non-Python vs. Python); (2) Education Component (Materials vs. Pairs vs. Technology); and (3) Questionnaire (Ease vs. Satisfaction). Paired T-Tests, in which survey data for each student was kept as a separate response variable, were used to compare mean differences in survey responses overall scores for Material, Partner and Technology. These tests were divided by lab type (Python and Non-Python) and question type (Ease and Satisfaction). The Paired T-Test approach is especially useful for situations with high among-subject variability, such as patients in clinical drug trials.

Results

This study made 96 observations on each of the 18 individuals (6 measures for each of 16 labs). This means that a total of 1728 observations were collected, a sizeable number by any measure and an indication of how Repeated Measure designs allow for strong conclusions with modest subject numbers. The analysis used the average of 8 labs for each metric. Thus we have 16 (size n=8) averages in the RM analysis (288 averages). The averages are more normally distributed than the raw value (central limit theorem) providing better fit to the assumption of normality. One-way ANOVAs found significant differences in overall scores among labs, but no significant differences between undergraduate and graduate students or any effect of previous experience on survey responses. For main effects, we found highly significant differences in the survey responses between Python and Non-Python labs (Table 2: $F_{1,17}$=14.348; P=0.001) and among the different types of educational components (Table 2: $F_{2,34}$=15.906; P<0.001) Materials, Pairs and Technology). We did not find significant differences between the survey response in terms of question type (Ease and Satisfaction). There were also significant 2-way interactions between lab type and educational component (Table 2: $F_{2,34}$=11.728; P<0.001), as well as between educational component and question type (Table 2: $F_{1,17}$=14.348; P=0.001), but not between lab type and questions type. No significant 3-way interactions were detected.

Table 2. Three-way repeated-measures ANOVA on student survey scores.

Repeated Measures ANOVA

Source	Sums-Sq	df	Mean-Sq	F	P	H-F† P
Main Effects						
Lab Type (Lab)[1]	10.893	1	10.893	14.348	0.001	.
Error	12.907	17	0.759			
Educational Component (Comp)[2]	31.812	2	15.906	15.284	< .001	< .001
Error	35.384	34	1.041			
Questionnaire Type (Ques)[3]	1.423	1	1.423	0.936	0.347	.
Error	25.846	17	1.520			
2-way Interactions						
Lab * Comp	5.819	2	2.910	11.728	< .001	0.001
Error	8.435	34	0.248			
Lab * Ques	0.680	1	0.680	3.083	0.097	.
Error	3.751	17	0.221			
Comp * Ques	6.973	2	3.486	3.518	0.041	0.041
Error	33.694	34	0.991			
3-way Interaction						
Lab * Comp * Ques	0.482	2	0.241	1.850	0.173	0.173
Error	4.427	34	0.130			

[1] **Lab Type** (Python, Non Python)
[2] **Educational Component** (Material, Pairs, Technology)
[3] **Questionnaire** (Satisfaction, Frustration)

† Huynh-Feldt corrected P value

Plots of 4 individual student responses illustrated the tremendous student variability in survey responses over the course of the semester (Figure 1). Paired T-tests found significant differences in the mean responses for Materials, Pairs and Technology in both Python and Non-Python labs (Fig. 2, 3). In general, the scores for Pairs were highest, followed by Technology then Materials. However, Technology and Pairs scored almost equally well in their Satisfaction scores for the Python labs and students also found the Non-Python technologies less satisfying than the lecture materials for the Non-Python labs. Figure 2 shows a transition graph for all 18 students, along with the mean scores and standard errors, for one of the Paired T-tests (Non-Python, Satisfaction survey scores), while figure 3 reports the mean responses for all the Paired T-tests without individual student responses.

Figure 1. Graph showing the Satisfaction scores for four representative students for all 16 labs. This subset of students spans both the Grad/Undergrad and the Level of Familiarity before the class. The chart illustrates the considerable variability among students and labs.

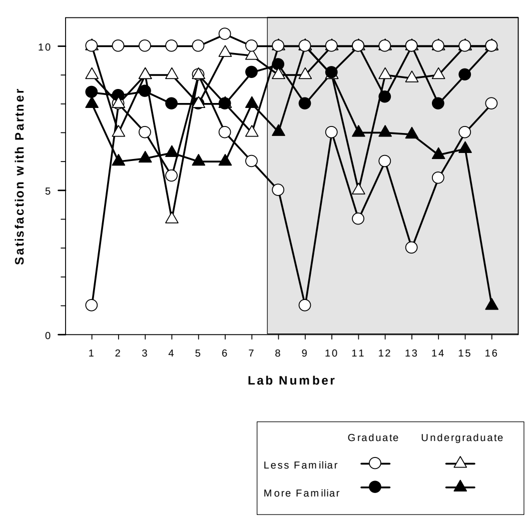
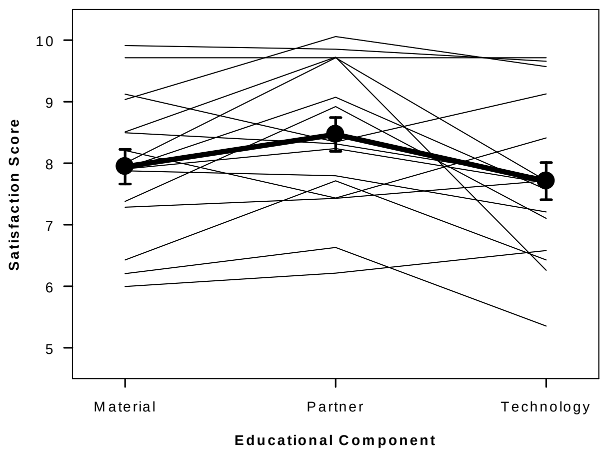


Figure 2. Transition graph showing average Satisfaction with NonPython Labs. Responses of all 18 students are represented by the thin lines, and the thick line connects the mean and standard errors for the groups, indicating how they differ among Materials, Partner and Technology.



Discussion

The survey was a highly sensitive indicator of student frustration and satisfaction with the course, despite the apparent simplicity of the survey design. Most of the students scored all aspects of each lab above 50%. However, within this range there was a considerable variability and strong differences among both students and labs in terms of survey scores. Figure 1 illustrates the typical responses of four individual students over the course of the semester. As expected, there was highly significant lab-to-lab variability, which reflected the wide diversity of exercises presented to the students, particularly in the Non-Python exercises.

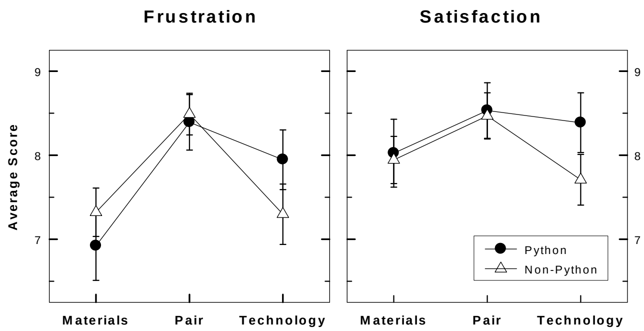
Encouragingly, we found no differences in responses between students with or without previous experience with the technology (either the web tools or programming experience) or between undergraduates and graduate students. This finding mirrors personal observations made by the instructor in the course. Many of the bioinformatics novices were just as good with the bioinformatics tools and at programming as the 'experts' and the undergraduates performed as well on tests as did the graduate students.

The RM-ANOVA found highly significant differences between student responses to the lecture material, the technology and working with a partner (Table 2). A closer look at the data using a paired T-test identified the strongest trend in the study: students consistently rated working with a partner highest in terms of both Ease and Satisfaction, and in both Python and Non-Python labs (Figure 3). Clearly, the aspect of collaboration was highly valued and the EP cooperative model appears to be very appropriate for Bioinformatics classes. Although we did not directly evaluate the impact of the EP model on student learning, cooperative learning has a long track record of boosting student achievement in SMET courses and student satisfaction is also correlated with performance. From an instructor perspective, there were two other enormous advantages to using the EP model. First, the students had someone to help troubleshoot problems, reducing their reliance on the instructor to answer questions. Second, EP effectively doubles the number of students who can take the course, which is an important concern given the extremely limited computer resources on campus.

The RM-ANOVA analysis also uncovered highly significant differences in student responses between Python and Non-Python labs (Table 2). The survey results appear to reflect the extremely different character of the material taught in the two halves of the course. Somewhat to our surprise, we found that these biology students tended to favor the Python programming section of the course over the Non-Python section (Figure 3). Although many of the students expressed trepidation about the programming section prior to the start of the course, and many expressed considerable frustration about programming during lab exercises, overall they seemed to find working the simpler 'cut and paste' labs more frustrating than the open-ended Python labs. This would suggest that students want to engage in more demanding work and that doing so with a partner enhances the experience.

The students appeared to be especially pleased with the Python technology (Figure 3), a fact that speaks well for the Python language as a learning tool since many students had no prior programming experience. The high overall survey scores appeared to confirm the students' general interest in bioinformatics and programming per se. This is especially important in light of the fact that 45% of the class was female and 60% had non-European heritage. Indeed, many of the students appeared to have considerable latent abilities with programming (S. Kelley, pers. obs.) and apparently just needed an opportunity and the right environment to express their talents. We suggest that the non-competitive EP cooperative learning model, combined with easy syntax of the Python programming language and an interesting application (Biology), opens the door to computer education for students who otherwise might never try such a class.

Figure 3**.** Transition graph showing the average scores with standard error bars for Materials, Pairs and Technology. The scores are broken down by Ease and Satisfaction, as well as by Python and Non-Python labs.



Even though we have 30 years of research on the positive effects of group-work (Slavin, 1995), higher education has 'yet to respond to calls for greater opportunities for collaboration and cooperation in SMET (science, mathematics, engineering and technology) courses and programs' (National Science Foundation, 1996). Professors continue to implement teacher centered teaching styles that focus on transmitting knowledge to passive learners. This traditional lecture model of teaching does not engage students or reflect what it is scientists will be expected to do once they enter the workforce, whether it be on a campus or out in the field (Arch, 1998; Springer et al., 1999). By adapting the Extreme Programming model to the bioinformatics class, we believe we have created a student-centered class that required the learner to engage with the material and his or her classmates. In the process of learning the content, the students learned the value of collaboration in problem-solving that will be needed in the workplace.

Limitations of the study and directions for further research

The two greatest limitations of this study were the lack of a control or comparison group. Given the small number of students enrolled in the course, we believed that dividing the class into experimental and control groups would have yielded insufficient data and would have deprived students of potential benefits of cooperative learning. Also, there already exists a plethora of research connecting achievement and cooperative learning, so the first priority was to establish a cooperative learning model that works well in the context of a bioinformatics class (or college computer classes in general). Controls are certainly the best way to judge learning and achievement, per se, but the focus of this study was on the effect of cooperative learning strategies on student motivation in a computer class. Thus, we plan to carry out a long term study on this continuing course that uses "fortuitous controls", which would be times when someone's partner does not show up for a lab and they are forced to work by themselves. We are still working out the details of how this might be accomplished. Additionally, qualitative data such as student interviews and longitudinal follow up with participants could yield greater understanding of the long-term effects of the use of the Extreme Programming model in Bioinformatics classes.

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A Task-Centered Approach to Freshman-Level General Biology

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Abstract: Many new instructional theories advocate centering instruction around a set of authentic tasks to improve application and transfer of knowledge and help students take more responsibility for their own learning. At BYU-Hawaii, a general education biology course was redesigned to follow this task-centered approach and then taught to two groups of students. Tasks were chosen for this course that required students to first learn and then apply their knowledge of biology. Technology was also brought into the course to help BYU-Hawaii reach its target areas for distance students. Overall, students feel that this course helps them take more responsibility for their learning and is more meaningful than other general education courses to which they have been exposed. Responses to tasks suggest that students who apply themselves learn critical thinking skills within the domain of biology and discuss biological topics in depth.

Keywords: general biology, task-centered instruction, authentic tasks, distance education, student-centered learning, authentic assessment

Introduction

Brigham Young University-Hawaii (BYU-Hawaii) has students from over 70 different countries attending classes. To prepare them better to attend BYU-Hawaii, efforts are being made to teach more students at a distance before they arrive on campus. The present thrust is to convert existing face-to-face, freshman-level general education courses to a distance education or hybrid format, to increase the effectiveness of instruction in these courses, and to help students take more responsibility for their own learning. Students will finish their first year of college in their own country before coming to Laie, Hawaii, where they will finish their degree on campus. The target areas for this approach currently include Mongolia, Korea, Hong Kong, and Taiwan. This approach has many advantages for BYU-Hawaii, including decreasing the need for student housing in a small and very full community, preparing students for college life before they actually attend classes in person, and helping them learn effectively.

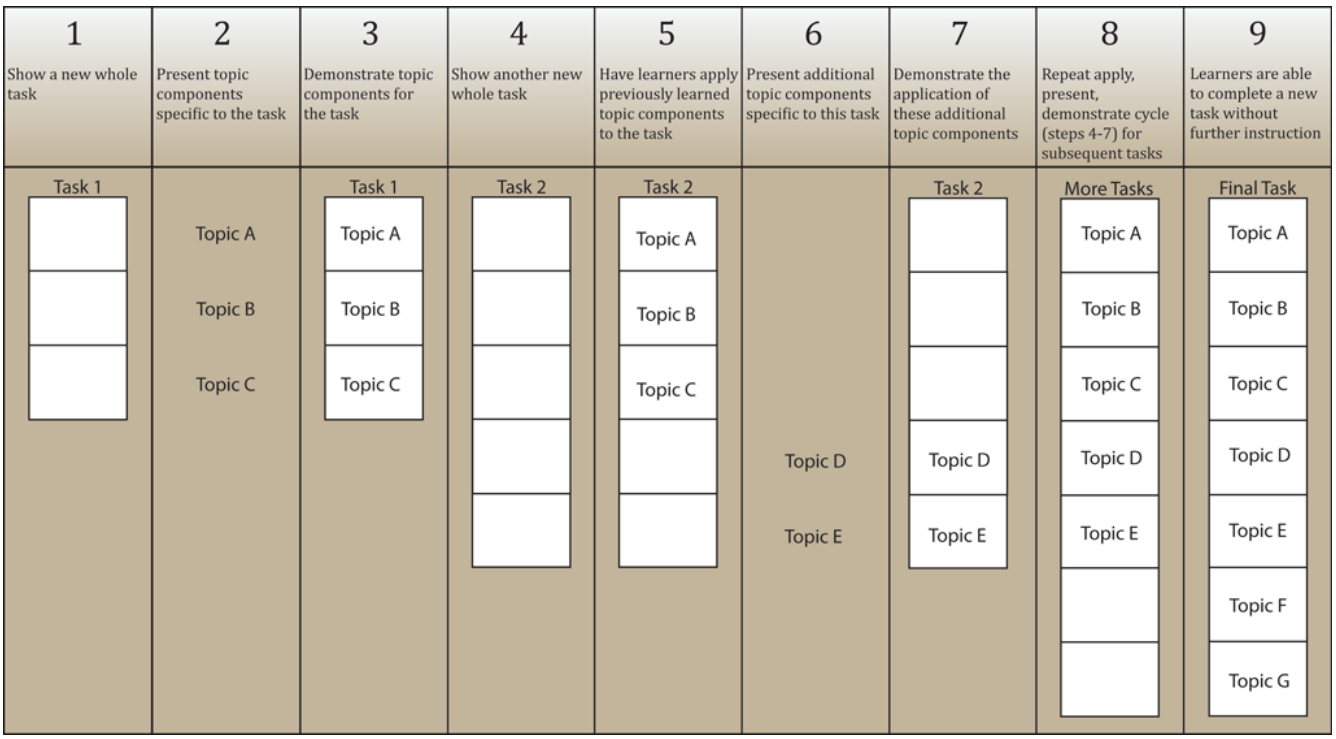
One of the first classes to be converted to this format and taught as a hybrid course was Biology 100. Biology 100 is a general biology course that gives freshman-level students a survey of the field of biology. Traditionally this course covered topics that include the introduction to biology, cells, molecules, photosynthesis, cellular reproduction, genetics, DNA, ecosystems, evolution and much more. Courses such as this that cover a breadth of topics are among the most common types of general education courses in universities today. Many university courses center instruction on topics rather than tasks and cover a high number of topics without requiring students to apply the information they learn to new situations. The passive lecture approach, while common (Lammers, 2002; Ediger, 2001), requires less responsibility from students for their own learning than other more constructivist approaches to learning (Harland, 2003; Brauner, Carey, Henriksson, Sunnerhagen, & Ehrenborg, 2007). Standard assessment methods such as multiple-choice tests that are commonly used in college classrooms, while sometimes able to determine depth of learning, are often used only as a way to encourage absorption and recall rather than application. Too often, students learn a little bit about each item and then remember that little bit for the test without applying it (Butler & Roediger, 2007; Reid, Duvall, & Evans, 2007). Concepts in these types of general education classes are not easily transferred because students have little chance to apply them to new situations (Specht & Sandlin, 1991; Minderhout & Loertscher, 2007, p. 178).

A Task-Centered Model

In contrast, many new instructional theories advocate centering instruction around a set of real world, authentic tasks (Herrington, Reeves & Oliver, 2006; Merrill, 2002a; Merrill, 2002b; van Merrienboer & Kirschner, 2007; Reigeluth, 1999; Lebow & Wager, 1994). An authentic task involves real-world application of knowledge to complete, is closer to something that a professional in the field would do, and applies knowledge from more than one subject area. Reigeluth explains that the first task should be the simplest form of a task that a professional would actually do, and subsequent tasks should increase in complexity (1999, p. 442). Examples of such learning tasks in the domain of biology include requiring students to find out if a certain observed trait is heritable, or having students determine if a certain chemical found in nature is actually man-made. These tasks, while complex, can be simplified and done by students if they are given the necessary support.

Merrill hypothesizes that centering instruction around a set of authentic tasks allows students to form mental models; holistic representations of parts, relationships, conditions, actions and consequences of a complete task (Merrill & Gilbert, 2008, p. 4; Merrill, 2007, 2002, p. 5). Centering instruction on tasks requires students to apply the information they learn in class to new situations. In *First Principles of Instruction*, Merrill prescribes that tasks used in instruction should be demonstrated to the students, and that students should be required to complete multiple whole tasks which apply some of the same information so these tasks can be compared to each other (2002a, p. 46).

Figure. 1. A graphical representation of a task-centered instructional strategy.

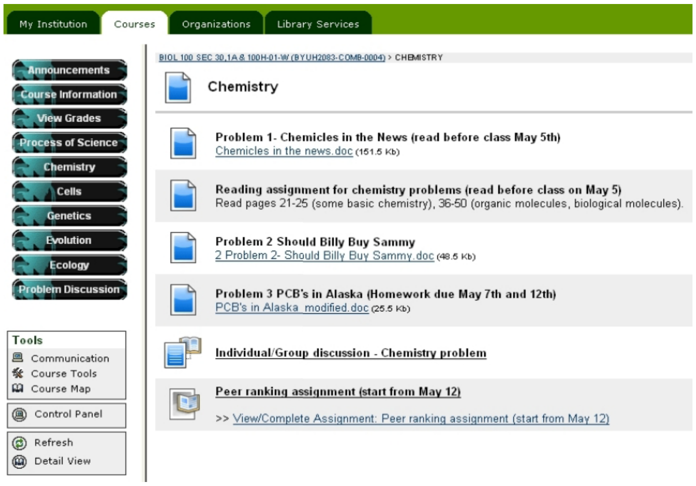


Instructional tasks should be designed to make students apply information they have learned to the task so that the experience of working through the task is added into a student's mental model along with the information (Merrill, 2002b). Instructional strategies that follow a task-centered approach should not present any information to students that is not applied to a task.

The Task-Centered Design

The existing BYU-Hawaii Biology 100 course was converted to follow this task-centered approach. One of the major trade-offs in this process was sacrificing broad information coverage for a deeper coverage of each topic. It takes more time to learn and apply a concept to a unique task than it does to just “skim” the concept. Dr. David Bybee, the Biology 100 instructor, examined his existing course and decided on topics that could be taken out of the course and those that were essential for students to form a foundation in biology. He chose to incorporate tasks into the course that fit within these different areas; the process of science, essential chemistry, cells, genetics, evolution, and ecology.

Figure. 2. The Biology 100 course online.



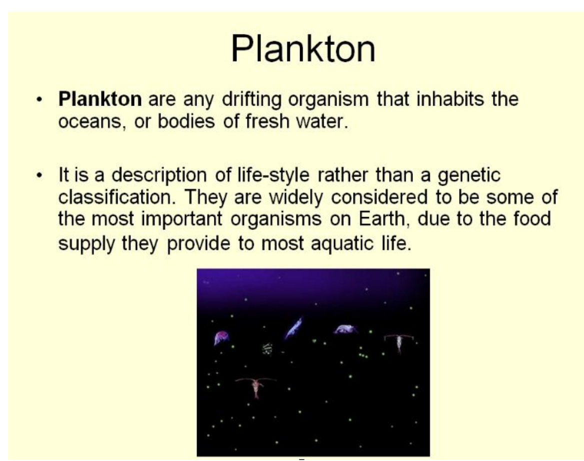
Tasks within these areas allowed students to apply their knowledge of biology to a new situation. For instance, in the process of science section, students learned information about the process of science and then completed three tasks that required application of their knowledge of the process of science. Students were scaffolded (Wood, Bruner, & Ross, 1976) to help them properly apply the information they learned to the tasks through in-class presentations that presented only information that was pertinent to the current task and how the information could be applied to tasks. Scaffolding in this class involved explicitly showing students how to complete the first task in a subject area using information about the process of science, then diminishing the level of support given to students for each subsequent task that students complete in the subject area. Information in the course was applied soon after it was presented. At the beginning of class Dr. Bybee explained to students some of the key differences between this class and a traditional general education class at BYU-Hawaii to help them understand what their experience would be like.

Figure. 3. A chart that was presented to students on the first day of class to help them understand what their experience would be like.

Traditional Class	This Class
Lectures in class	Demonstrations and practice in class
Learn about the same thing students read about in the textbook	Students read before class and come ready to apply what they read to a biology problem
Assessment is done with multiple choice tests	Assessment is based on how well students apply their knowledge of biology to a problem and how well they participate in class
Sit and listen in class	Participate practice and present ideas at the front of the class
Teacher imparts knowledge to students	Teacher and students solve problems together
Less work in class	More work in class
Knowledge is most important	Application of knowledge is most important
No need to be ready for class by reading and studying	Readiness for class will affect student's grades, but more importantly, their learning
What students learn depends on how well the instructor lectures	What students learn depends on how much preparation and critical thinking students do
Not too much fun	A lot of work, and a lot of fun

Basic information presentation, including textbook reading and lecture information has been moved from playing a central to a supportive role. Most of the tasks that Dr. Bybee chose for students to complete required students to understand certain concepts and definitions before being able to complete the task. This information was provided to the students in a variety of formats, including their textbook, classroom presentations and carefully prepared online tutorials. Traditionally this Biology 100 class required reading the entire textbook. In the redesign, students were asked to read only the pages in the textbook that apply to the task at hand. Since the tasks are not bound to a specific subject area, students had to gain background knowledge of additional concepts and definitions. They viewed online tutorials and listened to in-class presentations to give them this knowledge.

Figure. 4. An online tutorial that tells about Plankton.



Student Activities – Before Class

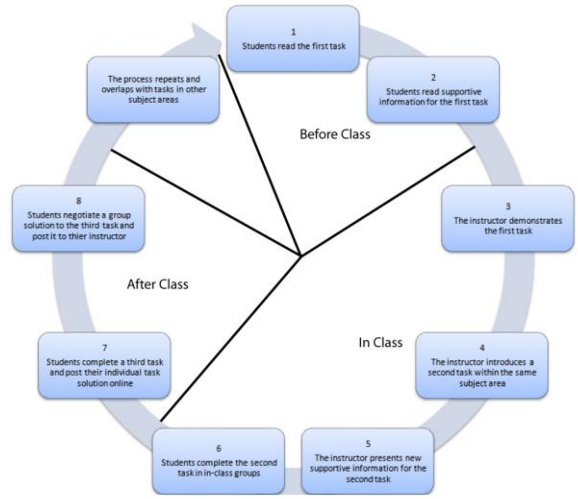
Students were involved in a minimum of three tasks from each topic area. Before each class, students were first presented with a task before learning about the subject area or knowing how to complete the task. Students accessed this task online in a course management system. Students then read their shortened textbook reading and other information that was relevant to the task. Because students had already read the task, the textbook reading was designed to help them gather information to help them complete the task.

For example, in the Ecology section of the class, students were required to read a real-world case study involving a description of trophic interactions in an isolated environment. Then questions were posed to students in this case study about these interactions. The case study and questions made up the first task that students should complete. Students who did not yet have knowledge of ecology would likely not be able to answer the questions when reading the case study for the first time, but they were encouraged to think about how the material presented in the task related to ecology. Students next read about 22 pages of their textbook that were selected because of their relevance to the case study. As students read in the textbook, they were encouraged to look for clues that helped them to complete the task by answering the questions in the case study. In this process of reading and thinking about the task, students began to understand ecology and the task before coming to the first ecology class session.

Student Activities – In Class

In each class, the instructor showed students how the information that they read could be applied to the task. Then the instructor presented a second task but diminished support for the task by demonstrating only a partial solution to the task. The instructor explained how information read in the textbook and elsewhere could be applied to complete the second task. Students broke into groups and solved the rest of this second task with each other. This peer interaction gave students the opportunity to discuss their knowledge of the topic area and task and the relationship between them. They defended their own responses to the task when disagreements arose.

Figure. 5. The weekly student process of before class, in class and after class activities.



Several classroom observations revealed that students participated well in demonstrations and enjoyed the instructor's presentations. Observers also noticed that group discussion time was quite animated. In one class session, students in groups debated and discussed the role of mitosis and meiosis in the redistribution of chromosomes and explained other pertinent genetics concepts to each other.

The task in which students were engaged during one observation was a genetics problem called *Desiree's Baby* (Schnieder, 2003). *Desiree's Baby* is a tragic story about a woman in the 1800's who has a baby that begins to show signs of mixed race in skin color. Her racist husband requires her to leave. Heartbroken, Desiree takes her own life and her baby's. Later the husband discovers that he is actually the person whose family line contains mixed race genes. The task required students to apply genetics to this story by discussing their knowledge of inheritance patterns and draw conclusions based on this knowledge. This story was not sanitized of other topics such as racism and 1800s culture, which was one reason that it was interesting to students. Almost all students were taking very active roles either explaining a concept or listening to one another. Many students also referred to their textbook and websites via laptop for more information on genetics.

Student Activities – After Class

After each class, students worked on a third task. In the genetics section, students worked on a case study about the occurrence of people with blue pigmentation in their skin (Leander & Husky, 2008). Their homework was to determine possible causes of this skin pigmentation, how to test for these causes, and whether this blueness in the skin is a heritable trait based on family trees. Students posted individual answers to these problems in an online course management system and then compared their answers to those in their group of up to 4 people. Then, as a group they negotiated a final response to submit to their instructor. Because the task was complex, there were a variety of answers given by individual students and groups. Most students hypothesized that perhaps the level of oxygen in the red blood cells was low for varying reasons, mainly genetics. Other responses speculated about the introduction of foreign drugs into the body, or environmental and lifestyle circumstances. Students also indicated ways that they could test these hypotheses, including studying the family tree of the people involved or studying the environment in which they live. Here is a quote from one of the group responses:

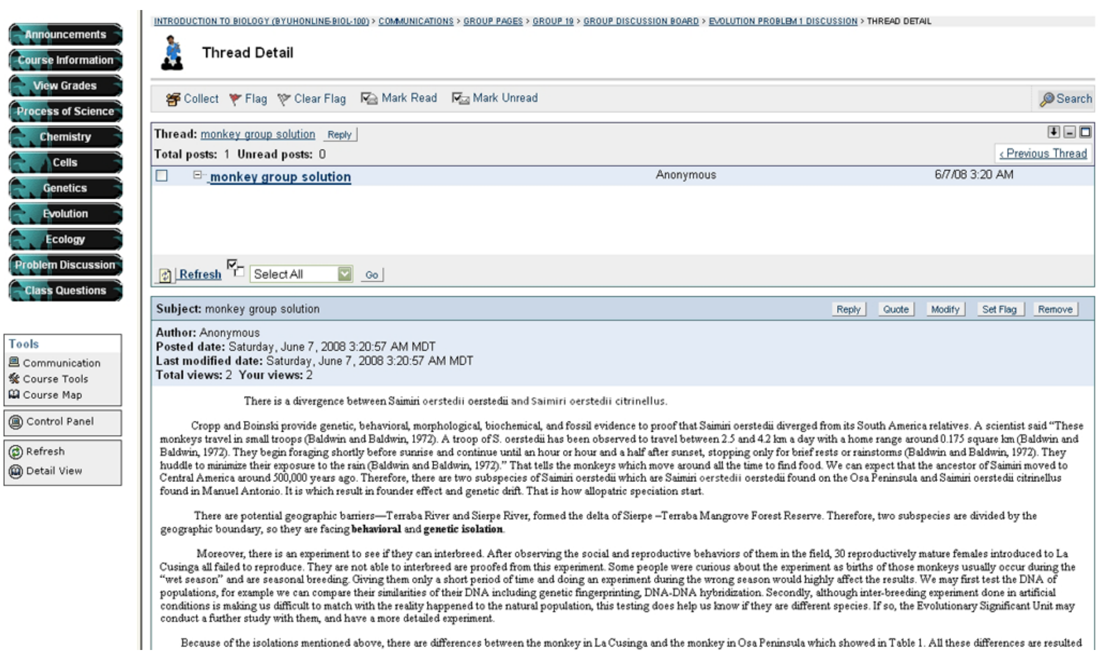
> The first [...] hypothesis that we considered was that this skin formation was [due to a lack] of a certain enzyme called diaphorase, as a result, blood levels of those who suffer from met-HB (methemoglobin) have a shortage of oxygen-carrying competence, also because this triggers methemoglobin levels [to] soar. Therefore, it is represented in the human being by the bluish tinge found on their bodies.
> To test this particular idea, we would compare blood samples of those who suffer from met-Hb and those who do not, and devise a way to measure the oxygen levels [in] the blood streams.

Another response to the same problem given by a different group of students includes the following observation;

> There was always someone within the pedigree chart who was a carrier of the recessive methemoglobinemia (met-H) gene, which limited and/or stopped the body's production of the enzyme diaphorase (which breaks down methemologbin into hemoglobin in red blood cells). The absence of this enzyme produced a disproportionate amount of methemoglobin in the blood, tinting it blue [...] People aflicted [sic] with this genetic disorder have skin which is literally purple-blue in color and dark purple lips. The hemoglobin in their blood has a reduced ability to carry oxygen which produces the blue color of their skin. The dominant, normal allele is responsible for the production of an enzyme (protein), called diaphorase that reduces the hemoglobin so it can be reused and pick up more oxygen.

All student group solutions included a family tree that represented the family in question and listed their traits in a genetic chart. Other unit tasks were similar to this one. Students were required to post their individual response to the task and then discuss each other's responses online in groups and decide on a final group response. Dr. Bybee observed that, relative to his traditional general biology class, students who invested their time in these online discussions were involved in a deeper level of discussion, and had an increased feeling of the importance of biology as a field of study.

Figure. 6. A group solution to an ecology problem in the Biology 100 online discussion board.



Assessment

In contrast to the traditional method of general education biology teaching at BYU-Hawaii, which often uses multiple choice tests to assess students' understanding of biology, a student's grade in this Biology 100 course is based mostly on authentic methods of assessment that determine how well they can apply information to a unique task. Assessment in the Biology 100 course is based on three main components. First and most importantly, a student's individual posts and group responses are graded based on how well they apply their knowledge of the topic area to the task, how thoroughly they outline the topic area, how well the evidence from the task is used to complete it, how well items read in the textbook and experiences in the class are applied, and grammatical correctness. These elements were part of a grading rubric used by the biology instructor to assess the ability of students to apply the knowledge they learned. Next, students report on how well they prepared for each class by choosing from options in a specific rubric. Finally, students rank each other on how well they contributed in the group work during each task.

Authentic assessment, including grading students ability to apply information to a task, focuses on deep understanding and application of knowledge (Gulikers, Bastiaens, & Kirschner, 2004; MacAndrew & K. Edwards, 2002; Oh, Kim, Garcia, & Krilowicz, 2005). Authentic assessment measures given by the instructor when measuring the application of knowledge have been found to be reliable and valid with high inter-rater reliability between internal and external experts in both written responses and oral presentations (MacAndrew & Edwards, 2002; Oh et al., 2005). Authentic assessment methods have also been found to measure application of learning rather than just "surface" learning (Reid et al., 2007; Gulikers, Kester, Kirschner, & Bastiaens, 2008). Self-grading increases student responsibility for learning and has been found to be a valid method of assessment when students follow a specific rubric (Edwards, 2007; Sadler & Good, 2006; Strong, Davis, & Hawks, 2004). Cheating and grade inflation are possible risks in self-grading, but studies have shown that the benefits of self-grading, including increased motivation and learning opportunities often outweigh the risks (N. M. Edwards, 2007; Strong et al., 2004). Peer-ranking as an assessment technique has been used in a variety of situations with high reliability and validity (Cho, Schunn, & Wilson, 2006; Magin, 2001; Wen & Tsai, 2006) especially when used with forced distribution (ranking) (Ryan, Marshall, Porter, & Jia, 2007).

Evaluation

Biology 100 has gone through one iteration of formative evaluation. This formative evaluation was conducted at BYU-Hawaii as a hybrid course with 89 students in 2 classes. Student perception results from this pilot test will be used to help BYU-Hawaii bring general biology to its target areas. The instruments of the evaluation included classroom observation, instructor observations, a class survey, and online discussion observations.

Students took a little while to get used to the format of this course which is radically different from other courses that they have taken at BYU-Hawaii. At the beginning of the course students had to learn to use an online learning management system, negotiate an unfamiliar grading scale, and learn to increase responsibility for their own learning. The perceived frustration level among students in the classes decreased from high at the beginning of the semester to low as students got used to the course format. Almost all other courses at BYU-Hawaii require attendance, so when this course did not require it, some students took the liberty of not coming. Despite all of the warnings given to students about how this course would be different than what they are used to, some students still treated this course as a traditional higher education course. As time goes on and more courses give more responsibility for learning to the students, they will likely begin to understand how to take that responsibility seriously.

Several classroom observations showed that overall, students actively participated in class discussions. However some students decided not to take responsibility for their own learning and avoided group discussion. Discussion groups were usually formed by culture and friendships since students were allowed to form their own groups. Plans are being made to conduct an instructor training that will help address some of these concerns. Group formation will be changed to make sure that small and cross-cultural groups will be formed and to require more effective participation.

Throughout the course, students' task solutions showed that they gained a deep understanding of biological topics. Dr. Bybee observed that some of his freshman students in this Biology 100 course were able to complete problems and tasks that he had used with his senior level students. This observation suggests that this course helps students learn critical thinking skills within the domain of biology and make conclusions that are similar to ones made by more experienced biology students.

88 students responded to an online survey about the Biology 100 class. Ninety-two percent agreed that this class gave them the opportunity to apply knowledge in meaningful ways. Over 81% felt that their interest in Biology increased as a result of this

class. Over 76% liked this class better than other general education classes they had taken. At least 92% of students felt Biology 100 helped them improve their critical thinking skills and 76% felt that it helped them improve their reading and writing skills.

Of course, not all survey responses were favorable. Almost 60% of students felt that online discussions were the least helpful activity to their learning. Observations on these discussions indicate that some students did not take these activities seriously, and some of the online discussion tasks were not complex enough to allow for differing solutions. Many (68%) students felt that the required readings (tasks, and textbook reading about the tasks) were the most helpful activities for their learning.

When responding to, "I would suggest the following items to improve the Biology 100 class for future students," Student responses generally fell into four areas: improve grading and feedback to make it more prompt, improve the organization in the course so that students understand their expectations, remove the peer-ranking elements of the course, and mandate in-class attendance. Other responses not in these categories include the following: "Please give us class more than once a week. Please destroy the grading system and rework it entirely. Please don't turn a teacher into an online supervisor for an internet course." Another student showed his/her desire to return to a traditional course format with the following comment, "Stop using blackboard and stick to the system that works- tests and quizzes."

Students also responded to the statement, "I especially liked the following aspects of the Biology 100 course," and responses to this statement also fell into four main categories: problems that allow learners to apply information to a unique situation, the lack of exams, the instructor's presentations, and in-class and online group work. One sample response to this statement illustrated a common feeling of satisfaction in being able to apply information to tasks: "The problems, how applicable everything was to real events and life [...] It was so awesome, and so helpful for applying book-knowledge to real life. LOVE it!" Another comment highlighted student responsibility for learning in the class:

> What I did like is the idea behind the class. Its [sic] much more geared towards effective learning because its more about the education rather than memorizing for the test. I think the philosophy of the class is unique because it allows kids to really learn if they take the time to apply themselves. its [sic] a bit more self guided than other classes so the students need to be serious about learning.

Another student responded with enthusiasm for the lack of tests in the class, "No tests! i [sic] liked the learning method of learning through our own analysis and discussions with others, it was new and interesting..."

One student's response summed up the main purposes of this course redesign:

> The readings helped me understand the basis for what we were discussing, and in-class discussions and instructor presentations helped me to focus that knowledge and come up with possible solutions to real problems. On line discussions helped me to develop my critical thinking skills more on my own because I was forced to come up with my own hypothesis, and argue either for or against others. This helped to hone my ability to think in a way that applied both what I learned from being in class, from the readings, and from outside information and logic. I LOVED this class!

Discussion

The observations and survey findings indicate that overall, students were excited and motivated in Biology 100. They especially enjoyed being able to apply information to complete relevant tasks and take more responsibility for their own learning. Most students preferred this method of teaching to other general education teaching methods to which they had been exposed. One limitation to the findings is that there was no systematic comparison of the performance of this class to another similar general biology class taught in the original way using lectures and tests. Using both authentic and traditional assessment in each class would help determine what types of knowledge students are learning and allow a comparison between the different classes. Another limitation is that the original Biology 100 final was not administered to students in this Biology 100 course. Results from the original final would indicate if students actually did gain a general knowledge of biology concepts in addition to the applied knowledge already measured by the instructor in students' task solutions. The focus of this course was application of concepts rather than memorization of biology concepts, but results from the original final would indicate if students actually did remember concepts through their application. A third limitation is that individuals who had a stake in the outcomes of classroom observations did these observations. So confirmation bias could have played a part in the report of classroom observations despite the observers' efforts to be objective.

Revisions

Based on the survey results, feedback will be improved to give grades promptly for student performance. Problems will be examined for complexity and some will be switched out for more applicable problems that will help improve group discussion. Future revisions to the course include conducting a traditional final test for all students and peer grading of group solutions to tasks is also planned to allow students to review and learn from each other's group solutions.

Revisions are currently being made to the Biology 100 course to prepare it to go out to its intended target areas. It is planned to be tested in Asia in January, 2009. Further evaluation data will be gathered to investigate the effectiveness of this approach to teaching general biology to BYU-Hawaii's target areas.

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A Biology Course for the Less-Than-Prepared Prospective Biology Major

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Abstract: Many undergraduate institutions are dealing with less-than-prepared students entering the biology major. When the biology department at College of Notre Dame of Maryland analyzed data from five past cohorts of prospective biology majors, it was evident that there was a significant correlation between their success in the introductory course in the major and their math SAT score (Spearman's rho = 0.058; $p < 0.001$). Based on these results, the biology department developed a preparatory course for students whose MSAT score was below a prescribed cutoff value and stipulated that a student must pass this preparatory course with a grade of at least C+ to take the introductory course. For the first four cohorts (n=93), 95.9% of those who enrolled in the introductory course in the semester following the preparatory course received a grade of at least C. For these students, there was no correlation between their grade in the introductory course and their MSAT score. This paper describes how the department determines which students take the preparatory course, explains the design of the course curriculum and assessment within the course, and presents an analysis of the first four cohorts of students to progress through the course.

Keywords: curriculum, SAT, MSAT, preparatory course

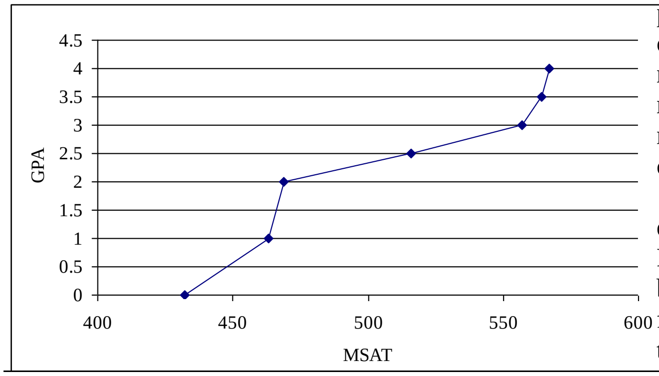
Introduction

Each fall semester, about two-fifths of the incoming first-year students at College of Notre Dame of Maryland, a liberal arts college for women, envision themselves as biology majors. As the instructor of the introductory biology course, I often found a mismatch between students' preparation for college biology and the demands of the undergraduate biology curriculum. Over the years, the biology department made several attempts to address this situation by incorporating workshops into the introductory course and by suggesting that students whom they judged to be less-than-prepared defer taking the introductory course until the spring semester. Neither strategy, however, enabled students to complete the introductory course in a manner that prepared her to be successful in subsequent biology courses. Therefore, in 2004, the biology department addressed the issue head-on by introducing a specific course for less-than-prepared students. It was our hope that each student taking that course would either (1) continue with her plans to major in biology and take the introductory course, but be more informed about both the nature of the discipline she was choosing and about her strengths and weaknesses as a student of that discipline; or (2) realize that the biology major did not match her academic strengths, complete her general education science requirement and look for a more suitable major. This paper describes how the department determines which students take the preparatory course, explains the design of the course curriculum and assessment, and presents an analysis of the first four cohorts of students to complete the course.

Placement of Students into the Preparatory Course

Guided by informal observation of students in the introductory course (BIO 111: Fundamentals of Biology) over numerous semesters, we conducted a formal statistical analysis of student grades in that course from five consecutive semesters. This comparison revealed a significant predictive relationship between MSAT score and a student's performance in BIO 111 (Figure 1). The Spearman's rho (non-parametric correlation) was 0.58, which is highly significant ($p<0.001$). There was, on the other hand, no significant predictive relationship between a student's performance in the introductory course and either verbal SAT score, overall high school GPA, or high school biology GPA. Our finding was later bolstered by an NSTA report (2004) that only 26% of students who took the ACT achieved on the math component a score that predicted their ability to earn a grade of C or better in a college biology course. An MSAT score, which has "floated" around 510, was set as the dividing line between students placed into the introductory course (BIO 111) and the preparatory course (BIO 110:Exploring Concepts in Biology).

Figure 1. Relationship between GPA earned in an introductory course and MSAT for five semesters of students (n=71)



Foundational Principles

The course for less-than-prepared potential biology majors is built on a foundation of five principles, each of which is substantiated either by educational literature (Mayer, 2003) or by the experience of students who had been enrolled in BIO 111 in prior semesters. First, research (Seymour & Hewitt, 1997) suggests that one of the greatest difficulties encountered by students in the sciences is trying to catch up with course material with which they have little or no prior knowledge while they keep up with the steady progress of the course into new subject matter. BIO 110, therefore, comprises six units[1] which, while not completely independent of each other, are not developed sequentially. This course structure enables a student who does not succeed academically in the first unit of the course to start fresh on the second, with no need to catch up and keep up at the same time. The 6-unit design also enables the biology department to address a second principle—the need to broaden the rather limited biological background (Uno & Bybee, 1994) of incoming students. Although two-thirds of students in BIO 111 regularly report that they have taken at least one biology course in high school beyond general biology, in almost half of the cases the course is Anatomy/Physiology. Therefore, the 6-unit design opens a window for students on areas of the discipline with which they might not be familiar. Third, many first-year students report that they did not realize that biology is a quantitative science like chemistry or physics. Because successful biology students recognize the deeply-rooted integration between mathematics and biology (Bialek & Botstein, 2004), BIO 110 is built around a series of biological problems, each of which requires a mathematically developed solution. Fourth, many first-year students tend to be surprised by the time commitment necessary to be a successful biology major, particularly by the demands of the laboratory component of BIO 111. BIO 110, therefore, includes an individual research project to provide students with an on-going major assignment throughout the semester. Because this multi-step assignment is conducted by students outside of class time, it challenges their time management skills.

The final principle of BIO 110 is strategy development (Paris, Lipson, & Wixson, 1983, p. 296). Previous discussion with students enrolled in BIO 111, both in *ad hoc* individual advising settings and in more formally structured focus groups, suggested that the targeted students in BIO 110 have a limited set of strategies. Students explained that they had encountered difficulty applying mathematical principles, reading scientific text, writing about biological concepts, and studying. The purpose of BIO 110 is to provide students with daily opportunities to consider the declarative, procedural and conditional knowledge that underlie good strategy development (Simpson & Nist, 2000) in the framework of six biology units.

Math Strategies

Students who must be placed in a remedial mathematics course in college are considered at-risk for college completion (Berenson, Carter, & Norwood, 1992). Although the students for whom BIO 110 was designed do not require remedial math, it appears that their math performance compromises their ability to successfully complete BIO 111. Because these students have little appreciation for the complex connections between biology and mathematics (Jungck, 2005), our intent was to present a biology course in which students can't separate biology from mathematics. Learning math with understanding (Carpenter & Lehrer, 1999) emerges from five types of mental activity. Students must construct relationships between new mathematical ideas and their prior knowledge, extend their mathematical knowledge in ways that clarify its application, consciously draw connections between their prior knowledge and the knowledge they are presently acquiring, and, finally, make their mathematical knowledge their own. To facilitate these types of thinking, BIO 110 is organized around math-based activities which are not mathematically sophisticated, but whose completion is necessary for building an understanding of biology. For example, in

[1] The six units are anatomy, botany, ecology, evolution, genetics, and microbiology. Specific information about the content of these units will be supplied by the author on request.

the botany unit, students work with two sets of oak leaves, deep-lobed and shallow-lobed. They develop a method to determine what percentage of the total outlined area of each set of oak leaves is taken up by interlobe spaces,[2] determine the number of stomata per mm^2 from nail polish casts, and conduct t tests to compare area and stomata values for the two sets of leaves. Then, based on an understanding of photosynthesis developed through use of models, they hypothesize the location of the two types of leaf in a single tree.

Because most of the students in BIO 110 are more familiar with the transmission model of teaching/learning mathematics (De Corte, Verschaffel, & Op'T Eynde, 1999), students are not merely presented with the necessary mathematical procedures; they are helped to develop them and are required to explain mathematical procedures both while they are carrying out the tasks and after they have completed them. Being asked questions like "What are you doing?" and "Why are you doing that?" on a regular basis helps students to realize they should be asking these questions of themselves. Moreover, when students work on a task that they find interesting and when they are expected to explain the math that they have utilized to solve the task, "they own that knowledge, stay interested in the mathematics, and do not fear working on problems in new contexts" (Lajoie, 1999, p. 131). The generative nature of this type of instruction in BIO 110 is borne out in the final unit of the course, in the study of a biomechanical model of a foot (Glase, Zimmerman, & Brown, 1981). Whereas students were hampered by mathematical applications earlier in the semester, at the end of the semester they comfortably and capably use math to determine whether the foot is designed for speed or for force.

Reading Strategies

Students enter college from secondary schools in which teachers assign them a total of 12 pages of textbook reading each day (Donahue, Voelkl, Campbell, & Mazzco, 1998). Moreover, many of these students are passive readers for whom it is more important to get pages read than to understand content (Alexander & Jetton, 2000). In college courses, however, faculty expect students not only to read far more textual information, but to understand and remember it on their own (Simpson & Nist, 1999).

College students can be categorized as either successful or unsuccessful readers based on three factors (Simpson & Nist, 1999): how much they think that learning a particular subject is at least partly their responsibility; how much they distinguish in their reading between concepts that they understand and those they don't, and then alter their reading based on that distinction; and how much they recognize the difference in reading requirements across and within disciplines and modify their strategies accordingly. Part of the transformation of unsuccessful readers into successful ones involves "nudging" them (Simpson & Nist, 1999) into thinking about their theories and practice of reading biology by introducing reading strategies that include both cognitive and metacognitive processes embedded in the context of biology.

BIO 110 concentrates on three types of biological literature (Pugh, Pawan, & Antommarchi, 2000)—the textbook, primary research literature, and trade books—and presents strategies that are inherent in reading each type. Strategies for reading the textbook focus on how to translate text formatting into conceptual hierarchies and how to read and use textbook diagrams. The second reading focus is primary research articles, the type of biological literature with which students report they have the least familiarity. There is a consensus in practitioner research journals (e.g., Levine, 2001; Muench, 2000) that introducing students to this literature has a positive effect on critical thinking. Each of the six units in BIO 110 culminates in the discussion of a primary research article that ties in with the biological question being considered. For example, in the microbiology unit that focuses on Koch's postulates, the students read Marshall and Warren's (1984) classic report in *The Lancet* of the relationship between stomach ulcers and *Helicobacter* infections. And in the evolution unit, after determining the effect of a severe drought on the finch population on one of the Galapagos Islands by working with a website that presents the data of Peter and Rosemary Grant (Bonner, 2006), students read "Intense natural selection in a population of Darwin's finches (Geospizinae) in the Galapagos," Boag and Grant's (1981) report in *Science* of the effects of that same event. Before the discussion of each primary research article, students are given a set of guide questions to prepare in small groups outside of class. These question sets become less detailed as the semester progresses. The third reading focus in BIO 110 is trade literature that provides students with a window on biology-based careers other than medicine. Students in BIO 110 are presented with a list of trade books, all of which are kept on 1-week reserve in the library. Each book describes the work of a biologist in a particular field, for example forensic anthropology,

[2] Students cut out photocopies of leaves that are pasted onto poster board. They are led to develop a method by which they can set up a proportion between the mass of $10cm^2$ of paper/poster board and their cut out leaves to determine area.

epidemiology, forensic entomology, conservation genetics, and tree canopy research. To avoid having the assignment feel like a middle school book report, the student is required for each book selected to develop a sequence of courses (in and out of the biology major) that she might take at College of Notre Dame to prepare her for further study in that area of biology; to investigate on line at least one graduate program that she might enter to further pursue that area of biology after graduation; and to write an essay that presents three reasons why she would or would not enjoy working within that career.

Writing Strategies

Research suggests that the goal of most high school students in their writing is to compose single sentences that convince the teacher that they understand what they have learned (Sitko, 1998). Rather than functioning as "knowledge-transformers" (Ferrari, Bouffard, & Rainville, 1998), they perform as "knowledge-tellers." This is a critical deficiency because people who can't write effectively usually can't carry out effective science (Moore, 1994). BIO 110, therefore, provides students with numerous opportunities to make their thinking visible (Ellis, 2004). Four main types of writing assignments are described here: Learning Logs, follow-up assignments to class activities, reflection papers, and the Independent Research Project (IRP).

Learning Logs require students to look back on the class period that just concluded and think about what they did in class that day, what they learned, how the content of the day's class connects with what they already know, how they will study the material, and what they don't understand. Students e-mail the instructor the answers to these six key questions by midnight of the day before which they have the next class meeting. Learning Logs are a low-stakes writing assignment, assessed as ✓⁻, ✓, ✓⁺.

After completing an activity, students are usually required to write a follow-up summary of the procedures or the outcome, formatted as either the Materials and Methods section or the Results section of a laboratory report. Each of the six units includes two or three follow-up summaries. Students are aided in the writing of this type of assignment by the website LabWrite, http://labwrite.ncsu.edu/www/. These middle-stakes writing assignments are assessed for how well they follow the laboratory report format.

Reflection papers constitute a major form of high-stakes writing assignment in the course. At the conclusion of each unit, students answer a series of questions, similarly structured for each unit, but specifically based on activities that were carried out and primary literature that was read during the unit.

The Independent Research Project (IRP) (Walvoord & McCarthy, 1990) is a second form of high-stakes writing embedded in BIO 110. For the IRP, each student selects two brands of a consumer product, chooses appropriate operational variables, defines each variable, designs and conducts an experiment by which each variable can be measured quantitatively, conducts a statistical analysis of the data, and graphs in Excel the data generated by her experimental procedures. The writing of the IRP is carried out in stages in the style presented in LabWrite.

Study Strategies

Research with first-year undergraduates (Van Etten, Pressley, Freebern, & Echevarria, 1998) suggests that many enter college expecting that the same study strategies that carried them through high school—memorization and last-minute preparation for tests—will be sufficient for success in college. Therefore, introducing students to a more diverse set of strategies is another focus of BIO 110. After each new topic is discussed in class, a second conversation develops around how that particular topic might be studied by students on their own or in study groups. Students are given opportunities to explain the declarative, procedural, and conditional knowledge on which their strategies are built and by which their understanding is assessed. "How do you know that you know this?" is the question that arises daily. These discussions continue throughout the semester, because changes in students' metacognition require extended periods of time (Simpson & Nist, 2000).

Course Implementation

Before first-year student course registration, students who intend to major in biology are identified from their college application materials. MSAT scores are reviewed and recommendations are made on a form that is placed in each student's advising folder. When the student meets her academic advisor to select her courses, the placement information is readily available.

The class size for BIO 110 is initially set at 18, but is adjusted to include all students who need to enroll. It has never exceeded 25 students. Three 2-hour classes a week permit a mixture of lecture, laboratory exercises, learning activities, and discussion. Because a great portion of class time is spent by students working on activities in small groups, older biology majors are trained to act as teaching assistants.[3]

[3] Because many of these students plan to work as TAs in graduate school, this provides them with invaluable training.

Assessing Student Progress

Assessment of learning in BIO 110 is carried out by the students and by the instructor. At the beginning of each unit, students take a short survey of their prior knowledge of the content of the unit that frequently indicates that students apparently either have a cursory understanding of the biological content or recall very little of the material they learned in high school. As part of each reflection paper, students assess how their understanding developed by comparing their prior knowledge of a concept at the beginning of the unit to their understanding at the completion. At the end of the semester, students are asked to assess themselves regarding the eight skill-based objectives of BIO 110 and choose three in which they think they made the greatest progress. The skills most frequently selected are reading and analyzing primary biological literature; studying various types of biological concepts and assessing understanding of a concept; and designing and conducting a scientific investigation.

Daily Learning Logs, which provide the most helpful day-to-day feedback about student progress through the course, are assessed as ✓$^{-}$, ✓, ✓$^{+}$. Because Learning Logs are returned to students at the class meeting that immediately follows the meeting on which they reflected, they provide immediate feedback to students. In addition, frequently the content of the previous meeting's Learning Log serve as the springboard for the subsequent class.

Information about student progress is also derived from reflection papers, the open-book formal assessment given at the end of each unit that students complete on their own time. Usually, students' grades on the first reflection paper are low. A student who receives an F on the first reflection paper is offered an opportunity to enter into a contract: the failing grade on her first reflection paper will not be considered in the determination of her final grade if she sets up an appointment to talk about how she is working in the course and if she does not receive a grade below a D on subsequent reflection papers. By the second reflection paper of the semester, almost all students receive a passing grade. Because the same format is used in the rubric for all reflection papers, students can easily map their progress from one unit to the next.

Students' work on the IRP follows a timeline that spreads out the research over the semester. On-going steps in the IRP received extensive commentary, but are assessed Submitted/Not submitted. The final full lab report is evaluated by an extensive rubric that assesses the quality both of the research and of the written report.

Analysis of Students Enrolled in the Preparatory Course

In the history of the first four cohorts enrolled in BIO 110 at College of Notre Dame (2004-2007), 93 students enrolled in the course (Table 1). Eleven of these students withdrew from the course before the end of the semester, four failed, and 78 (95.1%) passed. Fifty-one of these students enrolled in BIO 111 in the semester immediately following BIO 110.[4] Two of these students withdrew from BIO 111, two failed, and 47 (95.9%) passed with an average grade of C+ (75.9%). For these 47 students, there was no significant correlation between their grade in BIO 111 and their MSAT scores; in fact, all of them had an MSAT score that predicted a BIO 111 grade no higher than D (60%). By way of comparison, the average grade earned by students who were immediately placed into BIO 111 during these same four years (2004-2007) was also C+ (75.2%).

[4] In the first year, a grade of C was the prerequisite for enrolling in BIO 111; in subsequent years, the required BIO 110 grade has been C+.

Table 1. Outcome of first four cohorts to progress through BIO 110/ BIO 111 sequence. The numbers in parentheses in the first two columns indicate the number of students initially enrolled in each course. The number of declared, undeclared, and withdrawn students is based on the number of students who completed BIO 110.

Cohort	Passed BIO 110	Passed BIO 111	Declared major in BIO	Declared major in other than BIO	Undeclared	Withdrew from NDM/ LOA
2004-05	20 (24)	9 (11)	5	10	0	5
2005-06	19(24)	14 (14)	6	4	0	9
2006-07	21(25)	15(15)	9	4	0	8
2007-08	19(20)	9(11)	9	4	2	3
Total	78(93)	47(51)	29	22	2	25

We believe that the preparatory course, BIO 110, has achieved both of its intended objectives for less-than-prepared first-year biology students at College of Notre Dame. The skills embedded in the course have been used by some students to move successfully into and through the biology major. Twenty-nine students who statistically would not have even passed BIO 111 became successful biology majors, indistinguishable to instructors in 200-, 300-, and 400-level biology courses from students who were placed immediately into BIO 111. In the biology department's senior seminar course in spring 2008, two of the top three grades were received by students who had been enrolled in BIO 110 as first-year students; a junior biology major who had been enrolled in BIO 110 as a first-year student was accepted into the prestigious Dual-Degree Nursing Program with the Johns Hopkins School of Nursing. The graduating class of 2008 included five biology majors who had taken BIO 110 as first year students. At the time of graduation, their biology/chemistry average GPA was 3.02; their overall average GPA was 3.13. Their average MSAT score when they matriculated at Notre Dame was 470. BIO 110 has also accomplished its second objective: it has offered a positive network in which students can recognize that biology does not match their academic strengths. Twenty-two students who completed BIO 110 switched to a different major, either immediately after taking the course or after successfully completing BIO 111. For these students, however, in contrast to the students before the BIO 110 era, the change of major was not based on feelings of defeat or frustration, but on the realization that biology was not the best match with their academic skills and interests. The graduating class of 2008 also included seven students from the first BIO 110 cohort who completed undergraduate programs other than biology; their average MSAT score at the time of matriculation was 446.

In addition to the hoped-for outcomes of BIO 110, there have also been unanticipated positive effects. Because BIO 111 no longer includes less-than-prepared students, its conceptual rigor has been elevated with the incorporation of primary research literature and problem sets. BIO 110 has also had unanticipated effects on overall retention among all its enrollees. Out of the 78 students who completed the course in the first four years, 71.7% have remained at Notre Dame. This retention rate compares favorably with the national retention rates for students in this category. For all the students who enrolled in BIO 110, the course fulfilled an important role. It provided them with a context in which to evaluate both their abilities as students and the discipline in which they planned to focus; it also provided them with the necessary scaffolding to achieve success in college regardless of their eventual major.

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Editor's Note

Because of the extra length of this online edition of *Bioscene*, I have not written an editorial. However, I would like to encourage readers to submit cover art and articles for *Bioscene.* Moveover, the annual fall meeting will be held October 9-10, 2009, at Rockhurst University in Kansas City, MO. Further details will be made available at our website www.acube.org. The next issue for *Bioscene* will be the December print issue. Also, at the website are the forms for becoming a member of ACUBE. Forms and payments are to be sent to our secretary Tom Davis.

Stephen S. Daggett
Professor of Biology
Avila University

Website Review

Digital Science Libraries, a Wealth of Teaching Ideas!
Web site review of BEN the Bio-Science Educational Network
Access is through http://www.biosciednet.org

It is Wednesday evening, following a very hectic week of too many classes to prepare for and not enough time. Add to this is the fact that you have noticed that you are "losing" the Bio I class, your lecture on metabolism just does not seem to be gaining any ground with your students! You need a fresh new idea; a video clip? Possibly a brief in class lab exercise? Maybe your just imagining this and the class really does get the information but do they understand the concepts? You type "metabolism" into Google and get thousands of hits but which ones are of any quality? Searching through this vast information jungle can be all too time consuming and frustrating! So, where can you turn to get high quality peer reviewed ideas, without all the hassle?
Why not try a Digital Science Library! The BEN portal [Bio-Science Educational Network; BioSciEd.net] is a collaboration of professional societies that have built an online library of digital resources for pedagogic materials pertaining to biology. Established in 1999 by the American Association for the Advancement of Science (AAAS) and funded through NSF grants; BEN serves as a catalyst for strengthening teaching and learning in the biological sciences. Focused on undergraduate level education in the sciences, the aim of the BEN portal is to promote active productive learning through the development and availability of high quality **multidisciplinary biological sciences peer reviewed resources**. BEN provides links to more than 21 different professional society digital libraries. Over 10,000 diverse resources from 75 fields of study are available for use in the classroom. Types include, active learning activities, high-quality images, data sets, animations, assessments, journal articles, lesson plans, laboratory activities, teaching strategies and rubrics [just to name a few!].
So how is this site different? The information can be easily searched not only by topic and subject matter, but also by title, discipline, resource type (e.g. article, PowerPoint, video clip), pedagogical use, educational level, author, and authors institution! Moving with-in the portal is relatively easy and straight forward. So if it's a lab activity that you need or a rubric to grade the activity with; the resource can be quickly found.
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Next time you're preparing your course lessons or lectures, try BEN at www.BioSciEdNet.org and discover a wealth of high quality Biological Sciences Educational Resources!

Christine Bezotte PhD
Associate Professor of Biology
Elmira College

Letter to the Editor

There is a deficiency in biology text book presentations dealing with the question, if the universe is becoming more and more disordered, how can we account for biological order and for the apparent contradiction of the second law of thermodynamics. The standard presentation is that living systems are "open" with energy (nutrients) and light flowing into the systems offsetting the loss due to entropy, a measure of the unavailable energy and disorder.

However, living "open" systems react quite differently from inanimate thermodynamic systems where exogenous variables cause change in the system. For example, life systems seem to have internal biological clocks, following an irreversible cycle, growing, maturing and dying. Nutrients and light do not cause growth nor prohibit decline and death. Life proceeds irreversibly, as entropy increases in spontaneous processes and as time's arrow flows in one direction.

While energy considerations stem from the perspective presented by Clausius (1832-1888), the more fundamental understanding of the second law is attributed to Boltzmann (1844-1906). Entropy is defined in terms of probability, the net increase that occurs during an irreversible process associated with the change in state from a less probable to a more probable state. An illustration is a student's study area, presumably with use becoming disarrayed, a more probable state. By contrast, life forms grow to a more ordered, less probable state, even repairing disruptions. Macromolecules, like DNA, essential for life, are extremely improbable as there can be 10^{390} possible configurations and only a few are viable.

This paradox is resolved by the paradigm of the double helix reproduction of DNA. Given that highly ordered macromolecules can be reproduced precisely, then the organization of life's chemistry becomes feasible. Information and algorithms encoded in the nucleic acid sequences provide the necessary directing and organizing functions not unlike computer software. The aforementioned disarrayed student's study room can be brought into order with effort (energy) only if that effort is directed toward organization. That information could be used to lower entropy is also illustrated by Maxwell's Demon e.g. www.auburn.edu/-smith01/notees/masdem.htm.

For pedagogical purposes then, both views of the second law should be integrated. There should be a presentation of the information and algorithms in DNA and their role in the ordering of growth and the necessity of energy in any thermodynamic analysis accounting for biological order.

This explanation became evident in discussions with Prof. Christopher Jarzynski, University of Maryland.

Jacob Peterson
Professor Emeritus
Marashall University

In Memory

Laddie J. Bicak, 84, a long-time active member of ACUBE, died Wednesday, Dec. 24, 2008, at his home in Kearney, NE. He was born July 23, 1924, in Dodge, NE and was educated in there, graduating in 1942. After spending a year at Creighton University, he enlisted in the U.S. Army in 1943. He served as a medic in the 16th Armored Division during World War II.

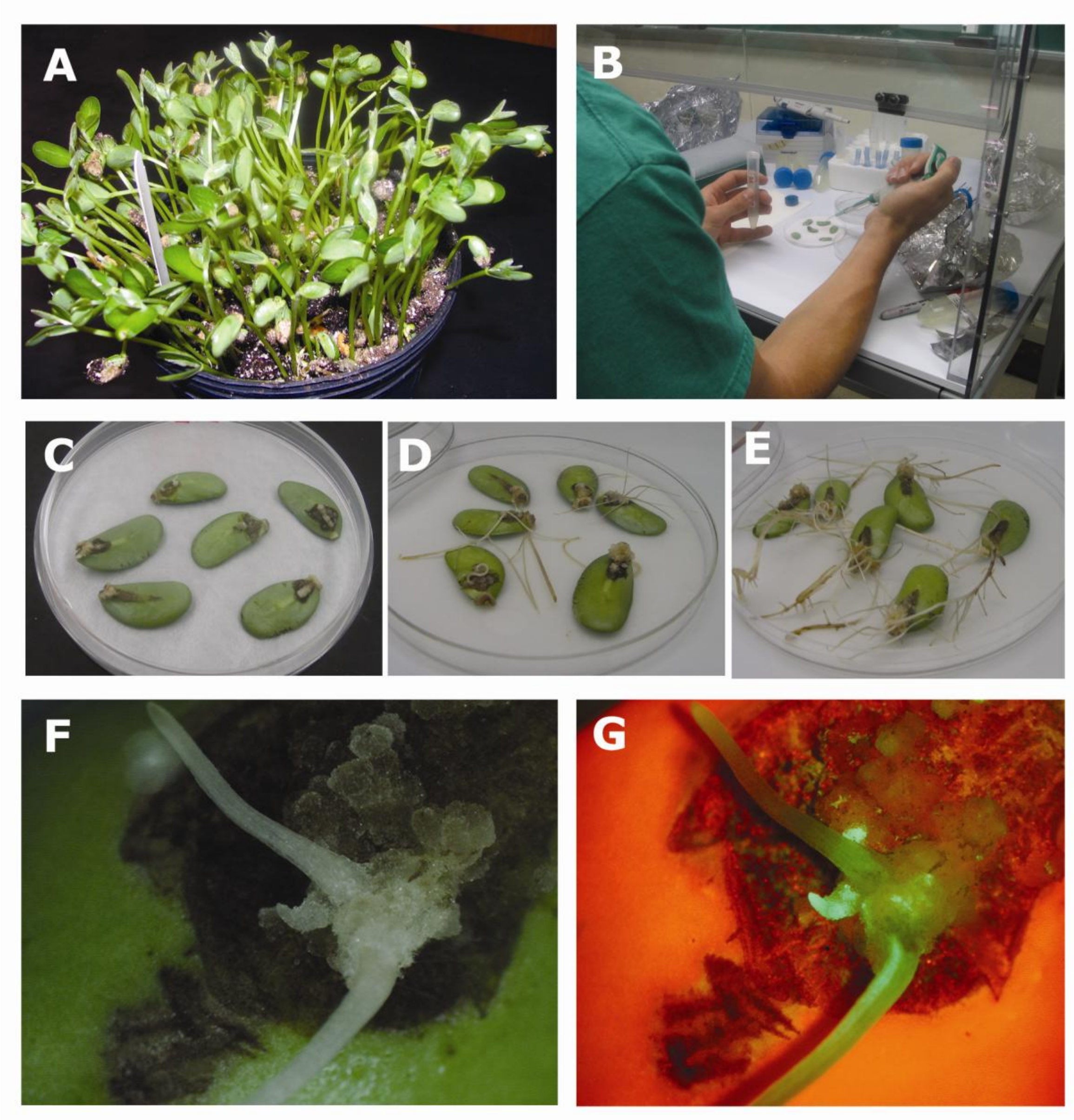
After his discharge in 1946, Laddie returned to school and earned a bachelor of science degree in biology from Wayne State College. He began his teaching career at Dodge High School. He continued his education and earned a Master of Science degree from the University of Nebraska-Lincoln and a doctorate in science education from the University of Minnesota.

Laddie was a professor of biology at the University of Nebraska at Kearney from 1962 until his retirement in 1989. He served as dean of the graduate school for nine of those years.

He married Iris Kauffold in 1951 and they had three sons and two daughters. He read widely and loved to travel. He inspired a number of his students and family to become teachers, as well.

Memorials are suggested to the University of Nebraska Foundation for the Laddie and Iris Bicak Scholarship fund at the University of Nebraska at Kearney.

Figure 1. from Keyes et al. (see page 9 for complete legend)



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