Biomedical Research Experiences for Biology Majors at a Small College

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***Abstract*:** A program-level assessment of the biology curriculum at a small liberal arts college validates a previous study demonstrating success in achieving learning outcomes related to content knowledge and communication skills. Furthermore, research opportunities have been provided to complement pedagogical strategies and give students a more complete science education.

***Keywords*:** Program-level assessment, content knowledge, primary literature, communication skills, undergraduate research

Introduction

Davis & Elkins College (D&E) is a private, four-year, comprehensive liberal arts college that stresses small class sizes and strong faculty-student interaction. The Department of Biology and Environmental Science offers a curriculum designed to promote science as a process of inquiry and instill within students an appreciation of the underlying unity and diversity of life. To meet the needs of students with diverse career interests, three degree options are offered: the Bachelor of Science (B.S.) in Biology, the Bachelor of Science in Environmental Science, and the Bachelor of Arts (B.A.) in Biology and Environmental Science.

In 2004, we published a program-level assessment of the B.S. in Biology degree (Stover and Mabry, 2004). We focused on student competence in the five areas outlined by our 2001 departmental assessment plan: 1) content knowledge, 2) writing skills, 3) speaking skills, 4) ability to interpret primary literature, and 5) research skills (laboratory and/or field).

As we indicated in the previous study, the interpretation of biological data requires a specific knowledge base. To comprehend and integrate information from different areas of biological inquiry, students should be familiar with fundamental concepts associated with each area, including the molecular basis of heredity, cell structure and function, biological evolution, and the interdependence of organisms. Furthermore, communication skills are essential for biologists as they generate data, share their findings, and build on the work of others. Successful communication depends on both the ability to effectively convey information (written and oral) and the ability to interpret and evaluate information presented by peers (Feldman *et al*., 2001). Analyzing primary literature allows students to enhance their critical thinking skills as they participate in the dissemination of scientific information (Houde, 2000; Smith, 2001). Finally, to fully understand and appreciate the scientific process, biology students should be engaged in hands-on, investigative activities (Glasson and McKenzie, 1998; Lewis *et al*., 2003).

In addition to math, physics, and chemistry requirements, biology majors at D&E must take five core content courses. Principles of Biology I (BIOL 101) introduces first-semester biology majors to cell structure and function, genetics, and developmental biology, while Principles of Biology II (BIOL 102) is taken in the second semester and deals primarily with the ecology and evolution of organisms. Genetics (BIOL 205) is a survey of prokaryotic and eukaryotic inheritance; Cell and Molecular Biology (BIOL 302) investigates metabolism, gene expression, and differentiation of eukaryotic cells; Evolution (BIOL 305) emphasizes the evidence, mechanisms, and genetics of organic evolution.

All D&E students are required to take the *College Basic Academic Subjects Examination* (C-BASE; Assessment Resource Center, University of Missouri) prior to graduation. As indicated by the departmental assessment plan, biology majors are expected to score "medium" or "high" on the *Fundamental Concepts of Life Science* component of the C-BASE. This component of the exam assesses knowledge of basic biology, botany, zoology, and ecology. Scores are reported by the Assessment

Resource Center as low, medium, or high based on students' success in answering biology-related questions. Although the exam is used primarily to evaluate the college's general education curriculum, results of the life science section complement course grades as an external, standardized measure of biology majors' basic content knowledge.

With the exception of BIOL 305, all core courses require written laboratory reports (BIOL 305 requires a term paper). Biology majors are introduced to laboratory reports in BIOL 101, allowed to hone their skills in BIOL 102, and expected to demonstrate competence in scientific writing by scoring between 80 and 100% on all reports required for BIOL 205 and 302. Figure 1 provides a sample laboratory report format.

BIOL 302 – Cell & Molecular Biology

Abstract (8 points)
Briefly summarize the report. Include basic aspects of each section in the summary. Start with an introductory sentence or two to describe the underlying question. In a few sentences, describe the experiments you performed to address the question. What were your results and how do they compare with information you found in the literature?

Introduction (20 points)
The introduction should consist of general background information. Basic concepts associated with the topic should be covered, but you should not discuss the actual experiments you performed. Reference all material you obtain from outside sources in the body of the text (author, date).

Methods (8 points)
Write out, in complete sentences, the procedures that you followed to perform each experiment.

Results (12 points)
Write out the result of each individual experiment. Include graphs and/or tables, as well as text, to present your data. Do not interpret data in this section; simply present your findings.

Discussion (40 points)
This is the most important section. In the discussion, you should attempt to interpret the data you have collected. Analyze the result of each experiment individually. How do these results compare to information found in the literature? Does the literature support or contradict your results? Offer potential reasons for conflicting results. Suggest alternative or follow-up procedures to further analyze the question. Reference any information you find to help explain your results.

Miscellaneous (12 points)
Lab reports should be written in paragraph form (double-spaced). Check spelling and grammar. Each section should have its own heading. You must reference all information you obtain from outside sources and include an alphabetical "literature cited" section at the end of the report. Items in the literature cited section should contain the following information: Author(s). Year of Publication. Title of Article. *Title of Journal* Volume: Page Numbers.

Figure 1. Laboratory Report Format for BIOL 302.

To fulfill departmental requirements, biology majors must complete Current Topics in Biology (BIOL 335), a one-credit course that involves the analysis and discussion of current research articles. As described in the 2004 study, students in BIOL 335 carefully analyze recent journal articles, which are given to them one week prior to an in-class discussion. Students and a faculty facilitator then discuss the paper and compare notes. The goal is for students to become comfortable with graphical representations of data and the interpretation of experimental results. The instructor usually selects articles with a common theme. Figure 2 contains instructions for analyzing journal articles, while Figure 3 provides citations of representative articles.

BIOL 335 – Current Topics in Biology

1. Citation
Include authors' names, year of publication, title of article, name of journal, volume of journal, first & last pages of article.

Example:
Cunningham, P., Geary, M., Harper, R., Pendleton, A., and Stover, S. 2005. High intensity sprint training reduces lipid peroxidation in fast-twitch skeletal muscle. *Journal of Exercise Physiology Online* 8(6): 18-25.

2. Research question
What biological question does this research address? What was known & unknown prior to this research? This information is generally found in the Introduction of the paper.

3. Hypothesis
A hypothesis is a statement of explanation to a question concerning some biological phenomenon. A hypothesis may not be clearly stated. You may have to infer what the hypothesis is, based on the procedures being used to address the research question.

4. Prediction
An "If…, then…" statement. If the hypothesis stated in step 3 is correct, then we would expect certain things to be true. The experiments conducted should test these predictions, leading to data that either supports or refutes the overall hypothesis.

5. Experimental approach
What, specifically, was measured or determined? Summarize the approach in your own words.

6. Results
What new information was produced? Summarize the results in your own words.

7. Conclusion
What do the authors make of the data? Are their conclusions valid? Is there any other possible interpretation? Do the data support the hypotheses? Are there any alternative hypotheses?

8. Now what?
A good paper may generate more questions than it answers. After reading this paper, what is the next question these authors (or other researchers in this field) should address?

Figure 2. Instructions for Analyzing Journal Articles (based on an instrument created by Dr. Catherine Gardiner, University of Northern Colorado).

BIOL 335 – Current Topics in Biology

Diet and Exercise
Halberg, N. *et al*. 2005. Effect of intermittent fasting and refeeding on insulin action in healthy men. *Journal of Applied Physiology* 99: 2128-2136.

Williams, N.I. *et al*. 2001. Longitudinal changes in reproductive hormones and menstrual cyclicity in cynomolgus monkeys during strenuous exercise training: Abrupt transition to exercise-induced amenorrhea. *Endocrinology* 142: 2381-2389.

Alternative Medicine
Schwartz, E. *et al*. 2002. Oral administration of freshly expressed juice of *Echinacea purpurea* herbs fail to stimulate the nonspecific immune response in healthy young men: Results of a double-blind, placebo-controlled crossover study. *Journal of Immunotherapy* 25(5): 413-420.

Solomon, P.R. *et al*. 2002. Ginkgo for memory enhancement: A randomized controlled trial. *Journal of the American Medical Association* 288: 835-840.

Sexual Reproduction
Mabry, M. and P. Verrell. 2003. All are one and one is all: Sexual uniformity among widely separated populations of the North American seal salamander, *Desmognathus monticola*. *Biological Journal of the Linnean Society* 78: 1-10.

Mack, P.D. *et al*. 2002. Sperm competitive ability and genetic relatedness in *Drosophila melanogaster*: Similarity breeds contempt. *Evolution* 56(9): 1789-1795.

Figure 3. Representative Journal Articles for BIOL 335.

To demonstrate an ability to communicate information related to biological research, biology majors are also required to participate in Senior Seminar (BIOL 397). Satisfactory completion of BIOL 397 involves oral presentations of research data. Students select scientific journal articles of interest to them, use the skills acquired in BIOL 335 to analyze the articles, and present the data (using Microsoft PowerPoint) to their peers and a faculty facilitator. Figure 4 shows the presentation analysis form utilized by the course instructor.

BIOL 397 - Senior Seminar

Student ______________________________

	Poor	Acceptable	Good	Excellent
Content				
Research Question:	1	2	3	4
Overall Hypothesis:	1	2	3	4
Prediction:	1	2	3	4
Methods:	1	2	3	4
Results:	1	2	3	4
Conclusion:	1	2	3	4
Personal Interpretation:	1	2	3	4
Follow-up Studies:	1	2	3	4
Presentation Style				
Eye Contact:	1	2	3	4
Articulation/Volume:	1	2	3	4
Movement/Interaction:	1	2	3	4
Fielding Questions:	1	2	3	4

Score _____

Figure 4. Presentation Analysis Form for BIOL 397.

Finally, biology majors are expected to demonstrate competence in basic biological research methods associated with laboratory components of the five core content courses. See Figure 5 for an example of a laboratory skills checklist.

BIOL 205 - Genetics

Student _______________________________

Biology majors must demonstrate competency in the following areas:

1. Basic statistics

- Probability _____
- Chi-square test _____

2. Laboratory techniques

- Slide staining/light microscopy _____
- Use of micropipette _____
- Restriction enzyme digestion of DNA _____
- Gel electrophoresis _____
- Culture maintenance _____
- Bacterial transformation _____

3. Experimental protocols

- Testing hypotheses _____
- Interpreting results _____

Figure 5. Laboratory Skills Checklist for BIOL 205.

The 2004 study tracked the progress of the five biology majors who completed each of the core content courses, the C-BASE, BIOL 335, and BIOL 397. All five students scored "medium" or "high" on the *Fundamental Concepts of Life Science* component of the C-BASE, scored 80% or higher on all laboratory reports in BIOL 205 and 302, successfully completed both Current Topics and Senior Seminar, and demonstrated competence in all core course laboratory skills.

We found that the greatest weakness of the assessment plan was the evaluation of research skills. Participating in laboratory exercises may reinforce biological concepts, and students may pick up some valuable skills in the process. Ultimately, however, students must be actively involved in scientific research to fully understand it. In the 2004 paper, we outlined a plan to implement and expand experimental systems developed as part of *Research Link 2000*, a project initiated by the National Science Foundation's Council for Undergraduate Research to provide convenient model systems for undergraduate teaching and research. We hoped that the experimental systems would facilitate the introduction of research-based laboratory activities into the undergraduate curriculum.

Unfortunately, budgetary constraints and a lack of release time prevented implementation of the proposed plan. However, we were able to capitalize on another opportunity. D&E was recruited to participate in the West Virginia IDeA Network of Biomedical Research Excellence (WV-INBRE). The WV-INBRE is a consortium of institutions of higher education in West Virginia, organized under the direction of the Marshall University School of Medicine (MUSOM) and the West Virginia University Health Sciences Center (WVUHSC). The consortium is funded through the National Institutes of Health (NIH) to develop biomedical research programs at the state's predominantly undergraduate institutions (PUIs) and to stimulate student interest in graduate training in the biomedical sciences. WV-INBRE provides equipment grants and pilot research grants to investigators at PUIs to fund undergraduate research. Furthermore, students at PUIs have the opportunity to work in biomedical research laboratories during the summer, under the direction of mentors at MUSOM and WVUHSC.

In the current study, we reassess the content knowledge, communication skills, and research experiences of our B.S. in Biology graduates, five years after the original assessment.

Methods

We tracked the progress of the 10 students in the B.S. Biology program (from 2005 to 2009) who completed the five core content courses, the C-BASE, BIOL 335, and BIOL 397. Student competence was evaluated according to criteria outlined in the 2001 departmental assessment plan. Five of the students participated in WV-INBRE-sponsored undergraduate research on the D&E

campus or as a summer intern at MUSOM or WVUHSC (Figure 6). Two of the five participated in research both at D&E and as summer interns at WVUHSC. One of the five interned at WVUHSC for two consecutive summers. Research projects spanned various biomedical disciplines, including cell biology, immunology, neuroscience, physiology, and toxicology. Research on the D&E campus required students to spend approximately nine hours per week in the laboratory, for a total of 24 weeks, during the school year. Summer interns worked, on average, about eight hours per day, five days per week, for a total of nine weeks. Students participating in research were given up to four credit hours of BIOL 390 (Undergraduate Research in Biology) and were required to orally present the results of their work in a public forum.

Figure 6. A D&E student at work in a toxicology lab at MUSOM.

Results

All 10 students scored "medium" or "high" on the *Fundamental Concepts of Life Science* component of the C-BASE (since 2005, just under 60% of non-science majors at D&E have scored "medium" or "high" on this component of the exam), scored 80% or higher on all laboratory reports in BIOL 205 and 302, successfully completed Current Topics and Senior Seminar, and demonstrated competence in all laboratory skills associated with core courses. All 10 students graduated with the B.S. degree in Biology. All five research participants put in the required workload and presented their data, first in poster format at a WV-INBRE research symposium (Figure 7), then as an oral presentation, either as part of D&E's annual Biology and Environmental Science Forum, or as part of the Chi Beta Phi (a national science honorary) National Conference. Of the five research participants, two went to medical school, and three entered graduate programs (in biotechnology, exercise physiology, and neuroscience). Of the five students who did not participate in undergraduate research, one is completing a graduate degree in sports medicine, one has graduated from optometry school, one is currently in pharmacy school, one has a hospital administrative position (she was a double major in biology and business), and one is working as a veterinary technician and is planning to apply to veterinary school.

Figure 7. A D&E student participating in a WV-INBRE research symposium.

Discussion

In many ways, a small liberal arts college can provide the ideal setting for learning science. Classes are generally small, and active learning is often encouraged. Previous studies have demonstrated that a small group dynamic (even in a large enrollment class) can improve student learning and performance in the science classroom (Tessier, 2007). Furthermore, class discussions can be utilized to stimulate critical thinking (Stover and Mabry, 2005), and case studies can be employed to address students' prior knowledge (Gallucci, 2006) and train them to develop experimental procedures (Dinan, 2005). Finally, it is sometimes possible to integrate the lecture and laboratory sections of a science course. Recent research has demonstrated that this "seamless" classroom experience can have a positive influence on both conceptual understanding and academic achievement (Burrowes and Nazario, 2008). The Department of Biology and Environmental Science at D&E has been able to incorporate all these pedagogical strategies into the curriculum.

Hands-on, independent research, as indicated by previous studies, allows students to hone the skills necessary to do science (in both laboratory and field), nurture a deeper appreciation of science, and sample scientific research as a career choice (Lopatto, 2004; Seymour *et al*., 2004; Clerkin, 2007). However, while it is always encouraged, actual scientific research may not be emphasized (or even possible) at a small liberal arts college. WV-INBRE has made it possible for some biology students at D&E to experience the best of both worlds: the informal, student-centered environment of the small liberal arts college and the high tech, hands-on environment of the biomedical research laboratory. While individual research experiences were certainly unique, each student who completed the 9-week internship and presented data was given a "pass" grade for BIOL 390. Presentations varied in terms of quality. Some students presented their "piece" of the research puzzle, while others attempted to explain the "big picture." However, they all had an experience that could not have been provided without the WV-INBRE grant.

It should be noted that the biology curriculum at D&E is quite rigorous (as it is at other institutions). Students who survive the gauntlet of biology, chemistry, and physics courses are, in general, very good students. Our placement of students in graduate and professional programs is consistently between 85 and 90%. However, personal communications from representatives at various graduate and professional programs suggest that research experiences can dramatically improve an applicant's chances of being accepted. Students interested in attending graduate programs in the sciences, in particular, can strengthen their applications significantly by participating in undergraduate research. Previous studies have suggested that students participating in undergraduate research have a higher likelihood of pursuing advanced study and, ultimately, a career in research (Nagda *et al*. 1998; Bauer and Bennett 2003).

We are still not completely satisfied with the B.S. in Biology program. Because the WV-INBRE internships are competitive, we cannot guarantee a research experience for every biology student. Furthermore, not every biology student is interested in doing biomedical research. We recently obtained funding to support a few undergraduate research projects in the ecological and environmental sciences, and we will continue to provide our students with as many opportunities for experiential learning as possible. Although we still have a long way to go, our ultimate goal is to provide an independent research experience for every student in the program to complement the active learning environment we provide in the classroom.

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