

# The Five-Tool Biology Major

**Shawn K. Stover & Michelle L. Mabry**

Department of Biology and Environmental Science

Davis & Elkins College

100 Campus Drive

Elkins, WV 26241

Email: stovers@davisandelkins.edu, mabrym@davisandelkins.edu

**Abstract:** Program-level assessment of the biology curriculum at a small liberal arts college indicates progress in the development of communication skills and content knowledge. The authors propose a mechanism to provide more research opportunities for students, giving them all the tools necessary to do science.

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

## INTRODUCTION

The New York Yankees' Alex Rodriguez is a five-tool player. The 10-year veteran has produced 44 home runs and 22 stolen bases per year, along with career batting and fielding averages of .308 and .977, respectively. Rodriguez also has a strong arm, averaging 360 assists per year from the shortstop position (statistics courtesy of [www.baseball-reference.com](http://www.baseball-reference.com)).

For the record, the five tools of baseball are: 1) hitting for average, 2) hitting for power, 3) running speed, 4) arm strength, and 5) fielding ability. Five-tool players may not lead the league in every statistical category every year, but they are the best all-around players in the game. They routinely produce key hits, timely stolen bases, and spectacular defensive plays.

A good scientist must also develop five critical tools: 1) content knowledge, 2) research skills (laboratory and/or field), 3) an ability to interpret primary literature, 4) writing skills (for grant proposals and manuscripts), and 5) speaking skills (for communicating with peers and the general public).

The interpretation of biological data requires a specific knowledge base. To understand and integrate information from different areas of biological inquiry, students should be familiar with fundamental concepts associated with each area, including cell structure and function, the molecular basis of heredity, biological evolution, and the interdependence of organisms.

Learning science means doing science. To fully understand and appreciate the scientific process, biology students should be engaged in hands-on, investigative activities (McNeil and D'Avanzo, 1997; Glasson and McKenzie, 1998; Lewis *et al.*, 2003).

Communicative 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). Reading primary literature allows students to enhance their critical thinking skills as they participate in the dissemination of scientific information (Fortner, 1999; Houde, 2000; Smith, 2001).

Davis & Elkins College (D&E) is a private, four-year liberal arts college that stresses small class size 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 to 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: Bachelor of Science (B.S.) in Biology, Bachelor of Science in Environmental Science, and Bachelor of Arts (B.A.) in Biology and Environmental Science. The current study represents a program-level assessment of the B.S. in Biology

degree. Specific criteria are used to assess development of each of the five scientific tools.

## ASSESSMENT METHODS

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. To demonstrate an understanding of basic biological concepts, biology majors are expected to score “medium” or “high” on the *Fundamental Concepts of Life Science* component of the C-BASE.

Biology majors are also expected to demonstrate competency in basic biological research methods associated with laboratory components of the five core content courses. See Figure 1 for an example of a laboratory skills checklist.

**Figure 1.** Laboratory Skills Checklist

<b>BIOL 205 - Genetics</b>	
Student _____	
<b>Biology majors must demonstrate competency in the following areas:</b>	
<b>1. Basic statistics</b>	
• Probability	_____
• Chi-square test	_____
<b>2. Laboratory techniques</b>	
• Slide staining/light microscopy	_____
• Use of micropipette	_____
• Restriction enzyme digestion of DNA	_____
• Gel electrophoresis	_____
• Culture maintenance	_____
• Bacterial transformation	_____
<b>3. Experimental protocols</b>	
• Testing hypotheses	_____
• Interpreting results	_____
<b>4. Laboratory report</b>	
• Format	_____
• Content	_____
• References	_____
• Writing style	_____

With the exception of BIOL 305, all core courses require written laboratory reports. Figure 2 provides a sample laboratory report format. Biology majors are expected to demonstrate scientific writing skills by scoring between 80 and 100% on all reports required for BIOL 205 and 302.

To fulfill departmental requirements, biology majors must complete *Current Topics in Biology* (BIOL 340), a course that involves the analysis and discussion of current research articles. The instructor usually selects articles with a common theme. Figure 3

contains instructions for analyzing journal articles; whereas, Figure 4 provides citations of representative articles.

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 requires oral presentations of research data. Figure 5 shows the presentation analysis form utilized by the course instructor.

**Figure 2. Lab Report Format**

<p><b>BIOL 302 – Cell &amp; Molecular Biology</b></p> <p><b>ABSTRACT</b> (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?</p> <p><b>INTRODUCTION</b> (20 points) The introduction should consist of general background information. Basic concepts associated with the topic should be covered, but you should <u>not</u> discuss the actual experiments you performed. Reference all material you obtain from outside sources in the body of the text (author, date).</p> <p><b>METHODS</b> (8 points) Write out, in complete sentences, the procedures that you followed to perform each experiment.</p> <p><b>RESULTS</b> (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.</p> <p><b>DISCUSSION</b> (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.</p> <p><b>MISCELLANEOUS</b> (12 points) Lab reports should be written out in paragraph form (double-spaced). Check spelling and grammar. Each section should have its own heading. You must reference <u>all</u> 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.</p>
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## RESULTS

The Department of Biology & Environmental Science instituted its current assessment plan in the fall of 2001. The present study tracked the progress of the five biology majors who completed each of the core content courses, the C-BASE, BIOL 340, and BIOL 397 by the spring of 2004.

All five students scored “medium” or “high” on the *Fundamental Concepts of Life Science* component of the C-BASE, demonstrated competency in all core

course laboratory skills, scored 80% or higher on all laboratory reports in BIOL 205 and 302, and successfully completed both the Current Topics course and the Senior Seminar.

All five students graduated with the B.S. degree in Biology. Two have taken entry-level jobs in forestry and fire management, two have been accepted into graduate programs in biology, and one will be attending medical school.

*Figure 3. Instructions for Analyzing Journal Articles*

### **BIOL 340 – Current Topics in Biology**

#### **1. CITATION**

Include authors' names, year, title of article, name of journal (may be abbreviated), volume of journal, first & last pages of article.

Example: Perrault S.D., R.R. Barbee, and V.L. Slott. 1988. Importance of glutathione in the acquisition and maintenance of sperm nuclear decondensing activity in maturing hamster oocytes. *Dev Biol* 125: 181-186.

#### **2. GAP IN KNOWLEDGE**

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. OVERALL HYPOTHESIS**

A hypothesis, in this case, is a statement of explanation to a question concerning some biological phenomenon. An overall 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 predictions to be correct. The experiments conducted should test these predictions and, therefore, lead to support for or against 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 4. Representative Articles**

**DIET & EXERCISE**

Hanninen, O. *et al.* 2000. Antioxidants in vegan diet and rheumatic disorders. *Toxicology* 155: 45-53.

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 5. Presentation Analysis.**

**BIOL 397 - Senior Seminar**

Student \_\_\_\_\_

	Poor	Acceptable	Good	Excellent
<b>Content</b>				
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
<b>Presentation Style</b>				
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 _____				

## DISCUSSION

In many cases, outcomes such as course completion and letter grades are insufficient to describe the specific knowledge and skills obtained by college graduates (Brakke and Brown, 2002). A program-level assessment helps ensure that all graduates of a particular department or program will obtain acceptable levels of skill and knowledge (Gilbert and Mason, 2004).

The C-BASE is a criterion-referenced academic achievement examination that evaluates competency in English, mathematics, science, and social studies ([www.arc.missouri.edu/collegebase](http://www.arc.missouri.edu/collegebase)). The test assesses basic knowledge in each of the four subject areas and provides performance rankings of interpretive, strategic, and adaptive reasoning abilities. The *Fundamental Concepts of Life Science* component of the exam assesses knowledge of basic biology, botany, zoology, and ecology. Although the exam is used primarily to evaluate the college's general education curriculum, results of the life science section effectively complement course grades as an assessment of biology majors' basic content knowledge.

Biology majors are introduced to scientific writing during their first semester at D&E. In BIOL 101, students write two laboratory reports, each preceded by a rough draft. The instructor thoroughly critiques the rough drafts to highlight flaws in format, grammar, and content. Writing skills are often undeveloped in freshman students (many are taking English composition simultaneously), and most are unfamiliar with the standard format required for laboratory reports. However, by the time biology majors complete BIOL 102, they are expected to have acquired the necessary skills to produce a thorough, well written laboratory report. In BIOL 205 and 302, they are expected to score at least 80% on every report.

Students are often intimidated by primary literature. They are unfamiliar with the technical jargon and are uncomfortable dealing with figures, tables and statistics (Smith, 2001). In BIOL 340, biology majors utilize a standardized analysis tool (Figure 3) to dissect journal articles, which are given to them one week prior to an in-class discussion. Armed with the results of their analyses, students (and a faculty facilitator) 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. Although students are apprehensive initially, they become quite adept at analyzing articles by the end of the semester.

Senior biology majors participate in BIOL 397. Presently, students select journal articles of interest to them, use the skills acquired in BIOL 340 to analyze the articles, and present the data (using Microsoft PowerPoint) to their peers. Presentations get progressively better as students become more comfortable with the process.

The greatest weakness of the current assessment plan is the evaluation of research skills. Participating in laboratory exercises may reinforce biological concepts, and students may pick up some valuable skills in the process; however, students must be actively involved in scientific research to fully understand it.

## FUTURE DEVELOPMENTS

In 2002, the department received funding to purchase modern equipment for cell and molecular biology labs. The instrumentation has enhanced the curriculum considerably and has allowed several students to undertake independent research projects in areas such as exercise physiology and toxicology. To give students an opportunity to expand their interests in other areas of inquiry, funding was recently obtained to purchase a new walk-in environmental chamber. The chamber will be an asset in all organism-based courses and will significantly increase research opportunities for students. Individuals interested in animal behavior, botany, or ecology will benefit from the new instrumentation by gaining experience in the design and implementation of long-term experimental protocols in a controlled environment.

In the near future, the department will implement and expand experimental systems developed as part of *Research Link 2000* ([www.cur.org/reslink2000.html](http://www.cur.org/reslink2000.html)), a project initiated by the National Science Foundation's Council for Undergraduate Research to provide convenient model systems for undergraduate teaching and research. These experimental systems will facilitate the introduction of research-based laboratory activities into the undergraduate curriculum. For example, the parasitic wasp *Nasonia* is much easier to handle than the fruit fly *Drosophila* and exhibits visible mutations and molecular markers useful for teaching genetic principles such as linkage and epistasis. Furthermore, three closely related species of *Nasonia* exhibit behavioral and morphological differences, allowing demonstration of evolutionary principles such as reproductive isolation, speciation, and adaptation. Stable environmental conditions for long-term *Nasonia* projects will optimize experimental results for students in genetics, evolution, and animal behavior courses. To facilitate study of plant biology, a specially derived strain of the tropical fern *Ceratopteris richardii* (C-Fern) will be utilized. Extended observations of the C-Fern sporophyte phase will be carried out under stable environmental conditions, allowing assessment of the long-term impact of temperature, humidity, and photoperiod on plant growth and viability. Additionally, ecology students will be exposed to a unique algal-invertebrate symbiosis through study of the sea anemone *Aiptasia pallida*. This experimental system will be used to demonstrate potential longitudinal effects of variables such as age, size, nutrition, and environmental stress on a symbiotic

relationship. By participating in supervised laboratory procedures associated with these courses, students will become familiar with experimental design and data collection techniques. Moreover, they will be able to follow up their course-based laboratory experiences with long-term independent research projects using any of the above *Research Link 2000* model systems. Ultimately, BIOL 397 will become a forum for sharing the results of independent research with other members of the department.

## CONCLUSION

Small class size is integral to the personalized undergraduate education offered at D&E. The authors recognize that the interactive learning environment associated with small groups may have contributed to the favorable assessment results.

We will continue to collect annual assessment data to validate the current study. While acknowledging the small sample size utilized for program assessment, we are encouraged by the preliminary results. When the integrated research component of the plan is in place, we are confident that D&E biology graduates will have all five tools necessary to produce key breakthroughs in the laboratory, timely discoveries in the field, and spectacular discussions in the classroom.

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## REFERENCES

- Brakke, D.F. and D.T. Brown. 2002. Assessment to improve student learning. *New Directions in Higher Education* 119: 119-122.
- Feldman, S., V. Anderson, and L. Mangurian. 2001. Teaching effective science writing. *Journal of College Science Teaching* 30(7): 446-449.
- Fortner, R.W. 1999. Using cooperative learning to introduce undergraduates to professional literature. *Journal of College Science Teaching* 28(4): 261-265.
- Gilbert, S.W. and C.L. Mason. 2004. A time for change: Program-level performance assessment. *Journal of College Science Teaching* 33(5): 5-9.
- Glasson, G.E. and W.L. McKenzie. 1998. Investigative learning in undergraduate freshman biology laboratories. *Journal of College Science Teaching* 27(3): 189-193.
- Houde, A. 2000. Student symposia on primary research articles. *Journal of College Science Teaching* 30(3): 184-187.
- McNeil, A.P. and C. D'Avanzo, eds. 1997. *Student-Active Science*. Fort Worth: Saunders College Publishing.
- Lewis, S.E., L.K. Conley, and C.J. Horst. 2003. Structuring research opportunities for all biology majors. *Bioscene* 29(2): 9-14.
- Smith, G.R. 2001. Guided literature explorations: Introducing students to the primary literature. *Journal of College Science Teaching* 30(7): 465-469.
- [www.arc.missouri.edu/collegebase/text1.html](http://www.arc.missouri.edu/collegebase/text1.html). Accessed March 18, 2004.
- [www.baseball-reference.com/r/rodrial01.shtml](http://www.baseball-reference.com/r/rodrial01.shtml). Accessed March 8, 2004.
- [www.cur.org/reslink2000.html](http://www.cur.org/reslink2000.html). Accessed March 30, 2004.

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