Structuring Research Opportunities for All Biology Majors

Susan E. Lewis, Lisa K. Conley, and Cynthia J. Horst
Department of Biology, Carroll College
100 North East Avenue, Waukesha, WI 53186
Phone: (262) 524-7279; FAX: (262) 524-7112
E-Mail: lewiss@cc.edu

ABSTRACT: Several years ago the Biology Department at Carroll College instituted a required research experience for all Biology majors. The research program consists of a three-semester series of courses that help students plan and carry out a research project of their own design. The research program gives students an opportunity to apply what they have learned in their coursework to a project in which they have strong interest, and builds skills in organization, time management, and personal responsibility. During the first semester of the program students are guided through the process of identifying and planning their project as they write a research proposal. During the second semester, students gather the necessary equipment, learn the appropriate techniques, and complete a pilot study. During the final semester, they complete the research, write a final report and present a poster at the annual science symposium held on campus. This program has recently expanded to include students majoring in Chemistry. Here, is discussed the successes and challenges of coordinating a program that involves 20 to 40 research projects each year.

KEY WORDS: Undergraduate Research, Mentoring, Curriculum Design

INTRODUCTION
Science education reform, at its roots, is a process designed to improve student learning. At the 1998 American Association of Higher Education Conference on Institutional Change, participants defined learning as a process that culminates in the ability: to ask the right questions and frame good problems, to acquire information and evaluate sources of information, to critically investigate and solve problems, to make choices among many alternatives, to explain concepts to others (both verbally and in writing), and to generalize to new situations (Ganter and Kinder, 2000).

Clearly, that level of learning requires more than a simple lecture approach to teaching. A key foundation of science education reform holds that learning is enhanced and students more fully understand the process of scientific research when they have opportunities for hands-on investigation. Students majoring in science, in particular, benefit from authentic research experiences. Various authors indicate that students more fully engage in learning when they participate in inquiry-driven investigations as compared to traditional “cookbook” labs (Project Kaleidoscope, 1991; Jarmul, 1996; National Research Council, 1996). In particular, the personal ownership of learning in student-designed investigations can increase retention of content significantly (Clark et al., 2000). Further, the investigations build skills in measurement, observation, writing, oral communication, and critical thinking that are transferable to all disciplines (National Research Council, 1996).

For the most talented of our students, authentic research experiences can come from participation in summer research programs, such as those funded by the National Science Foundation’s Research Experience for Undergraduates (REU) program. Competition for such programs is intense, however, and many students are constrained, for various reasons, from participating in them. Faculty members will also recruit their most talented students as research assistants in the faculty member’s own laboratory. However, providing opportunities for every student to participate in research is much more challenging.

The Biology Department at Carroll College has encouraged students to design and carry out independent research for over two decades. Because it was felt the skills developed in this experience were essential for all biologists, a research project was made mandatory for all majors in 1997. In 2000, the
Department of Chemistry and Biochemistry joined the research program and now an interdisciplinary Scientific Problem Solving program is offered that provides opportunities for Biology, Biochemistry, and Chemistry majors to design and carry out their own research. In this paper, the structure of that program is described, preliminary assessment data on the effectiveness of the program is presented, and methods to overcome various obstacles to successful implementation of the program are discussed.

INSTITUTIONAL BACKGROUND

Carroll College is a primarily undergraduate, comprehensive college with 2000 full-time students. Most Carroll students are female (67%), and many (40%) are the first in their family to attend college. The College has two 14-week semesters per year, with most students taking four 4-credit courses each semester. The Science Division offers degrees in Biology, Chemistry, Biochemistry, Forensic Science, Psychology, Computer Science, Environmental Science, and Geography. Carroll also has a strong Health Science Department, with programs in Exercise Science, Nursing, Athletic Training, and an entry-level Master’s degree program in Physical Therapy. Currently, students from two departments participate in the research capstone sequence: Biology with 20 – 35 majors per year (6 full-time faculty) and Chemistry/Biochemistry with 5 – 10 majors per year (4 full-time faculty). A relatively small percentage (5 to 10%) of these students will go on to graduate-level research after Carroll. Faculty members in both departments participate in mentoring research students and share in teaching the three seminar courses.

Carroll College is one of the many colleges and universities that doesn’t have a grand endowment or cutting-edge facilities. Carroll is a tuition-driven institution with an endowment of approximately $32 million. The science facilities are dated and space is very tight. Equipment holdings vary from excellent to ancient, depending on how recently a grant was received to support the acquisition of new equipment. On the other hand, students have access to everything that is here. In short, the research program is supported by whatever resources are available. It is hoped that this model will thus be useful to other institutions working under similar constraints.

DESCRIPTION OF THE PROGRAM

The core of the research program is a series of 2-credit seminars, typically taken by students in the spring of their junior year and both semesters of their senior year. The student learning objectives for the research sequence are outlined in Box 1. During each of the three semesters, the seminars meet for two hours per week. One hour is devoted to instruction or discussion pertaining to the design and implementation of research or the transition from college to post-graduate careers/education. In the second hour, students either meet with their faculty mentors to discuss their research or they attend a science seminar in which local graduate students or professionals present results or applications of scientific research. The focus of the three semesters is described in more detail below.

Box 1: Student learning outcomes for the capstone research sequence.

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

1. Demonstrate competency in the fundamentals of scientific inquiry, including:
   a. formulating a testable hypothesis
   b. designing experiments that test this hypothesis and yield meaningful data
   c. collecting and analyzing data
   d. interpreting data within the context of current knowledge in the field
   e. being able to define ethical practice in research and demonstrate ethical behaviors

2. Demonstrate the ability to independently:
   a. identify a problem
   b. suggest possible solutions
   c. apply most appropriate solution and evaluate outcome
   d. ask for help when needed

3. Demonstrate competency in searching for, reading, and critically evaluating scientific literature

4. Demonstrate effective time management

5. Provide evidence of growth in skills related to communicating scientific information both orally and in writing.
Semester 1 – Introduction to Problem Solving:
The first semester of the research sequence is focused on designing the research project the student will complete the following year. The objectives of the course are the development of the student’s ability to:

- formulate a scientific question and develop an appropriate research protocol,
- conduct library research for pertinent literature,
- develop an awareness of ethical issues involved with scientific research,
- formally present scientific information in both oral and written formats, and
- critique oral and written presentations of scientific information.

During the semester, students review principles and practices of scientific investigations, reinforce their library search strategies, design a research project, write a formal research proposal, and practice oral presentation skills. They also have an opportunity to discuss ethics in research through simulated ethical case studies. Students use two textbooks to support their work in this and subsequent courses: *Handbook of Biological Investigation* (Ambrose, H.W. III and K.P. Ambrose. Hunter Textbooks Inc., Knoxville TN, 1995) and *How to Write and Publish a Scientific Paper* (Day, R.A. Oryx–Press, Phoenix, AZ, 1994).

Students choose their own projects in consultation with a faculty mentor. Although the mentor helps the student design the research, students are not required to work on a project directly related to the mentor’s area of research expertise. This is based on the belief that students will be more committed to a project of their own design, even though the scientific rigor of such a project may be lower than one prescribed by the mentor. Students have an opportunity to indicate with which faculty member they would like to work, but typically no mentor works with more than four students. For this reason, faculty mentors sometimes work with students whose research area differs substantially from their own area of expertise. Student projects cover a diverse array of topics and levels of complexity, as evidenced by the sample project titles in Box 2.

The faculty mentor and the course instructors work with students throughout the project development process to ensure that the project will be workable with the resources available at the college. Students are encouraged to seek external collaborations if their interests cannot be accommodated on campus. Typically, four to six students complete their work in summer REU programs, and a few others work at the Medical College of Wisconsin, the Veterans’ Affairs hospital, or at other sites where they have both an on-site and a campus mentor. On-campus collaborations are also encouraged as necessary – particularly with members of the Mathematics Department who provide statistical consultations throughout the research process.

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<tr>
<th>Box 2: Sample Project Titles</th>
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<tr>
<td>The Effects of Estrogen on the Skeletal Muscle Tensile Strength of Gastrocnemius in Male and Female Rats</td>
</tr>
<tr>
<td>Homerange Size in Juvenile Piping Plovers (<em>Charadrius melodus</em>) from Hatching Until Natal Site Dispersal</td>
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<tr>
<td><em>Cmu1</em>, a Mutant <em>Chlamydomonas reinhardtii</em>: Characterization of Microtubules</td>
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<tr>
<td>Diversity of Aquatic Insects in Deep Marshes in Southeastern Wisconsin</td>
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<tr>
<td>The Effect of a GHRH Infusion on the Ovaries of Female Rats</td>
</tr>
<tr>
<td>Distribution and Quantification of Mononuclear Lymphoid Cells in the Northern Leopard Frog, <em>Rana pikiens</em></td>
</tr>
<tr>
<td>Correlations Between Aggressive and Courtship Behavior in Two Species of African Cichlids</td>
</tr>
<tr>
<td>Social Interactions of an Orphaned Juvenile Bonobo at the Milwaukee County Zoo</td>
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<tr>
<td>Primary Observation of the Characteristics and Morphology of Hemocytes Isolated from <em>Tenebrio molitor</em>.</td>
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<td>The Effects of Steam Autoclave Sterilization and Gas Sterilization on Four Types of Suture Materials: Silk, Cat Gut, Vetafil, and Vicryl</td>
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<tr>
<td>Effect of Long- and Short-day Photoperiod on Respiratory Rate and Escape Reflex Velocity on Brook Sticklebacks</td>
</tr>
<tr>
<td>A Taxonomic Survey of the Water Molds at the Greene Field Station of Carroll College</td>
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<td>Developmental Color Preference Changes in <em>Rana pikiens</em></td>
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**Semester 2 – Problem Solving I:** The second semester of the research sequence focuses on pulling together the skills, equipment, and supplies necessary to carry out the research. Students are expected to carry out a pilot study of their project (if appropriate), and some begin data collection during this semester. Students also refine oral presentation skills as they present a progress update to their peers. Because the research sequence is designed to aid students in the transition from college to future educational or career opportunities, time is devoted in this course to helping students compose a resume and practice effective job interviewing skills. The campus career center collaborates on this aspect of the course.

As the course title suggests, students are expected to work on problem solving skills, and to demonstrate effective time management as they learn to set priorities and work independently. In both the second and third semesters, students are required to develop a grade contract and time line for their research at the beginning of the semester. In the contract, they specify research objectives for the term, weight those objectives, and develop grading criteria against which they will be evaluated. This places the responsibility for effective time management on the students and they are held accountable with both a mid-semester and an end-of-semester progress report. Time management is often one of the most difficult obstacles for the students in the second semester, because the final “goal” is less well defined than that of the first semester (the proposal) or the third semester (the poster and final paper). The grade contract and progress reports have helped students significantly in this regard, as do the biweekly lab meetings with the mentors.

**Semester 3 – Problem Solving II:** In this course, students complete their research project. As part of the third semester course, students are expected to demonstrate proficiency in data collection and interpretation and select appropriate figures and tables for summarizing their results. In addition to a formal written report of their work, students present the results of their research in a science poster symposium held late in the semester. Posters are displayed in the science building throughout the day, with a reception in late afternoon. Students, faculty members, and administrators from around the campus are encouraged to attend. Members of the department’s Advisory Council are invited to evaluate posters as part of the department’s program assessment efforts. During this semester, many of the weekly meetings are structured like a typical graduate-level journal club, in which students participate in critical discussion of scientific literature. The journal articles they discuss are recommended by the guest speaker who will speak during the second hour of class.

In cases where students have participated in an NSF REU program (or equivalent), the students still participate in (and receive credit for) the Problem Solving seminars the following year. Because REU opportunities tend to be very rushed, students use the seminars to revise and improve upon their literature review, data analysis and written report, as well as to develop the ancillary skills stressed in the seminars (e.g., resume writing, etc.).

**ASSESSMENT DATA**

The formal assessment program for the research capstone sequence currently consists of a questionnaire survey asking students to evaluate their progress relevant to the student learning outcomes for the research series, and a focus group interview conducted by a member of the College’s Assessment Committee at the conclusion of the third semester. Data from the course surveys indicate that students feel they have grown substantially in the areas related to the outcomes and that they are satisfied with their research experience. Sample data obtained from the April 2000 survey of students in the final course (n=16) are provided in table 1.

In the focus groups, some students complain about the “unpredictable nature” of research and report dissatisfaction with difficulties encountered. However, most students state that they have learned and grown from such experiences. Most comments support the results obtained from the questionnaire above; namely, that students have learned a great deal in the research series and they feel that they will be better prepared for jobs in the sciences. Students have also made suggestions on how to improve the series, many of which have been incorporated over the years.

In addition to the formal assessment data, anecdotal evidence supports the view that the research program strengthens the educational experience of those students involved. In unsolicited letters, our graduates have stated that their experience in the research series has been invaluable. Alumni have donated money to the College specifically to support future students in the research sequence. Also, students in Biology have been extremely successful at receiving external grants for research and very active in presenting their research at professional meetings. In 2000-01, Carroll students received almost ten percent (5 of 57) of all research grants awarded by Beta Beta Beta, the National Biological Honor Society, to support undergraduate research. In the past five years, 11 of 37 students presenting research at scientific meetings received awards.

The experience of the Science Division faculty also indicates clear value to the research capstone sequence. Seven years ago, student research projects conducted in the sciences at Carroll College were often poorly defined, ineffectively executed, or not completed. Since the restructuring of the program six years ago, a definite improvement in the student research experience has been noted. The quality of the projects has increased and nearly all current students...
complete their research on time. There has been clear growth in student independence and time management. Perhaps most importantly, there has been significant improvement in student problem-solving skills and in their self-confidence as researchers.

Continued assessment and evaluation of the research program, focused on ways to improve student learning, has identified deficiencies in our respective core courses. Thus, review of student performance in this research capstone is fast becoming a valuable means of assessing the success of our programs as a whole.

Table 1: Sample assessment data for the research capstone experience. The assessment statement and the % of students responding “more true than false” or “definitely true” are shown.

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<th>Statement Provided</th>
<th>% in agreement</th>
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<tr>
<td>I feel that I am able to clearly formulate and state a research question supported by appropriate literature.</td>
<td>100</td>
</tr>
<tr>
<td>I feel confident that if asked to construct the research design and provide an outline of the appropriate methodology (supported by the literature) for a project in the future that I would be successful.</td>
<td>94</td>
</tr>
<tr>
<td>As a result of my research experience, I am better quipped to execute an experiment and to effectively collect data.</td>
<td>94</td>
</tr>
<tr>
<td>As a result of my research experience, I am better able to analyze data and interpret results.</td>
<td>88</td>
</tr>
<tr>
<td>As a result of my research experience, I am better able to set priorities and to manage my time.</td>
<td>82</td>
</tr>
<tr>
<td>By the end of the course sequence, I feel that I demonstrated the ability to work independently.</td>
<td>100</td>
</tr>
<tr>
<td>Overall, I feel that this course sequence provided a worthwhile experience.</td>
<td>94</td>
</tr>
<tr>
<td>I feel that the knowledge and experiences obtained from the research program will be useful in my chosen career path.</td>
<td>75</td>
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PROGRAM LOGISTICS

What are the implications with respect to faculty load? A full time course load for faculty in the laboratory sciences is four courses per year (non-laboratory science faculty teach six courses per year). Three or four of these courses have labs. Participation in the capstone (as a mentor or seminar instructor) occurs in addition to this course load. A faculty member will mentor from one to four (occasionally more) students each year. Responsibility for teaching the three-semester seminar sequence rotates among departmental faculty. One pair of faculty members will “progress” through the 3-semester sequence with the same group of students. In the year following this teaching responsibility, that pair is responsible for coordinating the speakers in the bi-weekly seminars, and for organizing the spring science symposium. Their responsibilities then return to only mentoring students until their turn in the rotation comes up again.

The number of students working with any given faculty mentor varies, but an attempt is made to keep it less than four. Because many of the students are interested in the health sciences, faculty members with research interests in those areas tend to be requested more often as mentors. Similarly, because whole-organism projects such as behavioral studies at the local zoo may seem more accessible to students than projects with, for example, a molecular focus, faculty members interested in mentoring behavioral or ecological projects are frequently requested. Students are allowed to work with a mentor from either department, and such cross-disciplinary collaborations are relatively frequent.

How are student research projects funded? Students are strongly encouraged to apply for external funding for their research. They have been particularly successful in receiving grants from Beta Beta Beta, the National Biological Honor Society. Limited funding
comes from departmental budgets and gifts from alumni. Occasionally, and of their own volition, students cover some of the costs. Because funding is limited, students receive significant mentoring in the initial stages of project planning to ensure that their research plans are cost-effective and appropriate with the resources available.

What are the implications regarding research space? Space is one of the major constraints. The science facilities do not have dedicated space for undergraduate research. If appropriate, students work in the small-animal room or in the greenhouse. More often, students set up their research in a corner of a teaching laboratory. Occasionally, even more creativity is required, and projects may be conducted in storerooms, basement mechanical rooms, or in student apartments if such space is appropriate and safe for the planned research. As mentioned above, several students complete their research over the summer, often in conjunction with an NSF REU program, which decreases the need for laboratory space on campus.

Conclusions

The undergraduate research program in the sciences at Carroll College has evolved from one with little structure and student accountability to one that is showing significant signs of success in enhancing the learning experience of the students. The three-semester format gives students the time and support they need to develop a well-reasoned and viable project. Students conclude the process with a strong understanding and appreciation of the nature of scientific research that will be of value regardless of whether or not they pursue careers in scientific research. Moreover, the skills students develop in problem solving, critical thinking, time management, and oral and written communication will be transferable to any career. Finally, many students develop a much greater confidence in their own abilities as researchers, problem-solvers, writers, and speakers as a result of successfully completing their research project.

The program is also important in that it has pushed us to identify the specific attributes desirable in the development of our graduates. That effort has led to the evaluation and modification of the research seminar. In addition, it has led to the reform of earlier courses in the departmental core curriculum as specific weaknesses in the preparation of the students entering the research sequence are identified and addressed. For example, in Biology, it was found that students entering the research seminar sequence were not comfortable with the process of formulating concrete research questions and testable hypotheses. This led to evaluation of how such skills are established in our freshmen and sophomore courses and refinement of the methods to accomplish this.

The interdisciplinary nature of the program is unique. Although still in its early stages, it is anticipated that both students and faculty will benefit from the shared sense of community and purpose that the research program reinforces. For the students, the interdisciplinary model reinforces the integration of science and encourages them to broaden their perspectives on research.

LITERATURE CITED