

Initiating Partnerships in Scientific Discovery at a Two-Year College via the Introductory Curriculum

Retention of students in science, technology, engineering, and mathematics (STEM) fields is influenced by their experiences in early stages of their education, including opportunities to interact closely with faculty members and participate in faculty research (Daempfle, 2003-2004; Packard, 2004-2005). Indeed, the best time to start undergraduate students in research is during their first and second years of college. A two-year-college setting is an ideal environment for such partnerships in discovery with students. At the same time, partnering with students in research is especially challenging at a two-year college.

Lack of time, inexperience of students, and limited resources are the main obstacles. Heavy teaching loads restrict faculty members' time, and fulfilling required coursework limits students' time. Understandably, first- and second-year students have limited or no prior experience of working in a research laboratory and require more hands-on mentoring. At a two-year college, faculty members cannot rely on post-doctoral associates, graduate students, or even upper-level undergraduates to train entering students. In addition, designated laboratory space for research is usually unavailable, and funding for research is scarce.

We face the very same challenges of time, training, and resources at our institution, Oxford College, a two-year division of Emory University located 40 miles away from the main campus. However, we have been successful in overcoming some aspects of these challenges in the last few years through restructuring our introductory-biology curriculum. Together with my colleagues, I have designed and implemented an introductory-course model that incorporates scientific thinking and the practice of scientific discovery into the laboratory program itself. In our two-course introductory sequence, students are exposed to the process and rigor of research by participating in a faculty-research project as part of their curriculum.

The design of our introductory-course sequence provides a comfortable setting for mentoring students in independent thinking, laboratory techniques, searching scientific literature, data analysis, and scientific communication. This makes for efficient use of both faculty members' and students' time. It also gives the faculty members an opportunity to fulfill both

teaching and scholarship responsibilities and to share their scholarship with a larger group of students. Incorporating faculty research into the introductory curriculum provides leverage for acquiring institutional support to improve teaching-laboratory resources. Teaching laboratories can then become the environment for conducting undergraduate research as well.

The model described in this article has had a visible impact on students at Oxford College. Use of this model at other institutions could initiate various partnerships with undergraduate students in their first and second years. Our introductory-biology curriculum utilizes a sequential approach because these "beginner" students learn best through progressive building of knowledge and experience.

Phase I: Getting Their Feet Wet

The introductory-biology curriculum for majors at Oxford College is a sequence of two courses. The first course (Phase I) covers essential concepts in cell biology, genetics, evolution, and biodiversity, and the second course (Phase II) extends further into genetics and molecular biology. Students have different levels of prior experience in biology when they enroll in the first course. It is not ideal to thrust these students immediately into a faculty-research project in their first semester. Students must have sufficient shorter experiences with research to develop their foundational skills in scientific thinking.

In our first course, we use the laboratory manual *Investigating Biology* (Morgan, Carter, 2008), which provides guidance for designing student investigations, appropriately tests student understanding, and includes an appendix on scientific writing. Students are introduced to the process of scientific discovery through multiple short investigative exercises at the beginning of the course. For example, students investigate the osmolarity of potato tissue using weight or volume as measurement parameters. These exercises teach students how to design appropriate questions for scientific investigation, develop testable hypotheses, and predict expected results based on the experimental design. While conducting the short investigations, students also learn about writing scientific manuscripts in a stepwise manner. For the osmolarity experiment, the

written assignment might be to produce the “results” section of a scientific manuscript. Details about our scientific-writing program and our collaboration with our library are described in Jacob and Heisel (2008).

In the second half of the first course, students form a peer-research team to develop a short independent project, which typically extends from a laboratory exercise in the laboratory manual. One exercise is investigating the rate of cellular respiration in mitochondria, particularly the succinate to fumarate reaction in the Krebs cycle. First, students conduct a general investigation to determine the effect of succinate concentration on the rate of the reaction. Then each team designs a unique investigation to extend from this study. The instructor provides many suggestions and guidelines for this project. Below are two examples of projects proposed by individual teams:

- Will sugar substitutes like Splenda® and Sweet’N Low™ act as effective substrates for the reaction?
- How does the inhibitor antimycin affect the rate of reaction?

This brief independent experience allows students to apply knowledge and skills from previous short investigations to a more extended research project. Students are also required to present their research findings as a complete study, in both oral and written form (Jacob, Heisel, 2008). Upon completion of the first course (Phase I) students should have the foundational skills to:

- design scientific questions and construct logical, testable hypotheses
- understand experimental design and conduct basic laboratory procedures
- select appropriate literature resources for scientific thinking and communication
- communicate science orally and in written form as expected in a research environment

In the first course (Phase I), students gain a strong framework to prepare them for the second course (Phase II) in which they partner with a faculty member on his or her scholarship.



Oxford College freshmen at the time, Urania Dagalakis and Helen Hill, collect field samples at Arabia Mountain, Lithonia, Georgia, for their semester-long research project in the second course of the introductory curriculum.

Phase II: Entering the World of Research

Research in the introductory laboratory typically involves short independent laboratory investigations extending from a structured laboratory exercise within a semester, similar to our approach in the first course (Luckie, Maleszewski, Loznak, Krha, 2004; Wyatt, 2005). In our curriculum we use the short-unit model for the first course so students are prepared for a more advanced approach in the second course. Our second course covers higher-level topics in genetics and molecular biology, and the laboratory matches the level of thinking expected at this stage. The laboratory program in the second course (Phase II) is designed to provide students with a more authentic experience with research, given that they are now prepared for more independent scientific thinking. The laboratory incorporates research that a faculty member is pursuing for his or her own scholarship. Student teams independently design original investigations that contribute to the broader questions of the faculty member’s research. This model is practiced in some upper-level courses but rarely in introductory courses.

The research incorporated into our second course is the topic I am pursuing for my own scholarship—exploring the microbial-community ecology of rock outcrops in the Georgia Piedmont using the techniques of molecular biology. Rock outcrops are a distinct feature of the local Georgia landscape, and there is currently no published data on the microbial communities

that survive this harsh habitat. Microbial ecology is now at the forefront of biological discovery (Ash, Foley, Pennisi, 2008). Student-research teams independently design questions for investigation that connect to this project. They also plan how and where to collect bacteria in the field, analyze data, and organize the presentation of their data as they see fit. However, all research groups use the same pre-determined set of laboratory protocols, rather than designing their own experimental approach for testing their hypothesis.

There are several reasons why each student-research team should follow the same laboratory procedures. The size of introductory classes is typically larger than upper-level courses. Weekly laboratory preparation for these courses requires more planning time and expense. The instructor would need to spend extended time with the students to determine methodology feasible for each project. If the class follows the same set of laboratory protocols, students can learn from each other during their laboratory work. Therefore, students will be more knowledgeable, allowing them to engage in a livelier discussion and critical analysis of each other's investigations.

The organization of the laboratory for a 15-week semester with 13 weeks of laboratory is as follows:

- Weeks 1 and 2: Introduction to molecular-biology techniques via a short investigation
- Week 3: Development of a research question and hypothesis
- Week 4: Sample-collection in the field
- Weeks 5-9: Laboratory procedures and data collection
- Week 10: Learning data-analysis methodology
- Week 11: Analysis of recorded data
- Weeks 12: Preparation of group presentation
- Week 13: Symposium on research projects

I use the first two weeks of the semester to introduce students to some basic techniques that are useful for their research project later. Students learn the principles and techniques of DNA extraction, PCR, gel electrophoresis, and gel analysis through a short investigation on human genetic markers. At this time students also write a short scientific manuscript to convey their results, so that their work can be reviewed in the areas of scientific writing, critical analysis, and incorporation of appropriate literature (Jacob, Heisel, 2008). By the third week of the semester, students form small research teams of three

or four individuals who work together for the remainder of the semester. The laboratory period in the third week is devoted to ways to design investigations. Prior to this laboratory, student teams read background information on the faculty-research project via the course's Blackboard Web site and prepare a few ideas about possible investigation questions. During the laboratory period, each research team refines its ideas to formulate an investigation question and a hypothesis. The rationale for the investigation and hypothesis must be based on information gathered from existing scientific literature. The instructor and librarians are available to help students navigate effectively through literature databases (Jacob and Heisel, 2008). At the end of the laboratory period, each team submits a mini-proposal presenting its research question, hypothesis, an explanation of the rationale citing the relevant references, and a short description of how the hypothesis will be tested. Here are two examples of investigations proposed by student research teams in my course:

- *Question:* Is the level of microbial diversity in vernal pools on the rock outcrop affected by microinvertebrates found in the same water? *Hypothesis:* Fewer types of bacteria will be found in vernal pools because microinvertebrates in the water affect bacteria populations. *Rationale:* Protozoan grazing impacts bacteria communities and affects species levels (Carlough, Meyer, 1990; Hahn, Hofle, 2001).
- *Question:* Are there differences in bacteria collected at various soil depths from an outcrop plant community? *Hypothesis:* There is a more diverse community of bacteria closer to the soil surface compared to greater depths. *Rationale:* Microbial communities decrease with soil depth due to the role of microbes in soil processes (Fierer, Schimel, Holden, 2003; Grueter, Schmid, Brandl, 2006)

The instructor plays no part in designing the investigations except to guide students in finding suitable resources, considering the feasibility of their question, and determining if the pre-determined laboratory protocols are appropriate for testing the hypothesis. During the following weeks, student teams collect samples in the field, conduct laboratory procedures, record data, and perform analyses. Each student keeps a research notebook to document observations and analysis. At the end of the semester, student teams present their research findings as a group in a class research symposium. Each student independently writes a complete scientific manuscript with supporting literature for critical analysis. The expected out-

comes from the second course, in which students go through the sequential steps of research, are that students have well developed skills to:

- independently design scientific questions and construct logical hypotheses
- understand the importance of existing knowledge in developing an investigation
- carry out laboratory procedures systematically
- be very resourceful in finding suitable references to support scientific thinking and communication
- be independent in thinking and develop good instincts for analysis
- write a convincing scientific manuscript and orally communicate an investigation according to professional standards
- engage and interact in scientific dialogue

From the faculty perspective, Phase II prepares students for independent research through an economical use of faculty members' time. Since the laboratory connects to faculty scholarship, equipment and supplies can be shared between teaching and research activities. Projects proposed by students contribute new ideas for faculty research.

Phase III: Independent Research

Several projects proposed by students and carried out during the course can be refined into longer-term independent research projects. After completing the introductory curriculum, students can think independently and make a full contribution to a project. I have continued several projects with my research students that were originally proposed by them or by other students in the second course. Most recently, a student team in the spring 2008 course discovered a rare bacterium found only in one other location, in Florida. This study will be further pursued by a sophomore undergraduate research student. Since students have already been introduced to scientific communication, they are also prepared to be co-authors on papers or professional presentations. Segueing students into research through coursework also allows for more continuity in a two-year college environment. A faculty member can get well acquainted with students as they complete the introductory-course sequence as freshmen. He or she can select suitable candidates from this group to continue as an independent-study student in the following summer or in

their second year. Sophomores who enroll in the course could also continue a project with the faculty member during the following summer.

Success of This Model

We have had significant success with this restructuring of our introductory curriculum. Direct measurement of our expected outcomes showed high retention of information-literacy skills from the first course to the second course (Jacob and Heisel, 2008). Although compilation of data is still in progress, I have also observed a higher degree of professionalism in student work in the second course than was previously the case, measured by the extent of information and critical analysis reported in their oral presentations and papers. Many students have continued in research projects with me or with other faculty members in the sciences. Since we launched this curriculum at Oxford College, all of my undergraduate-research scholars have begun with the introductory sequence, and they have been my most productive students. Two students who completed the introductory sequence and partnered with me in research presented their work at the annual meeting of the Association of Southeastern Biologists (ASB) in April 2008. Others have presented their work to the Oxford College community.

For several semesters I have also surveyed students at the end of the second course (Phase II). Approximately 100 surveys were compiled, and the students' responses were similar. When asked about their overall laboratory experience, 80 percent of the students indicated that they enjoyed the laboratory portion of the second course. About 48 percent of the students indicated that they had had a strong interest in research prior to the course, and 19 percent indicated little to no interest in research. However, 76 percent of the students indicated that they had a strong interest in research after the course. The results were similar when students were asked if the laboratory experience increased their interest in the field of molecular biology. When asked if the laboratory prepared them for independent research, 70 percent of the students felt well prepared, while 14 percent indicated that they felt somewhat prepared and 16 percent felt that it made no difference. Finally, 84 percent indicated that the first course in the sequence was very important to their success in the second course. Some examples of student comments:



In the laboratory, Oxford College students Halima Garba and Kimberly Joseph extract genomic DNA of bacteria cultured from soil samples obtained from their rock-outcrop collection.

- “I thought the idea of basing the entire lab experience around one large experiment with smaller parts was a great way for us to learn a little more closely what a real lab works like.”
- “I think the research project was especially helpful in helping me to learn what makes for a good topic for research.”
- “The process of writing a scientific paper helped a lot by the fact that we had already written a full paper in [the first course]. I also liked the ‘real lab’ experience of a continuing focus. It helped me to fully understand reasons for research.”

Adapting the Model for Your Institution:

The model described above is independent of discipline and type of institution. It would be appropriate for any introductory curriculum that includes a two-course sequence. A critical consideration is to intentionally plan and teach the first course so as to lay the groundwork for the second course. For the success of Phase II, our suggested model of short investigations in the first semester, coupled with scientific-communication opportunities, is a necessary foundation. Students in the first course should be given some preview of the second course, either through a visual display of student projects on a bulletin board or by instructors’ talking about the second course in class. To sustain this model, faculty members who teach various sections of the introductory curriculum must communicate with each other to coordinate and share teaching objectives. Development of the laboratory portion of the second course takes some advance planning and requires faculty members to:

1. *Select an appropriate faculty project for the introductory curriculum.* Examine the current resources at your institution to select a project that could be integrated into the curriculum with few difficulties. The project should be suitable for modification and simplification if necessary. Consider if students will be able to design independent research questions to connect to the overall project.

2. *Consider the fit of the project into a structured schedule.* Plan the outline for the laboratory schedule simultaneously with selection of the broad project topic. Select appropriate laboratory protocols to test a variety of hypotheses that will also fit into the learning objectives of the overall course.

3. *Involve students.* Testing the feasibility of the project and the available resources before launching the course can be an undergraduate-research project.

4. *Provide the type of support first- and second-year students need.* Establish sufficient support for progressive student learning during the process of research, such as clear guidelines, references, or handouts.

5. *Acquire new resources gradually.* Begin with the available resources and initially make small requests for additional resources to launch the first year of implementation. Evaluate the success of the first year and then report this to the administration to gain leverage to request more resources if necessary or to apply for external grants.

Conclusion

Establishing the right infrastructure for first- and second-year students to engage in scientific discovery leads to remarkable rewards at many levels.

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