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Animating a Biology Curriculum with Research

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Animating a Biology Curriculum With Research

As faculty in the biology department at The College of St. Catherine, a private liberal arts college for women, we are committed to graduating students well prepared in the practice as well as in the theory of biology. We are continuously evaluating our strategies for the teaching of scientific thinking and bench skills. We seek creative ways for students to construct their own understanding of the research process. With these goals in mind, we are moving from teacher-centered lectures to problem-based learning and are providing laboratory experiences that immerse students in the process by which scientific knowledge is acquired. To provide context for the value of science and research in daily life, we expect students in both our major and non-major courses to increase their awareness of the intersections of biology, ethics, and policy development. Because we work in an environment that explicitly supports women's pedagogy, curriculum transformation, and research, we are uniquely positioned to encourage active involvement of women in science and technology. However, because the methods we have implemented are the very methods that are most effective for adult learners in general (Knowles, 1998; Rogers, 1969), they should be readily applicable to coeducational undergraduate colleges and universities given adequate institutional support. We hope you find encouragement and insights in this article for your own efforts to enhance opportunities for students to experience the research process first-hand.

We encourage students to become immersed in research activities so they can gain understanding of the methods of scientific inquiry, explore their interests in and aptitude for research, and evaluate if graduate study is a good fit for them. In order to engage students in research early in their undergraduate education, we reinvigorated our introductory general biology courses over ten years ago, implementing a theme-based, investigative approach (Norton, et al, 1997). With support from an NSF Undergraduate Course and Curriculum Development Grant, we developed an experiential, hands-on approach to science for our beginning students. Working in the first semester with the theme of reproduction and in the second semester with plant interactions with the environment, teams of three to four

students initiate and design semester-long research projects. A variety of research organisms and basic lab equipment is made available to students so they can be creative in developing a project. Students are asked to find primary articles from the scientific literature and begin their maturation of skills in accessing, critically reading, and synthesizing scientific information from a variety of sources. Hypothesis generation supported by rationale gleaned from the literature is stressed. Beginning students also receive exposure to scientific writing. Research teams share their ideas with faculty mentors through preparation of research proposals that describe their question, hypothesis and associated rationale, and specific experiments. Also included in the proposal are descriptions (via data sheets) of what data will be collected and preliminary thoughts (via graphs or tables) on how data will be analyzed and presented. These projects are simple and investigate biological problems for which "right" answers may not be known. During the process, students pursue a question of interest to them while learning to collect data, graph and describe experimental results, apply

introductory statistical methods, increase computer proficiency, and present experimental results through poster or oral formats. Throughout this first year experience, faculty members serve as mentors. They review research proposals, function as "grant agencies" allocating funding for the projects, assist with experimental trouble-shooting, and act as facilitators for issues related to teamwork. Each laboratory section has two faculty mentors who extensively interact with students in small groups. The mentors also model the value of "putting heads together," demonstrate effective strategies for conflict resolution when they disagree, and share their own experiences and difficulties with the research process. These interactions set the stage for collaborative relationships between students and faculty (Rogers, 1969) as students move into the remaining courses of the biology curriculum.

While providing grounding in basic biological concepts, the general biology experience stimulates and reinforces student interest in research. During the second year of the biology curriculum, students learn several techniques in the laboratory component of the cell biol-



General biology research team members Dawn Valverde, Miranda Biegon, and Maria Robles collaborate on preparation of a paper describing the results of their student-designed project studying effects of nutrient deficiency on reproduction in *Drosophila melanogaster*.



St. Kate's ecology students Miranda Johnson, Carrie Booth, and Lorie Xiong collect stream macroinvertebrates to be identified as part of a comprehensive research project exploring how physical variables shape biotic communities in stream ecosystems. The investigation was driven by students' observations and ideas.

ogy and genetics courses. This fills a void students feel during the first year experience, where they have many ideas for projects but little skill at the bench or awareness of appropriate methodology. In cell biology and genetics, students are provided with lab exercises designed by faculty mentors and emphasis is placed on hands-on learning of techniques and on understanding why a protocol is used for a specific problem. Methods taught in the lab are tied as closely as possible to course topics. For example in cell biology, learning of membrane structure is accompanied by laboratory extraction of membrane lipids and analysis by thin layer chromatography. Understanding of protein structure is enhanced by SDS gel electrophoresis of proteins isolated by affinity chromatography. Concepts such as facilitation of protein folding by molecular chaperones are made more concrete by analysis of protein denaturation using spectrophotometry. Students

also acquire a sense of how the techniques they are learning are applied to research questions through weekly in-class analysis of faculty-selected scientific articles. To increase their competency in reading the scientific literature, they are taught approaches to deciphering methods sections, analyzing figures, and making their own interpretations of results. In the genetics course, students conduct a recombinant DNA project through which they learn techniques in analysis of DNA such as karyotyping, plasmid isolation, use of restriction enzymes, cell transformation, and gel electrophoresis. In the labs associated with both courses, students gain further experience with scientific writing as they prepare lab papers describing experiments and analyzing their results in the context of published research.

Students move into upper level courses selected from animal-, plant-, ecology and evolutionary-, and cellular and molecular-based options. In addition to becoming familiar with concepts and experimental methods characteristic of these biological sub-disciplines, students hone skills in quantitative reasoning, analysis and interpretation of data, consideration of contemporary world problems, and analysis of scientific articles. Laboratory formats are as diverse as the faculty teaching them—some consist primarily of pre-designed lab exercises. Others are a combination of structured lab exercises, computer simulations, and independent research projects where teams of students select a research question related to course concepts. Some of these projects require approval by the college's Institutional Review Board so students directly experience the importance of preparing thoughtful, detailed research proposals. In our majors' microbiology course, discussion topics and hands-on application of relevant laboratory techniques are integrated into the same, extended class period. Other courses focus on student-designed, original research projects that are directly related to the research interests of the faculty facilitating the course. In all of these formats, observational, methods development, and data analysis skills are refined. These teaching/learning activities have been backed by the college through hiring of a lab coordinator and additional faculty (with both teaching and postdoctoral experience and ability to establish viable undergraduate research programs), an increased supply budget, renovation of teaching and lab facilities, and by Instrumentation and Laboratory Improvement/Course and Curriculum Laboratory Improvement Grants from the National Science Foundation. These grants, matched by college funds, were used to equip a tissue culture facility, purchase basic equipment for the investigative general biology labs, and provide instrumentation for cellular and molecular analysis. Faculty interest and persistence in improving learning and research opportunities spur the grant writing—most of our state-of-the-art equipment has been procured in this way. Students can also acquire research experience through one-on-one work with faculty on original projects. In fact, a biology degree requirement is completion of either an internship or a research project. While about 80% pursue off-campus internships, other students talk to faculty to determine availability of research positions in faculty labs and fit of research interests. Students can choose from a range of research areas that currently include field biology investigations, behavioral and molecular approaches to studying invertebrates, and human-based research on handedness and the mechanics of limb movement. Along with specific research objectives, the projects are

guided by research contracts that identify student learning objectives and learning strategies. Student and faculty stipends, together with supply dollars, are available for these projects through Small Scale 3M Student/Faculty Collaborative Research Grants. These internal funds, from an endowment developed in 1988 with support from 3M Corporation, require submission of a grant proposal jointly prepared by the student and faculty mentor to the college's Center of Excellence for Women, Science, and Technology. The Center, established in 2000 as part of a strategic initiative at the college to collaborate with community partners, promotes women-centered, innovative teaching and learning in math, science and technology, develops strategies that enable girls' and women's pursuit of science and technology fields, and supports student-faculty collaborative research. A recent grant procured by the Center from 3M has quadrupled the level of support for each student/faculty project and covers student and research mentor participation in scientific conferences. With this increased funding, we anticipate that more students will opt for on-campus research experiences. Through these Large Scale Grants, the Center provides meaningful support to current research efforts and stimulates new research activities that will serve, it is hoped, as precursors to external funding opportunities. To give faculty comprehensive information and assistance in the grant-seeking process, an Office of Sponsored Research was established at the college in 2002. Made possible by an Extramural Associates Research Development Award from the National Institutes of Health, this office oversees both the pre- and post-award process such as budget development and facilitates grants workshops, grant preparation mentoring, and proposal review. Marking the impact of such institutional support are accomplishments of students involved in collaborative research projects. High wages alleviate students' need to supplement their income with outside jobs and they are able to focus on research activities. They have presented their work in our weekly Biology Seminar Series, at regional and national meetings, and have contributed to manuscripts being prepared for submission to peer-reviewed scientific journals.

Many of the students who are particularly interested in graduate studies also take advantage of the numerous summer undergraduate research programs sponsored by colleges and universities throughout the United States. Following their work at St. Kate's on projects with faculty, they use participation in these summer programs to get exposure to the environment of a major research institution, to interact with graduate students, and to explore potential areas of study.

A concern we have with these research options is the small number of students served by them. Individual faculty members have, at most,

the time and resources to work on projects with one to two students each year. For a variety of reasons that we intend to investigate and address, very few of our majors apply to the external summer research programs. Using the cellular and molecular-based courses as prototypes, we considered other means by which more students could be exposed to original research. Another motivating factor was feedback from students who have participated in summer undergraduate research programs at other institutions. Students were asked to evaluate these experiences in terms of their sense of preparedness and in comparison to their exposure to research at The College of St. Catherine. While they felt competent with the bench and literature analysis skills they brought to their summer programs, they came away with a sense of accomplishment for being involved in “real world research” that they had not gotten from their courses. Compared to the labs associated with their upper level biology courses, they found great satisfaction in working on projects that had meaning and purpose beyond the confines of their own learning. They seemed to convey that they learned more about experimental methods and design and thought more deeply about the meaning of experimental results when the goal of the project was relevant to a “real scientific laboratory” and contributed to the field. We felt challenged by this input. Our hold on a philosophy that our reasons for doing research at the college are different from those of major research institutions started to feel tenuous. Is it enough for our students that we view research as a form of teaching—that we maintain research programs so that they can learn the research process and explore their scientific potentials and interests in doing research (Hakim, 2000)? Might we better facilitate their learning by linking the curriculum more directly with lab activities that are pursued because they are original and have potential to benefit the scientific community?

Intrigued by these questions, innovations were made in the laboratory components of molecular biology and immunology. These courses were a natural fit as their in-class formats had recently been converted from faculty-centered lectures to student-centered learning initiated and stimulated through clinical scenarios, research problems, and case studies. Key features of this approach include group work, application of previously acquired knowledge, and students' identification of what they need to learn followed by out-of class learning. The goal is for students to construct their own understanding of concepts, with much teaching and learning from each other. The role of the faculty mentor is to provide resources (texts, websites, occasional mini-lectures giving context for cases), monitor group progress, ask questions, and direct groups towards key learning issues as necessary.

To extend this andragogical approach (Knowles, 1998) into the laboratory portion of these courses, a progression from learning advanced techniques to student-designed research projects is used. The first few weeks of the semester are spent learning relevant techniques, along with theory and history behind the technique. For example, in molecular biology students receive hands-on experience with PCR, DNA sequencing, informatics, and proteomics. In immunology, students do Western blotting, ELISA, immunofluorescence, and immunohistochemistry. The remainder of the semester is spent applying these techniques to research projects. What is unique compared to other courses is that the projects are directly related to the research interests of the course mentor. Working in teams, students read relevant scientific literature and generate a research question that addresses a small piece of an on-going faculty research project. Given student ownership of the research question, hypothesis, and experimental protocol, the role of the faculty mentor is to work with students to refine the projects so that they are doable and result in sufficient data that can be interpreted given the timeline of the semester and available equipment. To expose students to an emerging practice in scientific research where sophisticated and expensive equipment is required, some data collection using core facilities (such as the Imaging Center at the University of MN) is suggested. Rather than determining the week-to-week content of laboratory exercises, faculty mentors focus on student competencies and become familiar with students' approaches to thinking and can then facilitate improvement of critical thinking, support development of collaborative work, and encourage refined bench skills. For example, we have found that oral presentations are especially challenging for students. We need to help them become more proficient at synthesizing information and clearly conveying their learning to their colleagues. The format also provides for closer relationships with students than a cookbook approach. Student inquiries are more diverse and creative and this stimulates much more critical thinking and discussion during lab sessions. To further enhance the “real life” environment for these projects, students disseminate the results of their original research through poster presentations at the annual “Science at St. Kate's Day.”

The impact of these changes in the molecular biology and immunology courses include:

- Increased integration across our biology curriculum; students build on their general biology exposure to the research process and apply bench skills learned during the second year courses.
- Enhanced student confidence in their abilities to use scientific articles as tools. Rather than passively receiving protocols, stu-



Immunology students Jaci Tews, Pam Strobel, and Christine Michels review their experimental design as they use Western blotting to identify heat shock proteins in halophilic archaea. After completion of the course, Michels expanded the study into a research project where she has found expression of heat shock proteins homologous to TCP proteins.

dents access literature pertinent to their project and gradually make sense of it. Doing their lab work in the context of published information, they gain appreciation for the complexities of experimental design, develop critical modes of questioning, and take a more cautious approach to interpretation of experimental results.

- Learning of good practices in keeping lab notebooks and appreciation of their importance for refinement of experimental approaches and dissemination of results.
- Significant payoff in student learning and vitalization of faculty research for a monetary investment similar to that needed for traditional laboratory exercises. Students come up with questions and approaches that enrich faculty thinking and work enthusiastically on the projects. They see the projects as “real life research” and are excited by the potential of making original contributions to the scientific community. Progress is made on research questions during “teaching” hours, making it easier for faculty to sustain a year-round research program. This fosters a stronger research environment in the biology department while research skills and aptitudes are being developed in more students (Doyle, 2000).
- More student involvement in original projects with perked interest of some in further research. To date, both of the projects from these courses have evolved into follow-up collaborative work where a student brings her training and preliminary data from the course experience into faculty research labs. Here the potential for refinement of the projects into results that can be disseminated is being realized. A presentation on the molecular characterization of the extracellular hemoglobin from an aquatic oligochaete, begun in the 2005 molecular biology course and carried over to the research lab, will be made at the 2006 Annual Meeting of the Society for Integrative and Comparative Biology. A student who continued work

begun in the 2004 Immunology course on use of Western blotting for identification of heat shock proteins in a halophilic archaeon is preparing a manuscript describing her results for submission to a peer-reviewed journal.

- Professional value to the students with the research experiences and poster presentations strengthening their resumes and applications to professional and graduate programs.

Our view that research is integral to undergraduate education in biology is key to on-going changes in our biology classrooms and labs. As faculty, we are a cohesive team---we extensively share resources and discuss issues related to teaching, learning, and research. We encourage each other to try new pedagogical and learner-centered approaches, talk through and evaluate ideas for case studies and research problems, and share successes as we observe enhanced student learning. Of critical importance is the support we give each other in the difficult task of stepping back to let students think through concepts and problems for themselves (Rosenblatt, 1995). We are finding that self-directed learning and original research experiences generate a learning environment where students see themselves as active, responsible collaborators with faculty mentors. The skills our students develop in critical thinking, learning to learn, communication, and collaboration will carry-over to their graduate studies and professional careers. Because of the challenging and satisfying experiences they have had as undergraduate biology majors, they will be well prepared to pursue careers in science or science-related fields.

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