CUR Quarterly

CUR Focus

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Fueling a Future Beyond the Coal Mines

Career success for students in STEM (science, technology, engineering, and mathematics) fields rests on access to ample opportunities for educational research and training, facilitated by strong mentor-mentee relationships (National Research Council 2003). In the southern Appalachian area of Ohio, poverty, isolation, and some evidence of disdain for the sciences have combined to produce a population under-trained for America's changing workforce needs and at risk of falling further behind (Haaga 2004).

County-level 2008 data from the U.S. Census Bureau revealed that 27 percent of children under 18 in the region were impoverished, compared with state and national averages of 18 percent. Appalachian residents also have lower academic achievement levels than the national average. For example, in 2006 only 78 percent had graduated from high school, and while 30 percent matriculated at a college or university (compared to the national rate of 62 percent), only 7.9 percent eventually attained a baccalaureate degree (Harmon et al. 2003). Many science students have never used a microscope. In this socioeconomic climate, residents of the region who do enroll in college are in danger of failure—particularly in the sciences if they come from religious backgrounds that cause them to reject key biological concepts upon which many STEM fields are based.

The most effective way to engage students is to present real-world problems that can be solved using the tools of science (National Research Council 1999; Richardson 2008), which helps students understand that they are in a serious environment in which instructors and peers expect much of them. To develop an appreciation among Appalachian students for learning science, my institution, Ohio University Southern, has sought locally relevant, current topics for discovery-based investigation. Jeffery Greenlee of the Center for Appalachian Studies has noted that several studies have shown that Appalachian students succeed in school far better using hands-on pedagogies instead of being taught through theoretical, teacher-based approaches.

In 2009, a National Science Foundation CCLI (Course Curriculum and Laboratory Improvement) grant was awarded to Ohio University Southern (OUS) to improve opportunities in STEM education as part of NSF's effort to ensure that state-of-the-art equipment and learning opportunities are available to all students nationally.

One of the goals of the OUS biology department was to add a component of engagement, inquiry driven and/or research applications, to labs that could be student driven and seamlessly tie into the lecture topics throughout the year. We also wanted to develop in students a keen appreciation of the abundant benefits derived from gaining scientific knowledge throughout their lives, subsequent to college, whether they continued in STEM fields or branched off into other careers. Through using educational strategies designed to accommodate the region's unique history and perspectives on learning, we discovered a student population with remarkable work ethics and willingness to achieve.

Our starting point for more student engagement in science was defining a problem of significance to both biologists and students through course redesign. We began the course transition in introductory biology by identifying educational components with youth-friendly, civic-minded appeal. Biology instructors can find numerous examples of new technologies that offer society the potential for developing new sources of energy, improving health care, and driving global economies. But the majority of our students are more likely to grasp a context in which their own contribution mattered. Thus we felt that focusing on the industrial footprint and accumulation of chemical toxins in our region would encourage greater learning (Tripathi and Verma 2002; President's Cancer Council 2010). The new course syllabi for the three-quarter introductory course would include awareness of environmental sustainability issues, a community-centered project, and discovery-based problems central to the role and impact of environmental learning.

The First-Year Experience

Traditionally, first-year science majors at OUS were introduced to key concepts through a survey of the biological disciplines and "cookbook" lab experiences. Topics included the molecular basis of life, developmental biology, speciation, form and function, ecology and evolution. Regarding the broader context of the role of biologists in society, no real connections were drawn between lecture and lab activities.

The reformulated first-year experience was modeled on SENCER (Science Education for New Civic Engagement and Responsibility), a national education initiative that had been demonstrated to be successful with high school students (Popichak 2008). This model was deemed appropriate for our often underprepared college students. We prepared and challenged students for upper level biology courses throughout the first year. This was done by forming learning communities, which provided a collegial atmosphere to encourage and enhance the development of their own research projects. Students were expected, within their team projects to incorporate scientific proposal writing, experimental design, animal development, appropriate animal handling under federal guidelines, and collaborative research and data analysis.

One surprising outcome from implementing this format was the ease of its integration into the entry-level subject matter. We divided its components to fit within three quarters of study, although the components could be easily organized into two semesters.

The class, as a whole, became involved early in the first term by helping to choose an ongoing theme for the year. Students chose to study a problem potentially harmful to the community. We began with a literature review selected to examine the local effects of atrazine, the long-lived, European Union (EU) banned herbicide, atrazine on the sexual development of male amphibians. This topic was relatively simple to investigate in the field, and any findings could be correlated with their potential impacts on the community. We designated the project IDAP (Investigating Development in Amphibian Populations). Students were expected to understand the components of good research design and acquire the necessary background knowledge to perform a field study. These criteria were reinforced in the classroom over the academic year as IDAP was used to illustrate a number of topics under study.

Chris Cecil, science education major, searching for frogs and tadpoles in Symmes Creek.

The IDAP approach succeeded in enhancing students' critical thinking skills while students had to apply key biological concepts to basic investigative skills. Environmental awareness through sustainability issues was consistently discussed throughout the year as we critiqued media (news, research journals, and film) reports of risks to human populations from the increasing contaminants found in our water supply.

Details of the Revised Introductory Biology Course

During the first quarter of OUS's yearlong introductory biology curriculum, instructors are expected to introduce the role of the biologist, the chemical basis of life, energy cycling, and cell structure. During the first two weeks, students were assigned a data collection exercise which involved determining their own ecological footprints –based on required arable land usage to maintain their lifestyle as measured by six parameters of consumption–(Wackerngel et al. 2002). Team discussions yielded profound learning moments and new intellectual inquiry for civic engagement and environmental sustainability. Class discussions on scientific method and experimental design focused on controversial papers published at the end of the 20th century which warned of decreasing male sperm counts and altered secondary sex characteristics observed in animal populations (Carlsen et al. 1992). This was followed by reviews of current literature containing opposing research findings on atrazine, which is suspected of altering the reproductive development of amphibians when it enters the water supply (Hayes et al. 2002). Studies that were sponsored by industry versus those published by researchers in independent academic institutions (Dinan 2006) were scrutinized as faculty taught students the basis of experimental design, controls, and data collection.

Lectures on energy and hydrolytic cycling included examples in which animals might become exposed to toxic herbicides sprayed on plants. We measured our success in choosing relevant topics and increasing students' classroom engagement by noting avid student interest and discussion regarding government regulatory agencies, scientific research funding, and expressed concerns about the effects of chemicals in the water supply on human males.

In the laboratory component, hypothesis-driven research proposals were drafted that addressed the differences in experimental design and controls used in the various research papers on atrazine. We also included exercises in spectroscopy, population sampling, and statistical analysis because students would need the knowledge to perform their field study. During this first term, students independently discovered news media reports on major lawsuits that small Ohio cities filed against Syngenta, the manufacturer of atrazine. The cities claimed $350 million in costs to remove atrazine from their drinking water. Class members' awareness of environmental impacts was observed through their expanding discussions about the costs to communities of cleaning up chemical contaminants and about reports on health risks posed to humans by many other herbicides, pesticides and even medications carelessly disposed of (Suzawa et al. 2008).

We ended the term with two questions selected by students to address in their field study: Is Atrazine seeping into our local waterways? If it is present, are there correlations to developmental abnormalities in amphibians' reproductive systems? The student teams had demonstrated ownership of their project, but until they learned more about animal development and endocrine disruptors, they would be unable to perform the planned studies.

In the second quarter of our project, course topics primarily covered animal and plant form and function, life cycles, and developmental biology. Amphibians, especially the green bug-eyed Tree frog (our department's T-shirt mascot) became the stars of the lectures on these topics as we continued to relate lectures to IDAP. We covered anatomical structure, physiological processes, organ systems (notably endocrine and reproductive development), and metamorphosis. The first term had resulted in the class drafting two individual, but complementary research proposals, through their team's input, which focused on our two hypotheses (atrazine effects to amphibian abnormalities and water quality). These proposals were now expanded to include better methodology to help address the two questions we had initially selected and were approved as a collaborative field study to be performed during the third quarter in the spring. The ongoing process of experimental design necessitated gathering expertise from the academic staff, further student research, and faculty guidance on options available in terms of time, equipment, and feasibility.

In the laboratory, students were required to complete online training in animal handling and also needed to familiarize themselves with the regulatory processes needed to secure authorizations and permits for field research from Ohio University's Institutional Animal Care and Use Committee (IACUC) and the wildlife division of the Ohio Department of Natural Resources. The lab activities in the second quarter focused on gross anatomy. For IDAP, students were expected to identify structures in the normal frog that could show abnormalities from herbicide exposure during development.

The "frog team" foresaw the need to identify developmental defects in tadpoles and took the initiative to do more literature searches (Lenkowski et al. 2008). The "water team" researched methods to detect atrazine and practiced accurate pipetting and generation of linear curves on the Bio-Rad spectrophotometer. An expert herpetologist was enlisted to identify amphibians in the environment and determine endangered species to omit from the students' study.

The teams agreed to collect frogs and tadpoles at sites along Lawrence County's Symmes Creek, which drains into the Ohio River. Faculty mentors were careful to guide but not direct the design. The newly designed course was generating significant student interest in

IDAP and improved class test scores, compared with the traditional approach (a pass rate of 76 percent before the course redesign versus a 100 percent pass rate in the redesigned course), by the second term of introductory biology. We adhered to the philosophy that the learning experience would take priority over producing scientific findings; nonetheless, we encouraged field design and technique that ideally would be sufficient to generate data that might be used in a poster or publication.

In the third quarter of the introductory course, OUS biology majors were required to survey ecology, diversity, and evolution. In the classroom, IDAP was easily incorporated as we were able to relate each of these disciplines to our topic of interest. Though students were actively engaged learning the new material, our challenges in the field were only just beginning. Finding frogs in the wild proved difficult, and spring floods delayed class outings. The teams voted to set aside a couple of evenings and sought guidance from Appalachian area natives. These old-timers were slightly intimidated by university vans coming into their fields, but they actually found the unwitting college crew comically short on knowledge about how to "gig" frogs. First, it wasn't frog hunting season and, second, it was best to hunt them at night (to "gig'em" with a stick no less, a skill we found worrisome). And third (the natives kindly shared), it's best to get frogs at night by freezing them with a flashlight, but this final point definitely wasn't recommended as they warned us it was about as legal as hunting deer using such a method.

Teams were dispirited by a day's effort, finding no frogs and feeling a bit ridiculed by their lack of frog-collecting skills when compared to the swaggering tales of the uneducated locals. It proved another good learning experience on what it takes to be a scientist. Frustrations were soon allayed upon realizing that, as members of a scientific research project, we had permits granting special privileges for collecting at any time and by whatever means proved successful (within IACUC regulations). Students, now identified as a special team, gained in confidence as they tackled the new obstacles through brainstorming and improvising their own strategies. A few decided to make frog traps to leave overnight at designated collection sites. By the end of the quarter, we had succeeded in collecting some frogs and tadpoles—thrilling the students. The evidence of camaraderie and mentoring was rewarding, and information about the project was shared with friends and family.

Perhaps the most exciting event occurred when the team doing frog dissections found evidence of abnormalities, and, shortly thereafter, the team involved in water sampling reported evidence of atrazine in the water samples. Due to low sample size and student experimental error, we were unable to support our hypothesis connecting the two occurrences. However, the trend in frog developmental abnormalities indicated the students' work was not in vain. The need for controls, statistically significant sample variation, and careful investigations were vividly evident to students as they experienced real-life research—thus providing a meaningful and engaging learning experience

The 11 frogs collected were identified (American Bullfrog, Leopard, or Tree frogs) and students were able to confirm variation in testis size and presence, as well as confirm that tadpole abnormalities were prevalent. Of particular interest during dissections, the nine- to 12- week- old old tadpoles displayed 29% abnormalities in organogenesis and white mass in nerve tissue. The interpretation of data analysis led to active debate on species fitness through puberty and considered whether early fatalities might potentially skew the findings of a biological investigation.

According to Hayes et al., frog abnormalities are observed at levels of atrazine well below EPA-set safety levels. The students testing water samples were surprised to find that our tap water control registered higher-than-expected levels of atrazine. Through independent investigating, one student reported that the area around the city watershed was sprayed yearly with herbicide! By this time, students were absorbed in the significance of the project.

Ryan Evans, a biology student, performing dissections to test for abnormal gonads in a male frog.

Summary and Findings

IDAP proved to be a fun, engaging approach to learning biology. By the end of the year, students could see meaningful results from their yearlong effort and gained considerable knowledge from the experience. Students bonded within their groups and chose to stay as teams throughout the quarters of the course. Some portion of their grades were based on team participation (final proposal, labs) or based on debate between the teams, which had the added benefit of solidifying team identity and camaraderie. The fun of working outdoors and being part of a real investigation illustrated the multi-faceted nature of STEM education.

As we ended the term, concern over atrazine seeping into local drinking water and the potential health risks led several students to continue independent research projects over the summer. With a first-year research experience under their belts, students are more likely to expand their laboratory skills through volunteering in more advanced studies (AAHEA, 1999). Thus we believe our new approach has had beneficial impacts on student achievement, interest, confidence, and likely retention in STEM education.

Project Outcomes

Our project was evaluated under a grant in conjunction with the George Voinovich School of Leadership and Public Affairs in Athens, OH, to assess and summarize findings on students' ability to translate between field work and formalized representation of phenomena. Student information is gathered through questionnaires administered each term (Howard and Miskowski), group interviews performed for the lecture and lab components, and pre- and post- tests.

We found that retention rates for completion of the entire first-year biology course increased to 75 percent (9 out of 12 students) versus an average of 55 percent over the previous five years. We are now offering a complete second year of biology for majors, having for the first time achieved sufficient enrollment (8 -12 students).

The impact on student attitudes was also measurable through some students' continued participation in research-themed experiences. One student who intends to teach high school science presented a poster and participated in a student plenary session on the experience for a SENCER workshop. Another student who is majoring in chemical engineering (who initially slept through our biology lectures) gradually became curious about whether mercury seepage around the acid coal mines also contributes to growth defects in amphibians and was motivated to investigate methods to accurately measure this. He then volunteered his own time to help several classmates with their field studies.

Based on the success of the IDAP approach, we are investigating similar methodologies to help increase education in STEM fields in our region. Early contact with college for at-risk high school students has been demonstrated to be vital to their successful college matriculation (Bard School Early College, NY). We are currently developing a proposal to fund high school/college learning communities as a "gateway to college" for high school students during which they will receive mentoring and work with college-student peers. The proposal is aimed at training local science teachers on how to prepare science labs that expose high school students to college by allowing them to participate in field study alongside college freshmen.

To reach younger students, we have developed a new Academy of Excellence summer CSI (Crime Scene Investigations) program for middle school students in OUS labs. Overall, we seek to promote STEM enrollments in our region through student-driven, discovery-based learning that provides students with early experience in the realm of science.

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