Extending Your Research Team: Learning Benefits When a Laboratory Partners with a Classroom

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Classroom research experiences can provide outstanding learning opportunities for undergraduate students while also benefiting faculty research programs. However, such courses often require more faculty work than traditional lecture-based courses do, potentially discouraging instructors. Here, we propose one solution. We describe a research-based course designed and implemented by multiple members of a research team. The students in this course measured insects for an evolutionary genetics experiment while participating in classroom-based discussions, readings, and presentations focused on the nature of science. The benefits of the course were threefold. First, the students reported strong positive gains in understanding the nature of science and their attitudes toward science. Second, this course produced publishable data, which benefited faculty research. Third, members of the research team received valuable training in teaching, teamwork, and data management. If incorporated more widely in undergraduate curricula, courses such as this one could improve both research programs and undergraduate education.

Keywords: undergraduate research, classroom-based research, nature of science, scientific literacy, CURE survey

Faculty members at academic institutions often view their research and teaching agendas as separate and competing (Benvenuto 2002, Anderson et al. 2011, Basken 2011). Effort devoted to classroom teaching can reduce the time available for research development, manuscript writing, and the training of graduate students. This disconnection between teaching and research is particularly apparent with traditional forms of undergraduate science instruction, in which students learn from textbooks, lectures, and routine laboratory exercises, whereas authentic research is conducted only by research professionals, graduate students, and a few select undergraduates. However, this separation of teaching and research is only one model for academic life. Recent innovations in course curricula have demonstrated that authentic research can be brought into the undergraduate classroom, providing both benefits to the research programs of principal investigators (PIs) and superior learning opportunities for students (Lopatto et al. 2008, Weaver et al. 2008, Caruso et al. 2009, Knutson et al. 2010, Nadelson et al. 2010, Harrison et al. 2011, Kloser et al. 2011). Indeed, such courses can educate a broader spectrum of students and more of them in the processes of science (Lopatto et al. 2008, Weaver et al. 2008), which is consistent with national goals for improvements in university science education (Boyer Commission 1998, AAAS 2010, Holdren et al. 2012).

Research-based undergraduate courses can provide benefits for everyone involved, but they can also present challenges. Mentoring a classroom of new researchers is laborious, and managing the large data set collected by novice researchers can be overwhelming. We suggest that PIs should not undertake this challenge alone. Instead, PIs can involve their research team members as teachers, mentors, and data managers, effectively extending their research laboratory into the classroom. Postdoctoral researchers, graduate students, and undergraduate students can all contribute to and profit from the experience. Research-based undergraduate courses can therefore be useful not only to the PI and the enrolled students but to the entire research laboratory, providing the next generation of researchers training in leadership, teamwork, course design, and data management.

In the present article, we detail an example of one such course that involved multiple members of a research team in the design, execution, and evaluation of a classroom-based research experience. The original impetus for this course was the need for data collection. The research laboratory of the PI (CWM) had reared thousands of insects as part of an evolutionary genetics experiment. We were seeking an efficient and inexpensive means of obtaining morphological measurements on the insects. In addition, we wished to

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use the opportunity to provide students with an authentic research experience to improve their understanding of and enthusiasm for science. To achieve these goals, we designed a course for 20–30 undergraduate students, modeled after a first-semester research experience in a laboratory but with a heightened focus on increasing student knowledge about the nature of science.

Many university students graduating with science degrees lack a sufficient understanding of the nature of science. These students have often learned many scientific facts from their coursework, but they do not have more than a basic understanding of how science is actually practiced by scientists (Boyer Commission 1998). Students who pursue laboratory research experiences can develop a better understanding of the nature of science but often only if the learning goal is explicit (Lederman 2007, Sadler et al. 2010). Deepening student understanding of the nature of science may help students improve critical-thinking skills, make sense of science and technology research, understand the cultural value of science, and improve learning gains in other science courses (Driver et al. 1996, McComas et al. 1998). Therefore, we were committed to improving student understanding of the nature of science while simultaneously generating a large, standardized data set suitable for publication.

With these goals in mind, we treated the classroom as an expanded laboratory, which included experienced researchers (the teaching team) and an exceptionally large group of first-semester researchers (the students enrolled in the course). We grounded all of the students in our conceptual framework, the specific questions driving our study, and our experimental design. We used data collection as a vehicle to engage the students in a semesterlong group research effort and thereby also generated a large data set. Weekly classroom discussions were focused on improving student understanding of the nature of science. The majority of the weekly readings were derived from the primary literature, further immersing the students in how scientific knowledge is constructed and interpreted. Finally, a subset of the students formulated research questions, analyzed data from the course data set, and presented preliminary findings to their fellow students. All of the students were invited to participate in making inferences from the results.

Our aims with this article are twofold. First, we provide guidance for researchers interested in partnering their research laboratories with an undergraduate classroom. We comment briefly on the data collection achieved in the course and the benefits realized by the teaching team. Second, we present the results from survey and focus-group evaluations to illustrate the strong learning gains reported by the students from this course framework, in which explicit, discussion-based nature of science content was paired with student data collection.

The instructional team was drawn from a single laboratory (*http://entnemdept.ufl.edu/miller/millerlab/index.html*), including researchers at a variety of training levels. They included a PI (CWM), a postdoctoral researcher (JH), a PhD student (WLH-H), a recent college graduate and former researcher in the lab, and a current undergraduate researcher (KDH). The PI conceptualized the course but worked closely with members of the instructional team to design and implement it.

Course elements

Although efficient data collection was the initial reason for designing this course, it was important to ensure that the undergraduate students learned about science as a process and profession. We accomplished this goal by engaging the students in weekly discussions based on the primary scientific literature and by requiring them to prepare a class presentation about the nature of science (see supplemental abbreviated syllabus S1, available online at *http://dx.doi.org/10.1525/bio.2013.63.9.11*).

Scheduling, recruitment, and enrollment. The course was offered in the spring of 2012. We recruited students for this course by posting fliers and e-mailing advisers of a variety of science majors. Some of the students enrolled after hearing about the course from friends. The majors of the students enrolled in our course included anthropology, biology, chemistry, entomology, microbiology, wildlife ecology and conservation, and zoology. We targeted first- and second-year students; however, more third- and fourth-year students enrolled (21 juniors or seniors and 4 freshmen or sophomores). We offered the course on an experimental basis, using a general course number that is reserved for undergraduate student research.

Data collection. We trained the students to measure morphological traits of photographed insects on their personal computers with a free software program called Image J (National Institutes of Health; *http://imagej.nih.gov/ij*). Weekly take-home measurement assignments were designed to require about 5 hours for completion. We used two techniques to improve data quality. First, at four unspecified times, the students' measurements were compared with those made by experienced researchers. If the measurements deviated by more than 2.5%, the students received a reduced grade. Second, each photographed insect was assigned to three different students for measurement, and these measurements were later averaged if they were relatively consistent. We discarded all of the measurements of three students because of consistently low accuracy scores (more than 2.5% deviation from the professional measurements).

Discussions and presentations. Each week in the classroom, the students discussed content drawn from primary literature, media coverage of science findings, and documentary films and videos. The content for a given week followed a theme, such as "science and ethics," and the students completed online quizzes on the material before coming to class. In class, they participated in small- and large-group discussions that were facilitated by a rotating member of the instructional team. Other instructors were present to engage with the groups and to probe their thinking. The students also worked in pairs to present papers from the primary literature on the topics of past discussions. For example, one topic that we addressed was public distrust of science (see abbreviated syllabus S1). Prior to the weekly class meeting, the students watched the documentary film *Flock of Dodos* (2007), in which the topic of intelligent design is examined. The students completed an online quiz and then came together for a discussion about public distrust of science. During the following class period, two pairs of students presented related studies from the primary scientific literature, including one in which the efficacy of museum displays at promoting public understanding of evolution was assessed (MacFadden et al. 2007).

Methods used to evaluate course impacts on undergraduate student learning

We evaluated the impact of our course on our students' understanding of science using both quantitative and qualitative methods. The students quantitatively rated their own learning gains using the Classroom Undergraduate Research Experience (CURE) survey (Lopatto 2008) and provided in-depth, qualitative reviews of their course experience in focus-group interviews.

We used the CURE survey to evaluate the effectiveness of our undergraduate classroom-based research design. Many of the students voluntarily and anonymously completed a precourse survey soon after the course began and a postcourse survey at the completion of the course. The CURE survey assesses student perceptions of learning gains, attitudes about science, and student learning styles before and after research-based science coursework. The students rated the learning gains that they had made for each of 21 potential course benefits on a five-point Likert scale, with a score of 5 representing the largest gain (figures 1–3). The CURE survey results for this course were compared with a database of thousands of previous student responses to the CURE survey and the Survey of Undergraduate Research Experiences (SURE; Lopatto 2004; *www.grinnell.edu/academic/csla/assessment/sure*) (figures 1–3).

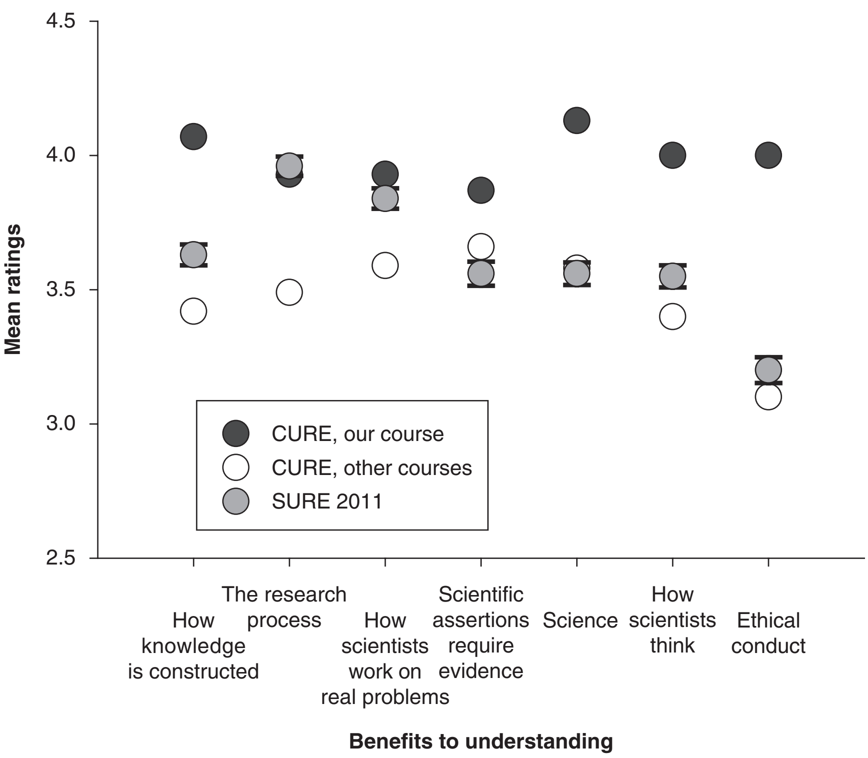

Figure 1. Mean self-rated benefits to understanding reported by students. The black circles represent the students in the present study (*n *= 15; 1, lowest gain; 5, highest gain). Here, postcourse gains correspond to content related to the nature of science, a major area of focus in the course. For comparison, we show the gains reported by students who completed a summer laboratory research experience in 2011 (using the Survey of Undergraduate Research Experiences [SURE]; the gray circles; the error bars represent two standard errors) and the overall mean ratings reported by other students who enrolled in classroom research experiences in 2011–2012 (using the Classroom Undergraduate Research Experience [CURE] survey; the white circles).

At the end of the semester, we invited the students to communicate their views about the course through one of two scheduled confidential focus-group interviews. Our goals for the focus groups were to better understand student self-rated learning gains in the CURE survey responses and to elicit more personal responses to the course as a whole. The questions for the focus groups were written before the course began by the PI of the study and included nine open-ended questions. An outside volunteer observer from the Department of Agricultural Education and Communication at the University of Florida moderated the two focus groups. The observer recorded audio of the focus-group discussions; later, the audio was transcribed by a professional transcription service. Two of the authors of the present article separately assigned open codes to the transcript (Holstein and Gubrium 2003). Once they were assigned, the open codes were reviewed and placed into broader categories, called *themes*. The authors consolidated their independent sets of open codes before identifying the themes in the discussion.

During the 15-week period, approximately 2000 insects were measured, each by three student researchers. These data would have taken at least a year to gather by our laboratory

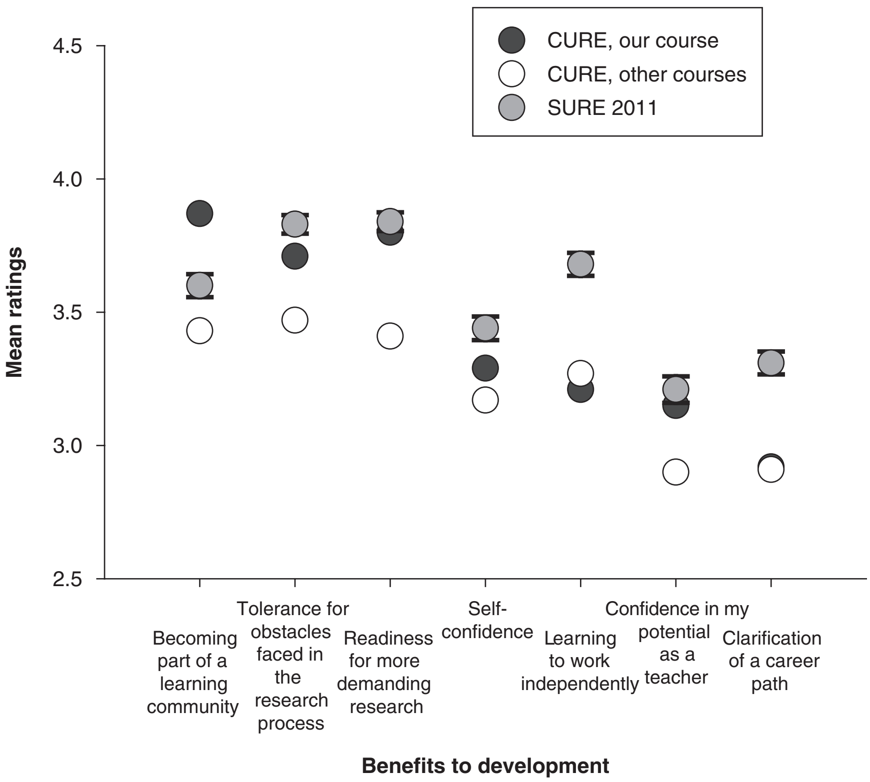

Figure 2. Mean self-rated benefits to development reported by students. The black circles represent the students in the present study. Here, postcourse gains correspond to personal, academic, and professional development. The data are shown using the same conventions as those in figure 1. Abbreviations: CURE, Classroom Undergraduate Research Experience survey; SURE, Survey of Undergraduate Research Experiences.

members alone. We compared the students' measurements with those of trained researchers and found an average similarity of 95.68% (with a median similarity of 97.41%). We consider the data gathered by the students in our course to be highly accurate, and it will be used for scientific publications.

Course impacts on undergraduate student learning

The students indicated that their primary motivations for enrolling in this course included learning about science and the research process and getting hands-on experience. Of the 25 students enrolled in our course, 13 participated in both the precourse survey and the postcourse survey. An additional five students completed only the precourse survey, and two others completed only the postcourse survey. Therefore, information from 20 of the 25 students enrolled in the course was obtained through the CURE survey. Demographic information is reported in table 1.

Thirteen students participated in the two focus-group sessions at the end of the semester, four in the first and nine in the second. Although focus groups are designed to elicit varying opinions from participants (Finch and Lewis 2003), the members of our groups expressed strong agreement on most matters. Only two themes elicited contention among the participants (supplemental table S1). The most prominent themes expressed during the discussions can be grouped into four different subjects: an improved understanding by the students of the nature of science; comparisons of the course to a research lab; the influence of the course on the students' career plans; and student opinions about the relationship between science and society, including the responsibilities of scientists to the public (table S1).

A prominent theme discussed by the focus groups was the nature of science and the research process. The students were asked to think about how their perceptions of science changed after taking the course. In response, one explained,

> Knowledge is not built by any one single person; there is a lot of cooperation from many scientists, many researchers, and basically, over time, that knowledge just gets expanded upon.

Some of the students in both groups expressed that they had been surprised to learn that science can be a creative endeavor. They contrasted the open-ended inquiry methods that they had discussed in this course with previous classroom lab experiences, in which following a set of steps produced a predictable result. When considering what aspects of the course helped them improve their understanding of science, five students explained that the in-class discussions increased their engagement with and understanding of the course material. While describing the benefits of classroom discussion, one student said,

> It also gave us more of an incentive to read the [assigned] papers, [to] become more familiar with the material. It is like we wanted to learn this [material] more so than just trying to memorize it for the exam.

Some of the students showed their understanding of the nature of science when discussing its limitations. One student helped another define the sphere in which science can operate:

> Student 1: Science is, in a sense, limited to what—to basically what can be determined by researchers using their research methods, using scientific procedures. It is not the role of science to go beyond its realm, to go into the religious beliefs and the metaphysical realm.
> Student 2: The natural world.
> Student 1: To go beyond the natural world, there you go.

Some students in both focus groups expressed that content in this course helped them understand the big picture

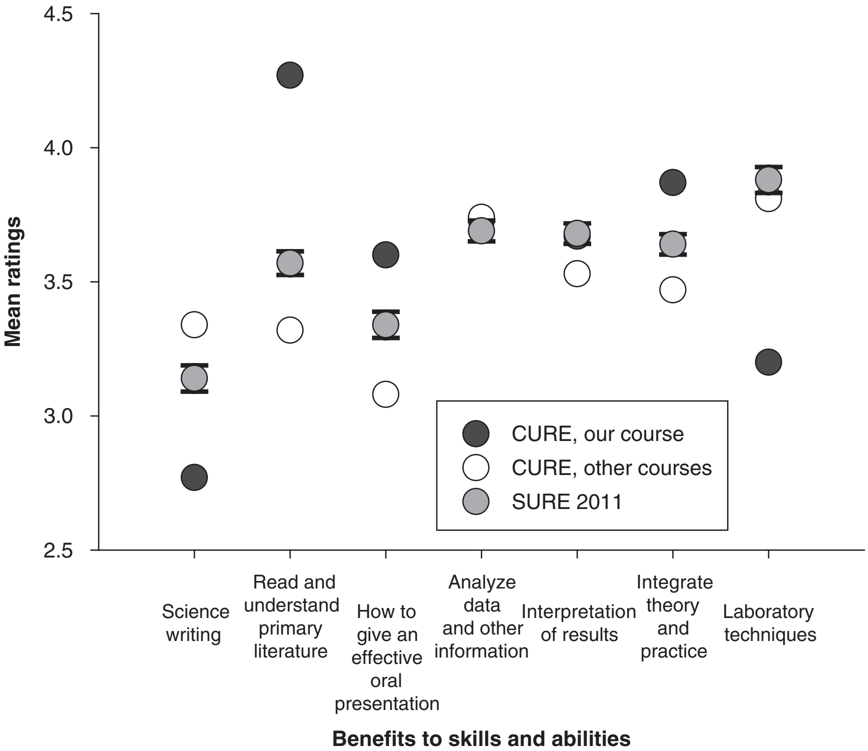

Figure 3. Mean self-rated benefits to skills and abilities reported by students. The black circles represent the students in the present study. Here, postcourse gains correspond to the skills employed in research. The data are shown using the same conventions as those in figures 1 and 2. Abbreviations: CURE, Classroom Undergraduate Research Experience survey; SURE, Survey of Undergraduate Research Experiences.

of science. For example, comparing other courses to this one, one student said,

> In class, we focus on specific mechanisms or reactions or something or just very, very specific details, and I won't really apply that to anything else. But now I can take a concept and try to see how it would work.

Some students also commented on the similarity of the course to a research lab. One student stated,

> The key thing to take from this course is that, yes, we did research, but it also taught us how to do research and how actual researchers work, giving us an idea of what it is like to be in a lab and what the topics discussed in a lab are.

Another student said,

> We had the full spectrum of people in the research process, and so if I have a question about graduate processes, then I would ask one of the graduate students. If I had a question about undergraduate research, I could ask the one who just graduated or the one who is still an undergrad. And it just gave it a very personal way to just find out what you needed to know, and so it really helped.

The focus groups identified one aspect of the course that they thought differed from a research lab: the frequency and breadth of classroom discussions about science. Four students expressed doubt that they would have the opportunity to discuss broad topics in science with their peers in a research lab. When comparing classroom and research lab experiences, two students who had the opportunity to volunteer in the laboratory of the instructors also said that they enjoyed participating in the same project in class and in the lab and felt that it gave them greater insight into the project's various components.

Another theme of discussion was the pursuit of a career in science. Multiple students expressed that this course would provide a valuable early undergraduate experience for students interested in science. One student remarked, "I think it would be invaluable in the first couple of years, if not your freshman year."

In contrast, a sophomore student felt that students would gain the most from the course during their second year, explaining,

> I think that taking it your freshman year might not be as good because you are still getting adjusted; you are still in a different mindset, whereas now, I am comfortable here, and I am looking to go up rather than trying to find my foundation.

Another student stated,

> I feel like anytime during your undergraduate experience would have some kind of benefit toward you. You take all these different courses, but you sit down and you actually think about it. Like, hey, what is my overall goal after taking this class? Why am I even studying this? You know? I feel like anytime that you can realize that is better than never.

All four students in the first focus group stated that their career plans had changed to include the pursuit of a graduate degree in research. Three students expressed that their focus had shifted away from medical degrees.

The second group articulated that participation in the course had not changed their ultimate career plans, but there was consensus in both groups that the members were now more prepared for, aware of, and open to research opportunities than they were before. One student in the first group had not previously understood that scientific research was a potential career for him:

> But, then this opens up that, yes, there are careers in zoology that are research oriented, that are looking into animal behavior and evolution that you can do research on, instead of having to just work as like a vet or work teaching at a zoo or something.

Finally, the groups addressed the relationship between science and society. Some students felt that scientists should

Table 1. Demographics of the students who completed the Classroom Undergraduate Research Experience (CURE) survey for our course and for all students who completed the CURE survey for other courses.

		Our students		All students	
		Precourse	Postcourse	Precourse	Postcourse
Number of responding students		18	15	4533	5796
Gender (percentage)	Male	28	33	43	42
	Female	72	67	57	58
Ethnicity (percentage)	Alaskan Native	0	0	0	0.05
	American Indian	0	0	0.37	0.22
	Asian American	6	13	20	17
	Black, African American	0	0	4	5
	Filipino	0	0	1	1
	Foreign national	0	0	2	1
	Hawaiian	0	0	0.05	0.04
	Hispanic, Latino	33	40	9	5
	Pacific Islander	0	0	0.18	0.18
	White	56	47	55	64
	Two or more races	6	0	5	4
	Other	0	0	4	4
Academic status (percentage)	High school	0	0	0.24	0.12
	First-year student	11	13	31	40
	Second-year student	33	40	31	28
	Third-year student	17	27	18	14
	Fourth-year student	33	20	17	15
	Graduate or medical student	6	0	0.60	0.53
	Other	0	0	2	2

adhere to a certain ethical standard and that the public should be better informed about the nature of science. One student framed communication issues between scientists and nonscientists in the context of funding:

> A lot of our funding does come from the general public, from taxpayers' money and all that. And a lot of opposition also comes from them when they [the public] don't understand what scientists are really trying to do. So, we need to better communicate those ideas to them.

Two students in the second focus group suggested that public distrust of science may result from dismissive attitudes exhibited by scientists. The first student explained,

> Despite scientists' qualifications, there is almost a sense of distrust towards the scientific community. Oftentimes, that is due to illiteracy, scientific illiteracy or just ignorance. But that is also due to the attitude and disposition of the scientists themselves. Oftentimes, you will get scientists who won't even bother with the general public or trying to explain their findings to other people, because to them it may seem like a lost cause, or they just feel like they are on a pedestal or something.

Another topic addressed by the students was the relative roles of science and religion. There was consensus among students who spoke that the role of science is sometimes misunderstood and that misunderstanding causes social conflict. However, the students had difficulty agreeing on the relationship between science and religion. The following is an excerpt from a brief argument:

> Student 1: I think that, basically, [science and religion] have nothing to do with each other and that one doesn't negate the other.
>
> Student 2, interrupting: I wouldn't say that they don't have anything to do with each other. But I would agree with you… that they don't negate each other. It's just something that exists side by side.

The students in the focus groups also discussed the value of research for human society. During the course, the students discussed the distinction between basic and applied research. One focus-group participant expressed a personal preference for applied research, saying, "I like to see an outcome." Another participant disagreed, stating,

> [The course] made me realize how important it [basic research] can actually be.… Even if there is not a goal, that in itself is kind of a goal, trying to figure out how these systems work.… If we can better understand this, maybe it opens up… avenues to other research.

Five other students in the focus group also expressed that basic research has great value for human society.

Benefits to the PI and the research team

The PI was able to share the time and energy investment necessary for this course with four other instructors, making it possible to teach this course in addition to a normal teaching and research load. Over 2000 insects were measured in the course of one semester, saving effort and grant funds.

The laboratory members involved in teaching this course also benefited. To be competitive for most faculty positions, even at research universities, applicants require formal course development and lecture experience. However, most graduate programs still do not provide such opportunities (Burke 2001, Austin et al. 2009). All instructors here gained skills, experience, and confidence that are likely to help them in future teaching endeavors and enhance their competitiveness on the job market.

Benefits to the course participants

The student responses to the CURE survey showed that many learning gains reported by our students exceeded those by students involved in similar courses and also those by students in summer research programs (e.g., SURE). The five highest-scoring items on the postcourse survey included both cognitive (i.e., incorporating learning content) and affective (i.e., incorporating attitudes toward the process) items. This is consistent with recent work suggesting that increasing student appreciation for science positively affects students' learning of science content (Nadelson et al. 2010). The highest reported scores reflect course goals for student learning (e.g., understanding how scientists think). The lowest reported scores reflected topics that were not given emphasis in the course (e.g., skills in science writing; the students in this course did not complete a traditional written assignment). However, some of the low scores in learning gains may have resulted from the fact that many of our students were juniors and seniors. For example, older students may have been more confident in their career path at the start of our course and therefore may have reported lower gains for this item.

These self-reported gains support the efficacy of incorporating classroom-based discussions and presentations together with individual data-collection efforts. Classes in which activities engage and require active participation benefit students by increasing their enthusiasm, retention of content, and depth of understanding (Holdren et al. 2012). Educational research has identified a need for more courses including these features in undergraduate science (Wood 2009, Holdren et al. 2012).

Many students commented on the resemblance of this course to a research laboratory (table S1). When taken together with the high learning gains in areas typically associated with traditional undergraduate research experiences, we infer that extending the lab into the classroom had strong positive effects for the students. The students may have been encouraged by the friendly and inclusive teaching team, which included a current undergraduate and a recently graduated student, both of whom were experienced members of the PI's laboratory (see also Denofrio et al. 2007).

Some of the high learning gains reported by our students suggest that classroom research experiences can lead to learning gains equivalent to or stronger than laboratory research experiences alone can (figures 1–3). Moreover, the students in the focus groups emphasized an improved understanding of science and the research process (table S1).

Training within a course structure may provide excellent preparation for later laboratory research experiences (NRC 2003, Weaver et al. 2008). The benefits of such courses include increasing student retention through graduation and increasing a student's likelihood of pursuing graduate STEM (science, technology, engineering, and mathematics) education, with strong positive effects for students from underrepresented groups in science—all benefits that would be most effective if they were realized in the first 2 years of undergraduate study (Weaver et al. 2008). In addition, after a course such as this one, students may be better prepared and more willing to pursue independent data collection in research labs, potentially increasing undergraduate contributions to academic research (Weaver et al. 2008). Finally, students may gain the opportunity to evaluate whether they enjoy the research process before committing to a university major or career direction (Harrison et al. 2011). For example, some students in our course who were intent on pursuing medical degrees discovered that they enjoyed research, which caused them to reconsider their education and career plans (table S1).

After the completion of this course, several students and PIs contacted us to report that students from our course had accepted laboratory research opportunities across the university in a variety of subject areas. Clearly, it would be informative to evaluate the long-term effects of classroom-based research.

Conclusions

Universities have been challenged to improve science education through authentic research opportunities and to increase the diversity of science majors (Boyer Commission 1998). Research-based courses can improve student understanding of the nature of science and reach a broader spectrum of students (Nadelson et al. 2010). Simultaneously, these courses can benefit faculty research programs and can provide laboratory members with marketable skills. For those interested in pursuing similar courses, we provide advice based on our own experiences (box 1). We encourage universities to support faculty members in developing these courses because of the large number of potential benefits to everyone involved.

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Box 1. A practical guide to expand your research team through classroom research experiences.

Find the instructors
Identify members of your laboratory who are interested in innovative science education. Select instructors with a variety of levels of research experience. If funding for the course is lacking, solicit volunteers for teaching; many students and researchers are eager for advanced-level teaching experience. Divide and assign tasks (e.g., grading, data processing) according to skills and interests. Employ frequent communication and group problem solving.

Find an existing part of your research program in which data collection can be learned quickly and easily
When it is possible, allow the students flexibility in when they collect data and capitalize on the fact that most have their own personal computers. Invest time before the semester begins in forecasting and solving technical issues in data collection and management, preparing for when dozens of students will collect data simultaneously. Provide a limited amount of variety in research tasks. Many students will enjoy contributing to a few different aspects of a single project or becoming involved in two separate projects. However, if each student attempts to master too many different techniques, training time may increase, and data quality may suffer. (Also see Kloser et al. 2011.)

Maximize student learning
Recognize that many students have not had and will not have another opportunity to learn such fundamentals as the nature of science, science ethics, and how science fits within our society. Provide early and reinforced content on foundational theory and the rationale for the study at hand. Extend the laboratory's philosophy into the classroom; for example, create a culture in which everyone's voice is heard, where creativity is fostered, and where a strong work ethic is valued. Simulate lab meetings through class discussions and reading of the primary literature. Promote interaction between the students and instructors. Course assessments should reflect learning goals for the students; for example, our teaching team wanted to emphasize science communication, critical thinking skills, and familiarity with primary literature. We asked the students to present and evaluate studies from the primary literature in the format we associate with conference talks.

Evaluate your effectiveness
Employ existing surveys, such as the CURE (Classroom Undergraduate Research Experience) survey (Lopatto 2008). Collaborate with education professionals to design and conduct focus groups.

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