Undergraduate Biology Lab Courses: Comparing the Impact of Traditionally Based "Cookbook" and Authentic Research-Based Courses on Student Lab Experiences

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Over the past decade, several reports have recommended a shift in undergraduate biology laboratory courses from traditionally structured, often described as "cookbook," to authentic research-based experiences. This study compares a cookbook-type laboratory course to a research-based undergraduate biology laboratory course at a Research 1 institution. The research-based lab course had several hallmarks of authentic research: a single longitudinal research focus, research questions with currently unknown answers, student-determined experimental designs, and collaboration among lab peers. Twenty students in the research-based lab were matched with 20 students in the cookbook lab on the basis of five demographic characteristics. This study found that students in the research-based lab had more positive attitudes toward authentic research, higher self-confidence in lab-related tasks, and increased interest in pursuing future research compared with students in the cookbook laboratory course. This study provides empirical evidence supporting the recommendations for incorporating more authentic research components in laboratory courses.

Recent publications, including *BIO 2010: A New Biology for the 21st Century* (National Research Council [NRC], 2003), *Vision and Change in Undergraduate Biology Education* (American Association for the Advancement of Science [AAAS], 2010), and *A New Biology for the 21st Century* (National Academy of Sciences [NAS], 2010), highlight needed changes for undergraduate biology, including a shift away from traditionally structured lab courses toward more authentic research experiences in undergraduate biology laboratories. The traditionally structured lab, common to high school and undergraduate settings (McComas, 2005; Sundberg and Armstrong, 1993), provides students with step-by-step instructions by which to carry out an investigation, earning the name *cookbook lab* that we will use henceforth. Cookbook labs typically engage students at a minimal intellectual level (Holt, Abramoff, Wilcox, & Abell, 1969; Modell & Michael, 1993); the recipe-like activities leave many students unaware of the significance of experimental results (Germann, Haskins, & Auls, 1996; Modell & Michael, 1993). Perhaps most disconcerting, cookbook lab courses often expose students to inaccurate representations of scientific research (Cox & Davis, 1972). Rather than modeling how scientists develop and warrant knowledge claims, cookbook labs often reflect how well students can follow directions with little regard for the conceptual and procedural understanding of the investigation.

The idea of redesigning cookbook labs has been promoted for over 40 years. In the 1960s, the Commission on Undergraduate Education in Biological Sciences recommended that "the best use of the laboratory in undergraduate instruction is to engage the student in the process of active investigation" (Holt et al., 1969, p. 1104). Subsequent academic committees and publications have echoed this recommendation, emphasizing the importance of an active learning environment that encourages independent thinking and problem solving within scientific inquiry (AAAS, 2010; Boyer Commission, 1998; NRC, 1996, 2000, 2003; Weaver, Russell, & Wink, 2008; Wood, 2003, 2009).

In accordance with these recommendations, colleges and universities have tried to implement a variety of lab experiences (Gehring & Eastman, 2008; Howard & Miskowski, 2005; Matthews, Adams, & Goos, 2010; Rissing & Cogan, 2009; Simmons, Wu, Knight, & Lopez, 2008;

Sundberg, 1997). These new laboratories have ranged in description from inquiry-based to investigative (Holt et al., 1969) to project based (NRC, 2003). Unfortunately, the ambiguity that surrounds inquiry-based teaching methods muddles the current literature on college-level inquiry-based courses (NRC, 1996, 2000; Weaver et al., 2008). Thus, we avoid the term *inquiry* and instead focus on the more specific recommendations of organizations such as AAAS and the National Academies to incorporate hallmarks of authentic research in undergraduate biology lab courses.

This study provides a different perspective than most current evaluations as it investigates a course that is intentionally designed to incorporate hallmarks of authentic biological research, such as the following:

- development of student-generated research questions whose answers are currently unknown,
- longitudinal focus on one set of research questions over the length of the course,
- implementation of experimental designs that are not predetermined,
- collaboration among peers, and
- presentation by students of results and ideas for future research.

Furthermore, this study compares students in the authentic research-based lab with matched-pair students in a cookbook lab offered concurrently at the same Research 1 institution. This type of comparison is rare in the university context as most existing studies focus on a research-based course with no concurrent comparison group (e.g., Grant & Vatnick, 1998; Miller, Witherow, & Carson, 2009).

This paper compares the affective student outcomes in the cookbook and research-based lab courses (a current study is underway to measure both affective and achievement outcome variables), raising the following research questions:

1. What is the impact of research-based versus cookbook undergraduate biology labs on student attitudes toward authentic research practices?
2. What is the impact of research-based versus cookbook undergraduate biology labs on students' confidence in executing biology lab related tasks?
3. What is the impact of research-based versus cookbook undergraduate biology labs on students' interest in doing biological research?

Methods

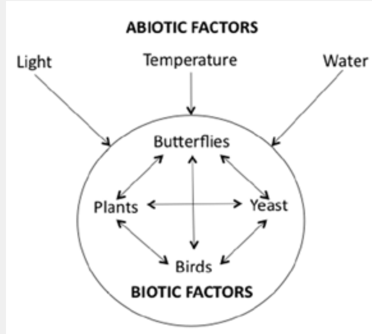
Course content and organization

As stated previously, the research-based lab engaged students in many hallmarks of authentic research—a single longitudinal research focus, research questions with currently unknown answers to the scientific community, experimental designs that are not predetermined, and collaboration among lab peers. Students in the authentic research-based (henceforth experimental) condition (n = 20) focused on learning scientific research methods in an authentic context, and less emphasis was placed on specific content and breadth of lab techniques. Of particular note, students focused on formulating hypotheses, selecting and analyzing data, and communicating results both orally and in writing.

Conversely, the cookbook lab engaged students in four modules on different topics for which the protocols were provided and the answers were previously known to the instructors and the scientific community. Students in the cookbook-based lab (henceforth comparison) condition (N_{total} = 108; $n_{matched}$ = 20) focused on a diverse range of experimental techniques and systems. Students conducted predetermined experiments that are described in detail in the laboratory manual. All of the experiments have predetermined research designs with known answers except for the animal-behavior module, in which students designed and conducted their own one-session experiments using both fish and ant model systems. Additionally, students engaged in an independent project on a topic of their own choosing that meets an additional four to five times outside of regular lab time. The goals for both courses were identified from course documents (see Table 1).

FIGURE 1

A schematic of the ecological model system from which students in the experimental lab course could develop their hypotheses.



Course teaching teams

The experimental condition had a teaching team led by a tenure-track assistant professor of ecology, a lab coordinator who holds a MS degree in biology, and biology PhD students who served as teaching assistants. The tenure-track professor was responsible for most of the Monday lectures, whereas the whole teaching team contributed to the 4-hour laboratory sections. Aside from the lab coordinator who had previously implemented a hands-on genetics curriculum in high schools, the members of the instructional team had no additional instructional training. The teaching team met weekly to discuss the outcomes of the previous week's activities and to plan for the following week.

The comparison condition had oversight from the department's lab coordinator who has a PhD in biology. This coordinator served not as an instructor, but as a facilitator for the instructors of the course. Instruction in the lab sections was done by the course assistants (CAs), who were predominantly upper-level undergraduate students who had previously taken the course, had served as an intern for the course, and had taken a preparatory course with the lab coordinator the quarter prior to serving as a CA. CAs were assisted by undergraduate interns. A small percentage of CAs were MS or PhD biology graduate students.

Study design

This study used mixed methods including student surveys, classroom observations, and student interviews to determine the impact of the two lab conditions on students' affect toward authentic biological research. As a thorough qualitative analysis of interviews and observations is beyond the scope of this paper, the results present only the pre- and postcourse survey data.

Several existing surveys, such as the Views of Nature of Science Questionnaire (Khishfe & Abd-El-Khalick, 2002) or the Colorado Learning Attitudes About Science Survey (Adams, Perkins, Dubson, Finkelstein, & Wieman, 2004), probe students' understanding of the nature of biology and attitudes toward biology. However, these surveys do not probe students' attitudes toward their engagement and self-confidence in biology lab practices. Therefore, we designed, piloted, and used our own survey instrument that specifically addressed biology lab practices. Surveys were vetted for face validity using a think-aloud protocol (Collins, 2003). Two rounds of think-aloud protocols were conducted with five undergraduate students each time to determine if the questions were measuring the desired constructs. The survey was also piloted with 40 students in another biology lab course and revised prior to administration of the survey in these courses.

Surveys were distributed to study participants prior to the start of both the experimental and comparison classes. The precourse survey included three blocks of Likert-scale survey questions on the domains of student self-confidence in executing lab tasks, student interest in biological research, and student preferences for biology lab course structure and organization. The postcourse survey included the same three Likert-scale blocks of questions from the precourse survey. In addition, the postcourse survey contained two new Likert-scale blocks of questions that asked about the frequency of specific events from the lab class and student recommendations for their respective lab course. Response rates for the surveys were 100% because the survey was a required part of the course.

Study participants

This study was originally designed as a randomized experiment with student volunteers being randomized into the experimental and comparison classes. Prospective students received an announcement informing them that they could choose either the existing biology lab course or volunteer to be randomly selected from a pool that would take the experimental course that would focus on a longitudinal research question in ecology. Only 20 students volunteered to participate in the randomization, so all volunteers were placed in the experimental condition. The comparison group was obtained by

TABLE 1

Comparison of goals for two undergraduate biology laboratory courses.

Goals for research-based lab (experimental)	Goals for traditional "cookbook" lab (comparison)
1. Students will be able to conduct guided inquiry on open-ended questions that reflects biological research practice in the context of ecology. 2. Students will be able to analyze open-ended, guided inquiry data and propose justifiable conclusions. 3. Students will conduct elements of scientific research both independently and collaboratively. 4. Labs will stimulate student interest in future biological research and encourage participation in research endeavors. 5. Students will develop critical-thinking skills in biological research that are transferable to other research experiences. 6. Students will experience the successes and failures of lab research. 7. Students will experience the successes and challenges of collaborative research. 8. Students will communicate results in a discipline-appropriate manner through various media.	1. To present an overview of the theory and practice of experimental biology using several representative fields of biology as model systems. 2. To teach the methodology by which a well-conducted experiment is planned, appropriately observed, and critically analyzed. 3. To provide a general framework for scientific writing and to train you for proficiency in written scientific presentation. 4. To stimulate interest in biological research; to familiarize you with scientific resources in the library; and to encourage future participation in research endeavors.

matching the demographics of the volunteers with those of students in the comparison condition. Each student in the experimental course was matched as closely as possible on five variables that included gender, class year, major, GPA, and previous research lab experience. Of the 20 matched pairs, 12 matched on all five variables, 6 matched on four of the five traits, and 2 matched on three of the five traits. GPA and research experience were the last two matched variables because they were self-reported. Given the competitive atmosphere at Research 1 universities, it is possible that reported GPAs or research experiences could be exaggerated or skewed differently between a group of volunteers and nonvolunteers.

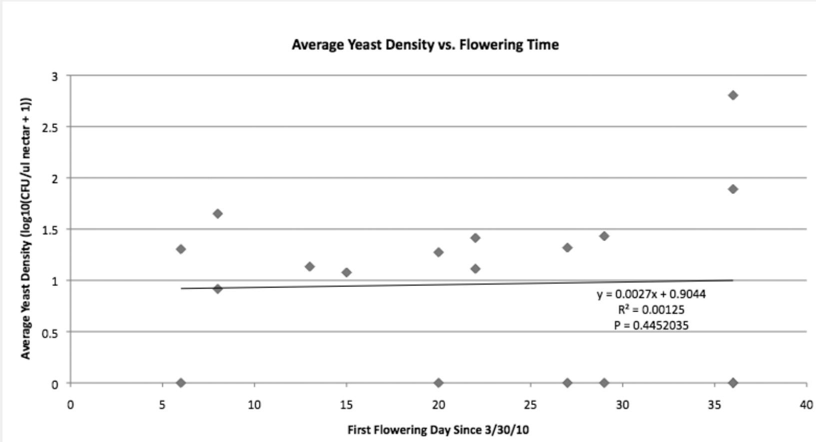
Table 2 shows the demographic breakdown of both the experimental and comparison matched pairs as well as the demographics of the remaining lab population not included in the study.

Data analysis

Likert-scale questions on the surveys were converted to a numerical scale and entered into SPSS for analysis using analysis of variance (ANOVA). Reliability among each block of questions, means, and standard deviations are reported for the pre- and postcourse surveys. Gain scores are shown for both conditions and effect sizes are reported for the postcourse survey scores. Means were compared using ANOVA, and gain scores were calculated and compared using a paired samples *t*-test. Distribution percentages are reported for each survey question in the Appendix online at http://www.nsta.org/college/connections.aspx.

FIGURE 2

An example of results from one lab pair based on their hypothesis that a relationship exists between yeast density and flowering time.



Results

Research Question 1: Impact of authentic research-based versus cookbook-based labs on students' attitudes toward authentic research practices

Students in both conditions were asked if they prefer labs with a single, continuous topic (Table 3). Student means in the experimental condition fell between *agree* and *strongly agree* for both the pre- and postcourse survey item. This mean increased for the experimental con-

TABLE 2

Demographics of experimental and comparison condition matched pairs and unmatched comparison condition students.

Condition	Gender		Class year			Major				Self-reported GPA			Research experience	
	Male	Female	Sophomore	Junior	Senior	Bio	HumBio	Undecl	Other	2.5–2.9	3.0–3.49	3.5–4.0	Yes	No
Experimental matched (*n* = 20)	9	11	7	7	6	13	2	0	5	0	6	14	9	11
Comparison matched (*n* = 20)	10	10	7	7	6	13	2	0	5	2	8	10	7	13
Comparison unmatched (*n* = 89)	35	54	18	19	52	36	34	4	15	7	31	48	44	45

Note: HumBio = an interdisciplinary biology major, human biology; undecl = undeclared majors.

dition but not significantly over the course of the quarter. In contrast, the pre- and postcourse survey means from the comparison group fell between *disagree* and *agree* and *strongly disagree* and *disagree*, respectively. This decrease was statistically significant over the course of the quarter. In comparing the two conditions, the experimental group's precourse survey mean was greater than a full standard deviation higher than the precourse survey mean of the comparison group. Therefore, it is not surprising that the postcourse survey mean for the experimental group is not only statistically higher but also practically higher as represented by the large effect size (Cohen, 1988, defined effect sizes of 0.2, 0.5, and 0.8 as small, moderate, and large, respectively).

Students were asked if they prefer to explore open-ended questions for which the answer is not predetermined (Table 3). Students in the experimental condition again reported means on the pre- and postcourse survey that fell between *agree* and *strongly agree*, and the gain was statistically significant. Students in the comparison group reported pre- and postcourse means that fell between

TABLE 3

Pre/postcourse survey means, standard deviations (in parentheses), gain scores, and effect sizes (postcourse results) for the question: "What is your level of agreement with the following statements related to biology lab courses?"

	Comparison (n = 20)			**Experimental** (n = 20)			**Effect size**
	Pre	Post	Gain	Pre	Post	Gain	
1. I prefer lab courses that explore a set of research questions focused on a single continuous topic.	2.5 (0.61)	1.9 (0.61)	– 0.60**	3.4* (0.81)	3.6* (0.61)	0.20 (0.95)	2.8
2. I prefer lab courses that explore an open-ended question for which the answer is not predetermined.	2.6 (0.61)	2.6 (0.95)	0.0	3.2* (0.83)	3.7* (0.49)	0.50** (0.89)	1.5

Note: Cronbach's alpha = 0.79. Scale = 1 (*strongly disagree*), 2 (*disagree*), 3 (*agree*), and 4 (*strongly agree*). Effect size for Cohen's *d* is traditionally interpreted as 0.2 = small effect, 0.5 = moderate effect, 0.8 = large effect (Cohen, 1988).

*Between-group significance based on analysis of variance ($p < .05$)

**Within-group significance based on paired samples *t*-test ($p < .05$)

TABLE 4

Pre/postcourse survey means, standard deviations (in parentheses), gain scores, and effect sizes (postcourse results) for the question: "What is your level of agreement with the following statements related to biology lab courses?"

	Comparison (n = 20)			**Experimental** (n = 20)			**Effect size**
	Pre	Post	Gain	Pre	Post	Gain	
1. I prefer to make my own decisions about what experiments to do in lab.	2.5 (0.51)	2.5 (.76)	.00 (0.76)	2.8 (0.72)	3.3* (0.64)	0.50** (0.76)	1.1
2. I believe that collaboration is an important part of lab research.	3.7 (0.47)	3.4 (0.75)	–0.30 (0.81)	3.7 (0.42)	3.8* (0.38)	0.10 (0.46)	0.67
3. I benefited from peer reviewing another student's work. †	—	2.3 (0.73)	—	—	3.3* (0.72)	—	1.4
4. I benefited from having my work peer reviewed. †	—	2.4 (0.81)	—	—	3.4* (0.67)	—	1.3
5. This lab experience helped me understand how to conduct scientific research that is similar to real world biology research. †	—	3.0 (0.76)	—	—	3.5* (0.51)	—	0.77

Note: Cronbach's alpha = 0.77. Scale = 1 (*strongly disagree*), 2 (*disagree*), 3 (*agree*), and 4 (*strongly agree*). Effect size for Cohen's *d* is traditionally interpreted as 0.2 = small effect, 0.5 = moderate effect, 0.8 = large effect (Cohen, 1988).

† Postcourse question only

*Between-group significance based on analysis of variance ($p < .05$)

**Within-group significance based on paired samples *t*-test ($p < .05$)

disagree and *agree* that were statistically lower than the respective experimental students' means. Notably, these two items represent the only two questions on which the precourse means differed for the matched students in each condition. Although students were matched as closely as possible between the two conditions, the different preference for the overall structure of biology labs is expected based on the self-selection into the two conditions.

Students were also asked about their level of agreement with state-

TABLE 5

Postcourse survey means, standard deviations (in parentheses), and effect sizes for the question: "In how many of the nine classes (or prelabs) did the following occur in your lab section?"

	Comparison (n = 20)	Experimental (n = 20)	Effect size
	Post	Post	
1. Collaborated on experiments with students in my section. †	3.1 (1.3)	4.6* (0.89)	1.3
2. Discussed how to execute lab protocols with a peer. †	2.9 (1.3)	4.1* (1.1)	1.0
3. Discussed conceptual topics of the lab with a peer. †	2.5 (1.1)	4.3* (0.92)	1.8
4. Performed different experiments than other students in my section that tested the same hypothesis. †	1.7 (0.87)	2.8* (1.5)	0.90
5. Shared experimental data with other students in my section. †	2.2 (0.67)	3.1* (1.0)	1.1

Note: Cronbach's alpha = 0.84. Scale = 1 (*0 classes*), 2 (*1-3 classes*), 3 (*4-6 classes*), 4 (*7-8 classes*), and 5 (*9 classes*). Effect size for Cohen's d is traditionally interpreted as 0.2 = small effect, 0.5 = moderate effect, 0.8 = large effect (Cohen, 1988).

† Postcourse question only

*Between-group significance based on analysis of variance ($p < .05$)

TABLE 6

Pre/postcourse survey means, standard deviations (in parentheses), gain scores, and effect sizes (postcourse results) for the question: "How confident do you feel in your ability to execute the following biology lab-based tasks?"

	Comparison (n = 20)			Experimental (n = 20)			Effect size
	Pre	Post	Gain	Pre	Post	Gain	
1. Develop my own scientific question	2.6 (0.82)	3.0 (0.80)	0.40 (0.88)	2.7 (0.92)	3.5* (0.69)	0.80** (0.95)	0.67
2. Design my own experimental lab protocol	2.4 (0.88)	2.7 (0.80)	0.30 (0.73)	2.6 (0.76)	3.3* (0.79)	0.70** (0.87)	0.75
3. Interpret experimental data	3.1 (0.76)	3.0 (0.86)	– 0.10 (0.83)	2.9 (0.64)	3.5 (0.69)	0.60** (0.76)	0.64
4. Present lab results to my lab members	3.1 (0.94)	3.4 (0.68)	0.30 (.058)	3.3 (0.73)	3.9* (0.37)	0.60** (0.61)	0.91
5. Write an accurate full-length lab report (Intro, Methods, Results, & Discussion)	3.1 (0.79)	3.3 (0.64)	0.20 (0.59)	3.0 (0.82)	3.6 (0.61)	0.60** (0.68)	0.48
6. Work as an undergraduate research lab assistant in a biology lab	2.8 (0.83)	3.1 (0.85)	0.30** (0.57)	2.7 (0.92)	3.6* (0.50)	0.90** (0.79)	0.72

Note: Cronbach's alpha = 0.86. Scale = 1 (*not confident*), 2 (*somewhat confident*), 3 (*confident*), and 4 (*very confident*). Effect size for Cohen's d is traditionally interpreted as 0.2 = small effect, 0.5 = moderate effect, 0.8 = large effect (Cohen, 1988).

*Between-group significance based on analysis of variance ($p < .05$)

**Within-group significance based on paired samples t-test ($p < .05$)

ments regarding authentic research practices that occurred in their lab condition (Table 4). Although the precourse survey means did not differ between the two conditions, the postcourse mean for the experimental group was statistically higher than the comparison group and practically significant, with a large effect size of 1.1.

Students were also asked about the importance of collaboration in the lab (Table 4). Both groups answered the precourse survey with means that approached *strongly agree*. This resulted in a significant difference between the two groups' postcourse survey means and a moderate effect size of 0.67. It is likely that the mean of the experimental group was also impacted by a ceiling effect.

Furthermore, students in both conditions were asked about the benefits of giving and receiving peer review, because both classes used this instructional strategy as part of their curriculum (Table 4). Students in the experimental condition reported that they benefited more from peer review than did students in the comparison group. In both cases, the effect size was over 1.25, indicating a large effect. Finally, students were asked whether the lab experience helped them understand how to conduct real-world biological research. Students in the experimental condition reported a statistically higher mean than did students in the comparison group that was approximately 0.75 of a standard deviation higher.

Students in both conditions were asked how often they participated in various activities found in authentic research (Table 5). Students in the experimental condition reported statistically higher frequencies than did students in the comparison group for collaborating on experiments with other students, discussing protocols with peers, discussing concepts with peers, performing different experiments to test the same hypothesis, and sharing experimental data with other students in the section. On average, students in the experimental condition engaged in these practices in at least one or two more class periods than did the comparison group.

Research Question 2: Impact of authentic research-based versus cookbook-based labs on students' self-confidence in executing biology lab-based tasks

Self-confidence and self-efficacy in performing tasks are important components in successful performance (Bandura, 1997). Students were asked about their self-confidence in executing lab-based and research-based tasks (Table 6). Scores on the precourse survey showed no statistical differences between the two conditions. Students in the experimental condition showed statistically significant gains in their self-confidence for each of the lab tasks that include developing research questions, interpreting data, and presenting lab results. Students in the comparison condition reported increases on five of the six measures, but these gains were generally smaller and only one—self-confidence in working as an undergraduate lab assistant—was statistically significant.

Research Question 3: Impact of research-based versus cookbook labs on students' interest in doing biological research

Students were asked about their interest in voluntarily continuing their participation in authentic biological research (Table 7). Postcourse surveys showed that students in the experimental condition reported a modest but significant gain in their interest in doing an undergraduate honors thesis, whereas students in the comparison condition reported a nonsignificant gain. Practically, the mean of the experimental group indicated that they were more interested than the comparison group and the effect size was a moderate 0.60. Students in the experimental group also indicated a significant

TABLE 7

Pre/postcourse survey means, standard deviations (in parentheses), gain scores, and effect sizes (postcourse results) for the question: "What is your level of interest for doing the following research-related experiences?"

	Comparison (n = 20)			**Experimental** (n = 20)			**Effect size**
	Pre	Post	Gain	Pre	Post	Gain	
1. Doing a biology honors thesis in experimental research.	2.4 (0.94)	2.6 (1.0)	0.20 (.62)	2.7 (1.3)	3.3 (1.3)	0.60** (.83)	0.60
2. Applying for biology undergraduate lab research positions.	3.7 (1.0)	3.5 (1.1)	–0.20 (0.97)	3.2 (0.97)	3.8 (1.1)	0.60** (1.1)	0.27

Note: Cronbach's alpha = 0.77. Scale = 1 (*strong disinterest*), 2 (*disinterest*), 3 (*interest*), and 4 (*strong interest*). Effect size for Cohen's d is traditionally interpreted as 0.2 = small effect, 0.5 = moderate effect, 0.8 = large effect (Cohen, 1988).

*Between-group significance based on analysis of variance ($p < .05$)

**Within-group significance based on paired samples t-test ($p < .05$)

increase in their desire to work as an undergraduate research assistant. Students in the comparison group did not show any significant change between the pre- and postcourse surveys in their interest in working as a research assistant, and the effect size between the two groups was small at 0.27.

From research question to results: An example of student product

We provide an example of the authentic research practices that occurred in the experimental condition in the following abridged example of the process based on one lab group's final paper.

Students in the experimental condition developed hypotheses based on an ecological model system that provided a diverse combination of biotic and abiotic interactions (Figure 1). Additionally, this system is the focus of the tenure track professor's research program, allowing him to bring a high level of expertise to the course while also allowing student data collection and analysis to further his own insights.

During weeks 1–2, students learned about the model system and hypothesis testing. During weeks 3–4, each team of two students then chose an abiotic factor (e.g., light, temperature, or water) and a biotic factor (e.g., flowering phenology, pollinator visits, or butterfly larvae abundance) to investigate regarding its relationship to nectar-living yeasts. Each team formulated several hypotheses that were submitted to the instructors who gave feedback during week 5. Hypotheses were revised and one example of a final hypothesis is as follows:

> We hypothesized that plants with earlier first flowering date (FFD) would consequently yield higher yeast density due to increased pollinator visits, attracted by greater number of flowers. Therefore, our null hypothesis is that there will be no correlation between FFD and yeast density.

During weeks 7–9, students selected which data to sample and the appropriate method of data analyses to test their respective hypotheses, selecting from a large pool of available data. Some of the data were collected by students in the class during the quarter and other data had been collected previously by instructors and stored in a central database. Figure 2 illustrates one example of student results based on analyzing the data chosen for the above hypothesis. From these results, the students concluded the following:

> The average yeast density calculated by CFU/ul nectar was not significantly associated with flowering time ($p = .45$; Figure 2). Thus, our second hypothesis, which stated that earlier flowering time determines an increase in yeast density, was not confirmed.

These excerpts are representative of the student research experiences in the experimental course.

Discussion

Recent reports emphasize the need for increased exposure of authentic lab practices to undergraduate students in lab courses (NRC, 2003; NAS, 2010; AAAS, 2010). Results from this study suggest that research-based biology labs can have an impact on aspects of undergraduate students' interest, self-confidence in performing lab tasks, and preference for components of authentic research when compared with students experiencing a traditional cookbook lab course. This work is significant because few comparison studies have been done at the college level on authentic research-based undergraduate biology laboratories. Given recommendations for a shift to more research-focused undergraduate laboratory courses, it is paramount to provide empirical evidence supporting these claims that research-based courses have an impact. This study adds to a small yet significant body of literature on this topic.

It is important to note significant, unavoidable limitations in the research design that affect the interpretation of the results. First, the teaching staff of the experimental course had more experience teaching university-level courses and possessed a greater body of content knowledge than did instructors in the comparison course. Most significant, this study used a small sample of students who all volunteered to participate in the research-based lab, whereas students in the comparison lab were nonvolunteers. The two groups of students likely differ in ways related to motivation, interest, and dedication (Rosenthal, 1965). Acknowledging these limitations, this paper nevertheless provides data on the impact of authentic research-based lab courses compared with cookbook labs. Furthermore, this study, although imperfect, did use a matched control group—a comparison condition that is lacking in many evaluations of recent biology lab courses. In order to make this claim more definitive, future studies will need to address the above limitations and use larger, randomized student samples. This type of study is in progress and will build on the results contained in this paper.

Overall, students in the research-based experimental condition showed more positive attitudes toward authentic research practice than did students in the comparison condition. The experimental and comparison groups differed on only two precourse survey questions, both of which related to lab organization preference (Table 3). Because randomization was not possible and only volunteers were placed in the experimental condition, it is not surprising that the two conditions differed on the precourse survey when students were asked about their preferences for single-question or open-ended lab courses.

It is possible that the frequency with which students participated in authentic research-based tasks affected student preferences in favor of authentic lab experiences. For example, the experimental group showed a stronger preference than did the comparison group for making their own decisions in lab, felt as though collaboration was important, and thought that this lab experience helped them understand how real scientific research was conducted (Table 4)—all constructs that also occurred more frequently in the experimental than in the comparison group (Table 5). Thus, it appears that the types of interactions defined by the different lab structures as well as the frequency of those interactions can have an impact on student preferences in the lab. For example, collaboration between students was a cornerstone of the experimental condition. Data collected by individual lab groups was shared with the entire class in a central database. Thus, students in the experimental condition cited more opportunities for collaboration. Whether it was the frequency or the quality of interactions that affected student responses is unknown, but it is likely that both contributed to students in the experimental condition self-reporting a greater benefit from collaboration.

Not only did students in the experimental condition share data, but they also were often observed taking initiative to help each other during downtime in the lab. Although peer critique was a feature of both the experimental and comparison labs, survey data indicated that students in the experimental condition benefited more from peer critique (Table 4). This possibly resulted from the reliance of students on each other for data; if one student was inaccurate in his or her collection or interpretation of the data, it would affect the group as a whole. Therefore, students in the experimental condition were likely motivated to give constructive feedback. Furthermore, because these students were all focused on the same ecological research paradigm for the full 10 weeks of the quarter, they had a stronger foundation for the content and therefore were able to provide higher quality critique.

Increasing student self-confidence and interest in conducting biology research is a major impetus of many biology departments. As expected from students taking an introductory lab course, self-confidence in performing lab tasks increased on nearly every question from students in both groups (Table 6). However, only students in the experimental condition showed significant gains on each item, gains that were moderate to large in effect size. In terms of interest, students in both lab conditions did not change their career interests in doing biology research because of their experience in this introductory lab experience (data not shown), but this is not surprising as many students took the course to fulfill a requirement for their already chosen medical career. However, the experience of the experimental research-based lab course increased students' proximate interest in biology research, doing an honors thesis or working in a campus lab, whereas this was not the case for students in the comparison group (Table 7). It is plausible to think that this impact on short-term interest could have an impact on students' long-term trajectories as further exposure to lab experiences could make a positive impression on ultimate career paths (Hidi & Renninger, 2006).

Conclusions

The results of this study provide information about the impact of research-based labs on undergraduate biology students' attitudes toward research, self-confidence in performing research tasks, and interest in future biological research. It is important that the authors recognize that alternate hypotheses derived from the limitations of this study may be at least partially responsible for these results. The authors are currently addressing these variables in the next iteration of the study.

If these results replicate in future randomized studies of larger sample sizes, universities will have to address many logistical and fiscal obstacles to overhaul their undergraduate lab courses. This includes designing an effective research-based curriculum, hiring content experts to facilitate the courses, establishing sustainable authentic research opportunities, and funding ongoing assessments of the program and its effects. Although difficult, these steps are necessary to fulfill the aims of *Vision and Change* (AAAS, 2010), *BIO 2010* (NRC, 2003), and many university biology departments across the country. ■

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