

Article

Classroom-Based Science Research at the Introductory Level: Changes in Career Choices and Attitude

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Submitted December 28, 2010; Revised May 3, 2011; Accepted May 4, 2011
Monitoring Editor: Mary Lee S. Ledbetter

Our study, focused on classroom-based research at the introductory level and using the Phage Genomics course as the model, shows evidence that first-year students doing research learn the process of science as well as how scientists practice science. A preliminary but notable outcome of our work, which is based on a small sample, is the change in student interest in considering different career choices such as graduate education and science in general. This is particularly notable, as previous research has described research internships as clarifying or confirming rather than changing undergraduates' decisions to pursue graduate education. We hypothesize that our results differ from previous studies of the impact of engaging in research because the students in our study are still in the early stages of their undergraduate careers. Our work builds upon the classroom-based research movement and should be viewed as encouraging to the Vision and Change in Undergraduate Biology Education movement advocated by the American Association for the Advancement of Science, the National Science Foundation, and other undergraduate education stakeholders.

INTRODUCTION

A growing body of research has established the benefits of authentic research experiences by undergraduates in the sciences (Seymour *et al.*, 2004; Lopatto, 2006; Laursen *et al.*, 2010). Students report gains in specific skills, such as research design, hypothesis formation, data collection, data analysis, computing, and information literacy. They also report gains in oral, visual (e.g., poster creation), and written communication, if these activities are part of their research experience. Students note personal gains, including greater independence of work and thought, tolerance for obstacles, readiness for new challenges, growing self-confidence, and a sense of accomplishment.

The main motives faculty have for engaging undergraduates in research are to recruit them into research careers and graduate education and develop their understanding of the nature and practice of science (Labov *et al.*, 2010; Laursen *et al.*, 2010). Although undergraduates report gaining in their understanding of what science is and how it is done, most also report that experiencing research confirms their previous career and education-related decisions, rather than prompting them to alter their plans (Fitzsimmons *et al.*, 1990; Seymour *et al.*, 2004; Lopatto, 2004, 2007). Researchers have noted that most studies of undergraduate research experiences focus on upper-level students, who are a self-selected population already interested in research. In contrast, the burgeoning movement to integrate research into lower-level undergraduate courses aims to reach students at an earlier stage in their academic careers who might not have identified research as a career or education path. Thus, the focus of our study is the exploration of how research experiences in the context of research integrated in courses influence students' academic and career interests and their intentions to pursue further education or careers in scientific research.

The majority of students reporting the benefits of undergraduate research are rising third- or fourth-year undergraduates, who have already declared a science major and who are seeking out research experiences to improve their résumés and their chances of being accepted into medical or

DOI: 10.1187/cbe.10-12-0151

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graduate school. These students thus represent a unique sample for surveys designed to understand undergraduate attitudes about research experiences. For these students, Lopatto (2007), employing the Summer Undergraduate Research Experience (SURE) survey for approximately 2000 undergraduate researchers, found only about 4% of undergraduate researchers report changing their pre-existing plans for a science career. Other researchers have reported higher levels of attraction to a science career by undergraduate researchers. Russell and colleagues (2007) conducted a survey for students who had participated in National Science Foundation (NSF)-funded research experiences. Their research indicated 29% of their respondents reported a “new” expectation of pursuing a PhD.

These investigations of the impact of undergraduate research on career choice are based on dedicated research experiences, usually a summer internship in which the student is not actively involved with course work or an independent research project in a faculty member’s research lab during the academic year. Because the constellation of benefits is so promising, however, undergraduate research opportunities are beginning to be integrated into the course curriculum (Lopatto, 2010). Key features of the research experience, including pursuing research questions to which no one has the answer, have been successfully incorporated into the course and lab schedule.

This undergraduate research laboratory course model has been employed at several institutions for upper-level science students (Boomer and Dutton, 2002; Elwess and Latourelle, 2004; Brodl, 2005; Howard and Miskowski, 2005; Drew and Triplett, 2008; Shaffer *et al.*, 2010). In each of these examples, research has shown course-based research experiences increase students’ mastery of content, interest and enthusiasm in the laboratory exercises, and critical thinking skills. Drew and Triplett (2008) reported a marked, although not highly significant, increase in students considering a career in the biological sciences. The course was open to students who were enrolled in the microbiology course and early career graduate students (Drew and Triplett, 2008). Although all of these studies were informative, none of them demonstrated that students made significant changes in career choices after participating in research in the classroom. Since the students enrolled in these undergraduate research laboratory courses were mostly upper-level science students, it may be that the students had already made up their minds as to career choices.

A national model of integrating research into undergraduate classrooms is the Genomics Education Partnership (GEP; Lopatto *et al.*, 2008; Shaffer *et al.*, 2010). The GEP program is a collaborative enterprise between colleges and universities and the Department of Biology and Genome Center of Washington University in St. Louis, MO. The GEP currently comprises several hundred undergraduate students at more than 60 institutions of higher education across the United States who are involved in laboratory studies of *Drosophila* genomics and bioinformatics in laboratory class settings. Students participating in this program report outcomes similar to students in other course-based research models. For instance, GEP students reported greater enthusiasm for research and science, greater appreciation for the process of science, and personal growth as developing scientists.

A model for integrating research in the classroom at the freshman level was recently reported by Ronsheim and coworkers (2009), who describe a novel inquiry-based and discovery-driven approach in teaching Introductory Biology at Vassar College (Poughkeepsie, NY). Students taking Introductory Biology are presented with several research modules throughout the semester in which they learn fundamental concepts in biology such as genetic variation and natural selection. In a third, investigative module, students explore how variation in local environments affects the biodiversity of soil communities. Results from study of this program demonstrate greater student retention in the major as well as greater faculty enthusiasm for teaching freshmen biology.

The Howard Hughes Medical Institute (HHMI) is supporting a nationwide integration of research into Introductory Biology courses through its Science Education Alliance (SEA; www.hhmi.org/grants/sea). The SEA course is modeled after Phage Hunters Integrating Research and Education (PHIRE) by Graham Hatfull at the University of Pittsburgh, Pennsylvania (Hanauer *et al.*, 2006, 2009; Hatfull *et al.*, 2006, 2010). The PHIRE program involves students in isolating mycobacteriophages from a soil isolate, annotating the genome, and hypothesizing as to the possible functions(s) of annotated genes. Hatfull (2010) argues that the PHIRE program allows students to shift from concrete processes in the beginning of the project (isolating phage from the soil) to more abstract processes, such as genome annotation. Caruso and colleagues (2009) recently implemented the Phage Genomics course with nonscience majors, documenting that participating students recognized “real” science is collaborative and came to understand the process of scientific discovery. Furthermore, Caruso and colleagues (2009) showed that non-science major students easily mastered lab techniques in spite of the fact that the majority of them had no prior undergraduate laboratory experience.

To further explore the impact of early undergraduate participation in course-based research, we aimed to address three research questions in this study: 1) Does an early experience with research in the classroom prompt students to think differently about career choices? 2) Do freshmen report increases in enthusiasm and confidence resembling those of upper-level students? 3) Do freshmen have a greater appreciation for what it means to be a practicing scientist? In this paper, we describe the content and structure of the Phage Genomics course at Cabrini College as well as the results of pre- and postcourse surveys and focus groups that questioned students on their attitudes toward science, research, appreciation for the practice of science, and career choices. We document that undergraduates reported increased interest in pursuing different career options after participating in the Phage Genomics course. We hypothesize that “catching” students early in their undergraduate experience, either with research within a classroom setting or individually with a faculty member, would have a substantial effect on their attitudes about different career options, such as graduate school opportunities. Furthermore, results from our study reinforce earlier research on the impact on undergraduates of course-based research. Specifically, students report increased enthusiasm for science and understanding of what it means to

work like a scientist and engage in discovery science at the freshman level.

METHODS

Participants and Class Structure

The Phage Genomics course that served as the context for our research is described in detail elsewhere (Caruso *et al.*, 2009), but we describe it briefly here as context for this study and to outline the particular ways the curriculum was implemented at Cabrini College. The course was open to both science and non-science majors enrolled in the college's honors program or to students with academic backgrounds similar to the honors students who expressed interest in taking the course. Of the 16 students enrolled in the course, 13 were entering freshman biology majors, nine of whom were in the honors program. The other three students were honors sophomore non-science majors who elected to take the course to satisfy their science general education requirement. The four students not in the honors program were students entering Cabrini College as biology majors who displayed a strong interest in the Phage Genomics course during prior student visits to the college. For incoming freshmen, the Phage Genomics course replaced the required Introductory Biology laboratory course for majors. In the fall semester, students met formally twice a week for a total of 4.5 h of laboratory instruction and work, and in the spring semester students met once a week for 3 h of laboratory instruction. Also, during the spring semester, students met at a once-weekly, 1.5-h period in which instructors presented the content normally taught in the yearlong Introductory Biology lecture series. Biology majors traditionally take 3 h of lecture and 3 h of laboratory for both the fall and spring semesters at Cabrini College. Since the fall semester is labor-intensive for the phage course, we felt students needed the extra hours during the fall semester to isolate and characterize their mycobacteriophages. The spring semester was not as labor-intensive and also had no hard deadlines to meet, so we felt it appropriate to give students the lecture part of the course at this time in an abbreviated format, particularly since the majority of students were honors students.

Course Content and Organization

The Phage Genomics course was structured and organized as outlined by the HHMI SEA and previously described (Caruso *et al.*, 2009). During the fall semester, students isolated their own mycobacteriophage (phage) from a soil sample on the college's campus. The students then purified a selected phage species and isolated its genomic DNA. Students then conducted a restriction digest analysis of a portion of phage genomic DNA to confirm genomic DNA integrity and to examine if the restriction pattern was similar to that of a previously characterized phage. In the fall semester, students also sent prepared electron microscopy grids fixed with their purified phage to Lehigh University (Bethlehem, PA), an institution equipped with an electron microscope that is capable of determining phage morphology. Students reported that seeing their phage for the first time is one of the highlights of the yearlong course. The genome for one of the student-isolated phages was sent to the Joint Genome Institute (JGI) for genomic sequencing near the end of the fall semester. The phage chosen for genomic sequencing was the one that appeared the

most unusual based on both phage morphology and DNA restriction digest analysis. Students were required to justify why their particular phages were so unusual during oral presentations. Students then voted as a group on which phage, based upon its interesting characteristics, would be the one chosen for further sequence analysis. Students felt the criteria used to determine which phage genome was sent for sequence analysis, which were based on the criteria used by course instructors, were fair.

Table 1A details course logistics for the fall semester. Because of the pitfalls encountered with individual students isolating and fully characterizing their phage, we allowed several weeks for students to finish important steps before proceeding to the following steps. Due to time constraints during the fall semester, students were encouraged to spend additional laboratory time outside of the normal scheduled laboratory period. The majority of students spent at least some time outside of scheduled laboratory time to get "caught up" with their experiments and maintain a similar level of progress with their peers.

During the spring semester, students used gene-searching tools to identify likely genes contained within the class's sequenced mycobacteriophage genome. For this stage of the course, students paired up in teams of two and worked on annotating specific sections of the sequenced genome using Genemark (<http://exon.gatech.edu>) and Glimmer (www.cbc.umd.edu/software/glimmer) software tools. Students were encouraged to come to agreement on "gene calling" and were told to be prepared to justify their gene calls to the entire group. As defined here, "gene calling" indicates justification of a segment of genomic DNA containing an open reading frame coding for a protein based on the gene-searching tools employed. Students also conducted comparative genomics studies to see if their annotated mycobacteriophages were similar to the known, characterized mycobacteriophage genomes. They did this using Phamerator, a software program specifically developed for the phage course by Steve Cresawn at James Madison University (Harrisonburg, VA). This program is currently used only by institutions teaching the Phage Genomics course.

Also in the spring semester, students in the phage course participated in lectures that are part of the traditional Introductory Biology course sequence. Topics included basic biochemistry, structure and function of macromolecules, cells, and cell membranes, cellular metabolism, evolution, and ecology. Topics such as genetics, cell and molecular biology, and physiology were excluded, since students were exploring these topics in detail as part of their Phage Genomics experiments. Table 1B shows a layout of the Phage Genomics course during the spring semester. Because students performed bioinformatics during laboratory sessions in the spring semester, the laboratory was much more structured than it was during the fall semester. However, a few students fell behind in their genomic annotation work and needed to spend additional time outside of scheduled laboratory periods in the computer laboratory for their analysis.

Data Collection and Analysis

To explore the impact of participation in the Phage Genomics research course on students' interests in graduate education and their understanding of the nature and practice of science,

Table 1. Phage Genomics course logistics

Week	Lecture topic	Lab activity	Total hours (in and out of the classroom) per lab activity
A. Fall semester			
1	—	Course and project introduction	5
2	—	Isolate phage from soil and identify pure phage species	15–20
3	—		
4	—		
5	—	Continued phage purification	15–20
6	—	Isolate quality genomic DNA and perform enzymatic digests	15–20
7	—		
8	—		
9	—	Determine phage morphology via electron microscopy	5–10
10	—		
11	—		
12	—	Student determination of phage characteristics and oral presentation	5–10
13	—		
14	—	Student naming and archiving of phage sample	5
15	—		
B. Spring semester			
1	Biochemistry	Annotate phage genome	15
2	—		
3	Structure and function of molecules		
4	—		
5	Cell structure and function		
6	—		
7	Cancer case study	Conduct comparative genomic analysis	15
8	Exam		
9	Biological membranes and transport mechanisms		
10	Diabetes case study		
11	Cellular metabolism		
12	Principles of evolution		
13	Ecology	Preparation of oral presentation and poster	7.5
14	—		
15	Exam		
		Presentation at Cabrini College Undergraduate Arts, Scholarship and Research Symposium	

we developed a survey instrument to measure the impact the course had on students' consideration of pursuing graduate-level education. The presurvey was administered the first week of class during the fall semester and the postsurvey was administered during the last week of class in the spring semester. For the Phage Genomics course, all students enrolled took both the pre- and postsurvey. The anonymous surveys were based on a Likert scale to indicate the degree to which students agreed with various statements or to indicate the students' degree of interest. The survey results were analyzed using the independent group's *t* test. We used the independent *t* test because we did not have enough information to pair the data from the pre- and posttest. Differences were interpreted as significant at the level of $p < 0.05$.

To gain further insight into students' survey responses, we conducted a student focus group during the final week of class and a second, follow-up focus group the semester after students completed the course. The facilitator for both focus groups was L. R., the Director of Cabrini's Center for Teaching & Learning. Twelve students (two groups of six students) participated in the first focus-group discussions. Five students participated in the follow-up discussion, which allowed us to

understand in greater detail why students thought the course allowed them to consider different career options. Student responses from all focus-group sessions were audiotaped and transcribed for analysis. Students and the facilitator referred to one another as "student #1," etc., during focus-group interviews in order to maintain confidentiality. The student focus groups were semi-structured (Anfara *et al.*, 2002), with the facilitator asking students a list of questions constructed by the course instructors. To analyze students' focus-group responses, we used a directed content analysis of these qualitative data to identify recurring themes (Hsieh and Shannon, 2005). Themes were individually coded by three of the authors, who then compared results and came to a coding consensus.

RESULTS

Students Report Increased Interest in Graduate Education

Students in our study reported an increased interest in attending postgraduate education. The results depicted in Figure 1

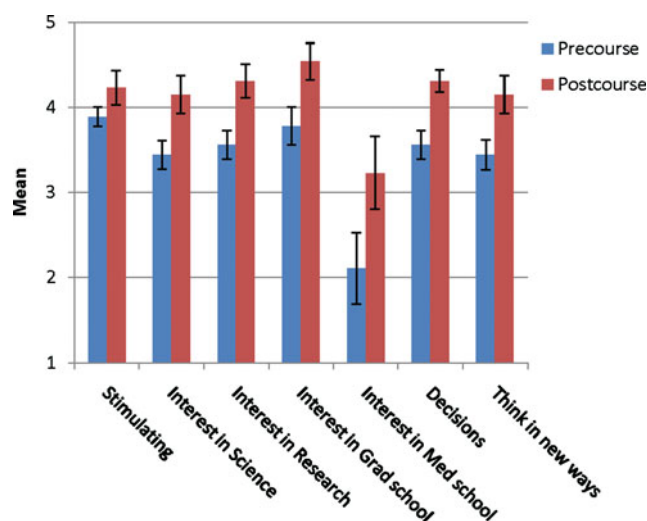


Figure 1. Student pre- and postsurvey attitude results for 13 Phage Genomics students. The items asked students how much they found the course content stimulating, how interested they are in science, how interested they are in research, in attending graduate school, in attending medical school, how much they enjoy making decisions in their work, and how the course resulted in their thinking in new ways. The bars represent the mean response. The error lines represent one standard error above and below the mean. Analysis with independent sample *t* tests showed significant increases in means from pre- to posttests ($p < 0.05$, directional hypothesis). When re-analyzed with the nonparametric Mann-Whitney test, all tests were significant except for Item 1, which measured how stimulating the students found the course content.

indicate students showed a significantly increased interest in considering graduate school after taking the course. This parallels the students' increased interest in laboratory research (Figure 1). Students taking the Phage Genomics course also showed a slight but statistically significant increase in their desire to enroll in medical school. The increased interest in medical school is consistent with the increase in overall interest in postgraduate science education.

Our survey, unlike some others (e.g., Lopatto, 2007), did not ask students to choose *between* a science PhD track and a medical school track, so it was reasonable that both interests increased. Therefore, we invited students who initially indicated in their freshman year a desire to enter medical school to participate in the follow-up focus group at the beginning of their sophomore year. Every student taking part in the follow-up focus group indicated an increased interest in pursuing science and research careers. Every student taking part in the follow-up focus group indicated they thought differently about career choices after taking the course (Table 2). One student indicated that "being on the same level as your teachers, and working with your teachers, and seeing that they had struggles too with the course, really gives you the confidence to move on to the graduate level." Perhaps seeing faculty struggle with troubleshooting experiments and the fact that the faculty "experts" did not know all the answers took away much of the mysticism of science research. This in turn may have given students the added motivation and confidence that they could do graduate-level work. Another student, a business major, who initially took the course to sat-

isfy her science course requirement, actually decided to minor in environmental science because of her Phage Genomics course experience (Table 2).

Interestingly, only one of the five students taking part in the focus group reported completely switching plans from pursuing a medical degree to pursuing graduate education in the sciences (Table 2). However, four of 12 students felt the Phage Genomics course had influenced their decision to consider graduate-level education instead of or in addition to their plans for a medical school education. One student indicated that, although she/he now has no desire to enter medical school, since taking the course she/he wants to become a lawyer and practice environmental law. Several of the other students, although still considering medical school, have indicated an increased interest in graduate education. For instance, one student indicated that "the course really did open up my eyes to see the intersection between medical school and a PhD program so now I have been looking at MD and PhD programs." Yet another student still plans to enter medical school but stated "I now want to do pediatric medical research." We take these student responses as indications that students considered a broader range of career choices that involved scientific or research foci after taking the Phage Genomics course.

Students Report a Change in Understanding about Research

Our survey results also showed students' interest in science increased significantly, even though the majority of the students began their college careers as biology majors (Figure 1). Students also reported greater interest in research in general (Figure 1). These results parallel those from other studies in which students conducting course-based research reported more positive attitudes toward both science and research (Boomer and Dutton, 2002; Elwess and Latourelle, 2004; Brodl, 2005; Howard and Miskowski, 2005; Drew and Triplett, 2008; Shaffer *et al.*, 2010).

We feel student attitudes have changed since taking the Phage Genomics course because of the research nature of the course. During the focus groups, students emphasized that the research aspect of the experience was most valuable (Table 2). Five of 12 students reported enjoying the "realness" of the course with comments like "the setbacks in lab gave us more perspective and respect for individuals that do original research." Students also appreciated not knowing the outcome of an experiment, which they viewed as different from more typical "cookbook" labs. For example, one student noted that "in chemistry lab, when you do the exercise, you already know what the outcome is going to be, and that's what makes it boring. But with the Phage Genomics lab you are not sure what the outcome is going to be" (Table 2). Furthermore, eight of 12 students indicated that freshman students benefit from the course because it allows students to truly appreciate what biological research is really like early on in their undergraduate careers. For instance, one student indicated that "most Introductory Biology courses are a repeat of labs you did in high school, unlike the phage course. I don't want to come to college and do the same things I was doing in high school because there's nothing new in that." Another student indicated that "taking the course

Table 2. Coded themes for student impressions on scientific attitudes with selected student quotes

Theme	Representative student quotations
Five of 12 students indicated the Phage Genomics course allowed them to think differently about considering graduate school education or other career options.	<p>“Being on the same level as your teachers, and working with your teachers, and seeing that they had struggles too, along with you, really gives you the confidence to move on to the graduate level.”</p> <p>“The course made me interested in becoming an Environmental Science Minor in addition to my Business Major.”</p> <p>“I honestly think the course is a lot of what graduate school or a job is like, especially because we had a number of setbacks like contaminations. That’s real science.”</p>
Four of 12 students felt the Phage Genomics course influenced their decision to pursue graduate-level education instead of or in addition to a medical school education.	<p>“Since taking the course, I’m actually considering switching my major from Pre-med to Biotechnology, and then going to grad school for forensic science or virology.”</p> <p>“If I don’t get into Medical School, I want to get my PhD in Cell and Molecular Biology and become a college professor.”</p> <p>“The course really did open my eyes to see the intersection between Medical School and a Doctorate program, where I was just at first, just narrow-minded, wanted to do the doctor route. But now, I have been looking at MD, PhD programs.”</p>
Eight of 12 students indicated the course was more beneficial for first-year students than if the course was offered later in their undergraduate education.	<p>“In regards to freshmen, I totally agree with freshmen taking the course. I mean, I think it’s a great class for freshmen to be exposed to real research experiences.”</p> <p>“Most Introductory Biology courses are a repeat of labs you did in high school, unlike the phage course. I don’t want to come to college and do the same things I was doing in high school because there’s nothing new in that.”</p> <p>“Taking the course as freshman got me excited about my major more so than doing canned experiments typical of Introductory Biology labs.”</p>
Five of 12 students valued the “realness” of the course.	<p>“The setbacks in lab gave us more perspective and respect for individuals that do original research.”</p> <p>“It’s cool to do something and know that you are actually doing it for a purpose.”</p> <p>“It’s good to know that there are other people who are out there doing the same thing you are doing and they are interested in the same type of research that you are interested in. So, that’s pretty cool.”</p>
Ten of 12 students enjoyed not knowing the outcome of an experiment as opposed to “cookbook” labs.	<p>“In chemistry lab when you do the exercise you already know what the outcome is going to be, and that’s what makes it boring, but with the Phage Genomics lab you are not sure what the outcome is going to be.”</p>
Nine of 12 students gained a sophisticated understanding of the research process and what it means to be part of a community of scientists.	<p>“The setbacks in lab gave us more perspective and respect for individuals that do original research.”</p> <p>“I now understand that anything can go wrong in a biology lab.”</p> <p>“I think the course is almost like a big phage family with all the schools involved because they are all working for the same goals.”</p>
Seven of 12 students enjoyed the hands-on aspects of the course.	<p>“We kind of just jumped right into the lab experiments from the beginning of the semester and I thought that was really cool.”</p> <p>“I would tell students to take the course because of all the hands-on activity the first year.”</p>
Eight of 12 students valued the ability to be able to learn from their mistakes.	<p>“A good thing about the lab was if you made a mistake you would be able to learn from it and then go back and repeat the experiment.”</p> <p>“I think the most exciting part of the course for me was after I failed really miserably in isolating genomic DNA and had to repeat the experiment I was able to isolate lots of it and the professors were so excited.”</p>

as freshman got me excited about my major more so than doing canned experiments typical of Introductory Biology labs.”

The student focus group indicated that seven of 12 of the students came to appreciate the hands-on nature of the phage course, with comments such as “I would tell students to take the course because of all the hands-on activity the first year.” Students also valued being able to learn from their mistakes with comments such as “A good thing about the lab was if you made a mistake you would be able to learn from it and then go back and repeat the experiment” and “I think the most exciting part of the course for me was after I failed really miserably in isolating genomic DNA and had to repeat the experiment I was able to isolate lots of it and the professors were so excited” (Table 2).

We also feel students gained a sophisticated understanding of the research process and what it means to be part of a

community of scientists (Table 2). For instance, one student indicated that “the setbacks in lab gave us more perspective and respect for individuals that do original research.” Another student stated, “I now understand that anything can go wrong in a biology lab.” Overall, student focus-group responses showed they now understand that mistakes are useful and persistence in science is important.

Another promising outcome of the course was the difference in student retention in the fall semester Phage Genomics versus the typical Introductory Biology course. Specifically, in 2009–2010, only 80.0% of the students enrolled in the traditional Introductory Biology course completed the course. Of those enrolled in the Phage Genomics course (the Introductory Biology lecture equivalent), 100% completed the year-long course. Furthermore, only 25% of students enrolled in the traditional Introductory Biology course proceeded on to Introductory Biology II in the spring. This is largely because

many incoming students declare biology as their major but change majors after taking Introductory Biology I or receive such poor grades that they need to retake Introductory Biology I before moving on to Introductory Biology II.

DISCUSSION

A traditional Introductory Biology course typically involves lectures and laboratories that serve to communicate established knowledge to the students. Too often, this course setup emphasizes learning content at the expense of learning scientific processes, and fails to engage students in how science really works. There is reason to believe this approach to teaching prompts students to reject majoring in science or considering graduate education or careers in science research (Brenner, 2003; National Research Council [NRC], 2003, 2007; Handelsman *et al.*, 2007). We show that a yearlong hypothesis-driven laboratory course not only leads to increased student enthusiasm about science but also notably increases student desire to pursue science, particularly graduate-level studies, as an occupation.

The most notable outcome of our work is the increased interest in graduate education expressed by our students. This is particularly notable because previous research from Lopatto (2003), Hunter *et al.* (2007), and Seymour *et al.* (2004) have described how research internships and other undergraduate research experiences clarify or confirm rather than change undergraduate decisions regarding pursuit of graduate education. Our study demonstrates a change in students' career interests, which we hypothesize may be due to the research experience occurring early in the undergraduate careers of these students. We believe that students early in their career may be more willing to think about career paths. Several students articulated that they felt on an equal footing with their professors and that seeing their professors not knowing the outcome of an experiment or not knowing all of the answers gave them confidence they could undertake graduate-level work. Other students, although still considering medical school as their first career choice, are now considering graduate school opportunities as well. This might be particularly encouraging for those students who are interested in science but feel coming into college that they do not have a strong enough aptitude to contemplate graduate-level work.

The research in the classroom model is gaining even greater momentum. For instance, Woodin *et al.* (2010) note that the NSF has recently funded 29 projects to develop course-based undergraduate research experiences in the past year alone. However, to our knowledge, whether these types of courses have the potential to change student attitudes and career choices for nonmajors has not been the subject of study. Caruso and colleagues (2009) offered the Phage Genomics course at the University of Maryland exclusively to nonmajors and have shown that nonmajors are fully capable of mastering the techniques students employ to isolate and characterize phage. It would be interesting to see if nonmajors' attitudes about science change and whether they consider the possibility of science as a career option after their phage experience. The phage course at Cabrini College was open to all honors students,

biology majors, and nonmajors. Three of our students were nonmajors, and what was particularly encouraging was that one of them, a business major, actually decided to minor in environmental studies after taking the phage course.

Although these are preliminary results at a small liberal arts college, we were very pleased and somewhat surprised that beginning undergraduate students showed such a statistically significant degree of interest in graduate school education after taking the phage course based on our survey instruments. This has inspired the faculty teaching the course to offer more opportunities in our Phage Genomics course to discuss the many possible career paths students can embark upon with a biology degree. Doing so will hopefully have an even more profound influence on students deciding on careers in the biological sciences. Since the Phage Genomics course touches aspects across different domains of life science, such as microbiology, genetics, and bioinformatics, we also plan on providing information to students about interdisciplinary fields and applying biology to interdisciplinary careers. This should be of especial interest to non-science majors.

Most of the students enrolled in Phage Genomics at Cabrini College were in the honors program, so it is possible that our results are not indicative of the typical biology student enrolled in the yearlong Introductory Biology laboratory course. To address this issue in the future, we plan on enrolling all students entering Cabrini College with a declared biology major in the Phage Genomics course. By doing so, we can compare the change in attitudes of representative Introductory Biology students with honors students taking the Phage Genomics course.

Future studies are also aimed at determining whether there is a causal relationship between particular Phage Genomics course elements and career and/or educational intentions. We will be reassessing both students currently enrolled in the current Phage Genomics course, as well as upper-level students who were enrolled in Phage Genomics during their freshman year. It will be interesting to determine their perspectives regarding the influence of the course on their career choice paths up to and after graduation. We are also interested to see whether there are greater retention and graduation rates of science majors taking the Phage Genomics course.

ACKNOWLEDGMENTS

We thank Erin Dolan, Assistant Professor of Biochemistry in the Department of Biochemistry at Virginia Tech University, and Editor in Chief of *CBE—Life Sciences Education*, for critical review of our manuscript and for the many helpful ideas that were incorporated into the manuscript. We also thank the Monitoring Editor, Mary Lee S. Ledbetter, Professor in the Department of Biology at the College of the Holy Cross, for thoughtful suggestions for and improvements to our original manuscript. The authors also thank the American Society of Microbiology's Biology Scholars Program (NSF Award 0715777) for helping to develop the research ideas incorporated into the manuscript. The student pre- and postsurvey instruments were approved by the Cabrini College IRB as Phage Genomics Attitude Survey #BIO10-03. The student focus-group work was approved by the Cabrini College IRB as Student Focus Group Surveys for Honors Biology course as #BIO10-02. Support for this work was provided by HHMI-SEA.

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