Introducing Primary Scientific Literature To First-year Undergraduate Researchers

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In the past decade, recommendations for reforming the way we teach science to undergraduate students have surged. In particular, emerging research suggests that students benefit from self-guided learning practices that are focused on core concepts and competencies rather than on content coverage. (National Research Council 2003, 2007, 2009; American Advancement for the Advancement of Science 2011)

It is well-established that performing undergraduate research greatly enhances the educational experience (Lopatto 2004; Seymour et al. 2004). The process of researching a topic in the primary literature, designing experiments, implementing those experiments, and analyzing the results is critical for developing the analytical skills necessary to become a scientist. Furthermore, students benefit from undergraduate research experiences through increased graduation rates (Nagda et al. 1998), increased pursuit of graduate education (Kreme et al. 1990; Hathaway et al. 2002), and increased interest in science careers (Fitzsimmons et al. 1990).

Our institution, North Carolina State University, has a strong culture of mentoring upper-level undergraduates in research projects within investigator-funded research labs. First-year undergraduates, however, can find it difficult to secure positions in research laboratories for varying reasons (e.g., lack of personal confidence, labs being filled before students arrive on campus, reluctance of faculty mentors to take on "unproven" students). Therefore, some students with great potential withdraw from STEM (science, technology, engineering, and mathematics) disciplines before they have a real chance to become engaged in the discipline beyond simple coursework.

To provide some of our first-year students with an authentic research experience, we participated in a program funded by the Howard Hughes Medical Institute, the Science Education Alliance-Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) program (http://www.hhmi.org/grants/sea/index.html). In this program, students each isolated and characterized a novel mycobacteriophage in the first semester, and then annotated the genome of one of the phages in the second semester. The student experience at our institution incorporated critical aspects of undergraduate research, including: project ownership; keeping a detailed laboratory notebook; disseminating research findings in both oral and written forms; and— the focus of this article—reading and discussing relevant primary scientific literature.

Other papers have been published on introducing undergraduates to the scientific literature. Notably, the C.R.E.A.T.E. approach (consider, read, elucidate hypotheses, analyze and interpret data, think of the next experiment) has been shown to enhance upper-level undergraduates' analytic abilities, positively affect students' confidence in understanding the literature, and provide insight into the scientific process in an intensive course focusing on primary literature (Hoskins et al. 2011). Another study showed that weekly journal clubs, in conjunction with independent undergraduate research and opportunities to present the research, increased student confidence and scientific literacy and facilitated the transition to graduate school for students in their final three undergraduate semesters (Kozeracki et al. 2006).

Not surprisingly, most studies investigating the benefits of introducing undergraduates to the scientific literature have focused on upperclassmen. One study that did center on first-year students examined the integration of information and science literacy. However, students only read one "model" journal article and selected one journal article to read on their own in a general biology course. The authors of the paper state that while this was a start in introducing the students to the literature, it was not sufficiently intensive to produce literate graduates (Porter et al. 2010).

The unique aspect of our research is that it focuses on first-year students in the context of an original research experience, in which students read literature relevant to their own work. In our courses, reading of primary scientific literature was introduced early, in a low-stakes manner that then required written summaries, classroom discussion, and, gradually, full student responsibility for guiding classroom discussion of the assigned research articles. At the completion of the second semester, students reported a high degree of exposure to and confidence in reading the scientific literature. They also reported that reading the literature increased their depth of understanding of their own research and their ability to communicate their research to others.

Project Outline

All participants were first-year students at North Carolina State University (NCSU), although many had sophomore standing due to either Advance Placement credit or participation in an "early college" high-school curriculum in which they earned college credits. All students were enrolled in a two-semester, first-year laboratory research course (described below). Students chose the course on their own and since it did not fulfill requirements toward any major, the students were for the most part, high achieving students who were self-motivated to conduct research; ~75 percent were in the university's honors program.

As noted, this two-semester course was part of the SEA-PHAGES program. The following discussion focuses on the third year we offered this program. At NCSU, we refer to the fall semester as Phage Hunters and the spring semester as Phage Genomics. The course is primarily an experiential-learning environment, with minimal time devoted to lectures. In Phage Hunters, students individually isolated a novel bacteriophage (phage) that infects *Mycobacterium smegmatis* from the environment, purified it, observed its plaque morphology, characterized its structural morphology by electron microscopy, isolated its genomic DNA, and performed restriction analysis of the DNA. Toward the end of the semester, students voted on and selected the "most interesting" phage; its genomic DNA then was submitted for sequencing over the winter break.

In the spring semester's Phage Genomics, we divided the students into four teams of four students. Once we received the finished genome, we divided the sequence into four parts and each team of students worked on annotating a different section of the genome.

During the course of the two semesters, students were given multiple opportunities to communicate their own research, as outlined below. Assignments were graded and students were provided with detailed, written constructive feedback. Because of the nature of the projects, students presented their work individually in Phage Hunters, and then in groups in Phage Genomics.

During the first semester (Phage Hunters), each student made a three-minute oral presentation early in the semester. The students also each made an oral mid-term presentation on their research, followed by a mid-term lab report on their research in the format of a standard biology journal article. Students also submitted final written lab reports and gave final oral research presentations to the class.

During the second semester (Phage Genomics), each team of students made three group presentations regarding the work they were doing in annotating their portions of the bacteriophage's genome. These were followed by a capstone poster presentation at the university-wide undergraduate research symposium ("teams" were shuffled based on students' interests in three topics chosen for posters). The grading rubric is included in Appendix 2.

Students also read six papers over the course of the two semesters. In the first semester, they read one essay and two primary journal articles. In the second semester, they read three primary journal articles. The papers that were read and discussed in the course are listed in Table 1. Over the course of the two semesters, students were provided with an increasingly challenging format for discussions of these essays and journal articles; thus, they became increasingly more responsible for dissecting the procedures used and results of the research described in the written material.

Regarding the essay students read during the first semester, each student read the paper prior to the discussion and came to class prepared with three interesting points presented in the article and one question they had about the paper. The discussion was instructor-led, with students contributing from their written summaries.

Students wrote more detailed analyses of the second and third papers read during the first semester. These written discussions (rubric provided in Appendix 1) required students to give an overview of the purpose of the work, describe two of the experiments or figures in the paper, and then summarize the conclusions of the paper. The discussion of the second paper read was instructor-led, but required active student participation in describing the goals of the paper, the individual figures/results, and the conclusions. The discussion of third paper was primarily student-led. Individual students volunteered in advance to present one figure in the article, and an instructor guided the class in tying all of the pieces of the paper together. During the first semester, we did not issue grades for the oral discussions of the three journal articles. Grades associated with those articles were based on written assignments and class participation.

Table 1. Papers Read and Discussed by Students

	Semester 1, Phage Hunters, wet lab portion
1	Villarreal, L. P. Dec. 2004. Are Viruses Alive? *Scientific American*
2	Debarbioeux, L, D. Ledu, D. Maura, E. Morello, A. Criscuolo, O. Grossi, V. Balloy, and L. Touqui. 2010. Bacteriophages Can Treat and Prevent *Pseudomonas aeruginosa* Lung Infections. *JID.* 201:1096-1104
3	Belle, A., M. Landthaler and D. A. Shub. 2002. Intronless homing: site-specific endonuclease SegF of bacteriophage T4 mediates localized marker exclusion analogous to homing endonucleases of group I introns. *Genes Dev.* 16:351-362.
	Semester 2, Phage Genomics, computer lab portion
4	Abuladze, N. M. Gingery, J. Tsai, and F. Eiserling. 1994. Tail Length Determination in Bacteriophage T4. Virology. 199:301-310.
5	Xu, J., R.W. Hendrix, and R. L. Duda. 2004. Conserved Translational Frameshift in dsDNA Bacteriophage Tail Assembly Genes. *Molecular Cell.* 16:11-21.
6	Malys, N. and R. Nivinskas. 2009. Non-canonical RNA arrangement in T4-even phages: accommodated ribosome binding site at the gene 26-25 intercistronic junction. *Molecular Microbiology*. 73:1115-1127.

In the second semester, students were split into three groups for the reading assignments. Each team was assigned one journal article and was entirely responsible for the in-class presentation of that article. An additional rubric (see Appendix 2) was employed for these presentations of journal articles. Students also were required to turn in a written report as described above (Appendix 1) for the two papers their group was not responsible for presenting.

Students' Assessment of Their Learning

At the end of the second semester, students were asked to answer questions about their gains in learning using an optional, anonymous survey we prepared using the Qualtrics survey tool (www.qualtrics.com).

Table 2. Student Survey Questions

1	Prior to this course series, I had considerable exposure to reading primary scientific literature (journal articles).
2	At the conclusion of this course series, I had considerable exposure to reading primary scientific literature (journal articles).
3	Prior to this course series, I was confident in reading and understanding primary scientific literature (journal articles)..
4	At the conclusion of this course series, I was confident in reading and understanding primary scientific literature (journal articles).
5	Reading and discussing primary scientific literature gave me a deeper understanding of my own research
6	Reading and discussing primary scientific literature increased my ability to present my work to others
7	Reading and discussing primary scientific literature improved the quality of my poster presentation at the campus-wide undergraduate research symposium

Survey questions are shown in Table 2. All questions in the survey used a Likert scale with 1 = strongly disagree and 5 = strongly agree. The questionnaire asked students to assess both their exposure to and confidence in reading primary scientific literature at the conclusion of both semesters. They were also asked to reflect on their exposure to research literature and their confidence level regarding their ability to read it and understand it at the start of the course. We did not survey the students at the start of the course because we assumed that it was likely that first-year students did not truly understand what it meant to "read the literature" at that time and might over-estimate their skills. Permission was obtained from the North Carolina State University Institutional Review Board to perform the survey. Although we have completed three years of teaching this course in a similar manner, with similar outcomes, this article focuses only on students' assessments collected after the third year.

On the whole, the 16 students surveyed in the third year reported little exposure to and little confidence in their ability to read primary scientific literature prior to the start of the course. However, they reported that they had a great deal of exposure to primary scientific literature by the end of the two-semester course, as well as a high level of confidence in reading and understanding the research articles On a 5-point Likert scale, the mean student rating for exposure to the literature increased from 2.44 to 4.44 over the two-semester course. Confidence in reading and understanding the literature increased from a mean score of 2.06 to 4.25 at the end of the course.

Students all either agreed or strongly agreed that reading and discussing related primary literature provided a deeper understanding of their own research. The mean score on the 5-point Likert scale was 4.44. Furthermore, students reported that reading and discussing the primary literature helped them communicate their own research to others (mean Likert score of 4.19). And more specifically, students felt that their experience dissecting the literature improved the quality of their poster presentations at the campus-wide undergraduate research symposium (mean Likert score of 4.06).

Faculty observed that the students clearly demonstrated the ability to translate what they read in the literature to their own work. The students' improved ability in communicating effectively, not only in their journal article presentations, but about their own research also was apparent to the instructors of the course. It was further validated when one student group's poster won an award at the campus-wide undergraduate research and teaching symposium, where they were competing primarily against upperclassmen in faculty research labs.

Conclusion

We describe a successful method for introducing first-year undergraduates to primary scientific literature using an incrementally challenging format that starts with faculty guiding the students through discussion of academic research papers, then gradually giving more responsibility for leading the discussions to the students. Students reported a dramatic increase in their confidence regarding their ability to read the literature, as well as greater insight into their own research. This experience enhanced their ability to discuss their own work with others, both casually and in a formal presentation environment. Students also demonstrated the ability, in multiple cases, to incorporate the findings and approaches taken in the literature into their own research. Instructors found that students improved in the oral presentation of their research, which was validated by positive feedback from other faculty, judges, and students at the campus-wide undergraduate research symposium. This improvement was likely the result of the multiple opportunities provided throughout both semesters of the course to present their research and also to present their conclusions about the research literature they had read.

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Appendices

Appendix 1. Rubric for written summary of journal articles.

Evaluation Method

2 pts. - Overview
6 pts. - Results
2 pts. - Summary

The write-up should be one page or less, 10 or 12 pt (preferred) font, single spaced.

When evaluating journal articles, look for and address the following:

Overview

-Provide title, authors, and journal reference.
-An explicit statement of the purpose and focus of the current work.

In other words, put the work in context and state what the authors are trying to prove, disprove, or find out.

Results

For at least two experiments, summarize:
-What question was addressed?
-What was done (broadly, not specific protocol steps)?
-State the result obtained.

Decide in advance what experiments are best to cover. I suggest you
read the Results section of the paper, referring to the Materials and Methods for details and clarifica tion as you go along.

Summary

-What did you learn?
-What do the authors state still needs to be done?
-Was the paper good or bad? Why?

Appendix 2. Oral presentation rubric.

Group presentations should each last approximately 15 minutes (questions/discussion not included in time-limit). Depending on the group, there will be 4-5 students per group. Each student needs to participate in the presentation of each assignment.

Grading Rubric:

Remember, you are being graded on all presenters' style, not just your own. This means you should help the other presenters practice! You must present the background information, the question(s) posed in the work, describe the outcome and meaning of each experiment, and discuss the relevance of the work, overall.

Content (40 points)

Provides pertinent information

Sound, rational data analysis

Organization (20 points)

Information logically introduced, arranged, and explained

Presentation (10 points)

Speaks clearly and loudly

Uses appropriate language/terminology

Slides are visually appealing

Group Peer Evaluation (30 points)

For each presentation, each member of the group will anonymously grade the other group-members' participation in the analysis phase and presentation preparation. Up to 30 points can be assigned. We will add the average peer score for each student to his or her overall grade rubric to come up with the individual scores. This means that 70 percent of the grade is shared among group members, and 30 percent of the student's grade is based on his or her peer participation assessment.

For each peer evaluation, we request submission of both the number score and a short statement with your reasoning for the score. Peer evaluations are confidential.

The instructors reserve the right to take off additional points (up to full credit for the presentation) if any student shirks the group responsibility.

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