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 and 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 second 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 (Hopkins 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 (Kozerczak 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 informatics 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 litera-
Because of the nature of the projects, students presented were provided with detailed, written constructive feedback. And each team of students worked on annotating a different finished genome, we divided the sequence into four parts and each team of students worked on annotating a different finished genome, we divided the sequence into four parts. 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 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.

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.

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### Table 1. Papers Read and Discussed by Students

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<tr>
<th>Semester 1, Phage Hunters, wet lab portion</th>
<th>Semester 2, Phage Genomics, computer lab portion</th>
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### Table 2. Student Survey Questions

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<th>Question</th>
<th>Rating</th>
<th>Description</th>
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<tr>
<td>1. Prior to this course series, I had considerable exposure to reading primary scientific literature (journal articles).</td>
<td>Prior to this course series, I had considerable exposure to reading primary scientific literature (journal articles).</td>
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<tr>
<td>2. At the conclusion of this course series, I had considerable exposure to reading primary scientific literature (journal articles).</td>
<td>At the conclusion of this course series, I was confident in reading and understanding primary scientific literature (journal articles).</td>
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<tr>
<td>3. Prior to this course series, I was confident in reading and understanding primary scientific literature (journal articles).</td>
<td>Prior to this course series, I was confident in reading and understanding primary scientific literature (journal articles).</td>
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<td>4. At the conclusion of this course series, I was confident in reading and understanding primary scientific literature (journal articles).</td>
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<td>5. Reading and discussing primary scientific literature gave me a deeper understanding of my own research.</td>
<td>Reading and discussing primary scientific literature gave me a deeper understanding of my own research.</td>
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<tr>
<td>6. Reading and discussing primary scientific literature increased my ability to present my work to others.</td>
<td>Reading and discussing primary scientific literature increased my ability to present my work to others.</td>
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<tr>
<td>7. Reading and discussing primary scientific literature improved the quality of my poster presentation at the campus-wide undergraduate research symposium.</td>
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Survey questions are shown in Table 2. In 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 had 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 confi-
Because of the nature of the projects, students presented were provided with detailed, written constructive feedback. As outlined below. Students chose the course on their own and since it did not fulfill requirements toward any major, the students 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.

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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.

During the second semester, three 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 about questions about their gains in learning using an optional, anonymous survey we prepared using the Qualtrics survey tool (www.qualtrics.com).

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<th>Table 2. Student Survey Questions</th>
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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 confi-
dence 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). 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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**References**


**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, refer to the Materials and Methods for details and clarification 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
dence 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.

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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 drinks the group responsibility.

Susan Carson
North Carolina State University, sue_carson@ncsu.edu

Susan Carson, PhD, is the academic coordinator of the biotechnology program, teaching associate professor of plant biology, and the director of the National Science Foundation-funded Integrative Molecular Plants Systems Research Experience for Undergraduates at North Carolina State University. She graduated from Rutgers University with a bachelor of science in biotechnology and from the University of North Carolina, Chapel Hill, with a PhD in microbiology. Her area of scientific expertise is molecular mechanisms of bacterial pathogenesis, although her current research focuses on the genomics of bacteriophages, developing biotechnology applications related to phages and phage products, and functional microbial genomics and RNA diversity. Miller teaches graduate-level microbial genetics, and co-teaches with Susan Carson the course described in this article. He is the author of more than 40 peer-reviewed research papers and other publications.

Introductory Biology Course Involves Every Student in Authentic Research

Clark A. Lindgren, David Lagatta, Grinnell College
Lindgren@grinnell.edu

For many years our general approach to building research experiences into the biology curriculum involved sprinkling pieces of the scientific process throughout our courses. For example, we added exercises that exposed students to the scientific literature and mini-research projects that taught students some of the rudiments of scientific inquiry.

Although we were generally pleased with the value of these activities, several factors led us to consider a more radical approach. First, since most of these activities were only feasible in the laboratory sections of our courses, because labs hold fewer students and are scheduled for longer blocks of time, students often failed to connect their inquiry-based activities with the other pedagogical goals of the course. Second, the time required to include these inquiry-based elements crowded out a curriculum already packed with mountains of facts and concepts.

The resulting need to expand our core introductory sequence to four courses created scheduling challenges for our students, especially students who did not intend to major in biology but needed or wanted a biology course for other academic goals, such as a biological chemistry major, a neuroscience concentration, or general education requirements. Finally, the introduction of more research activities into our curriculum, where our students experienced the thrill of authentic research, whetted our appetites to do more. We became intrigued with the prospect of taking this approach to the next level.

Thus, after running some pilot courses, we introduced an entirely new biology curriculum in the fall of 2000, which began with a course called Bio 150: Introduction to Biology Inquiry. Unlike our previous efforts, Bio 150 did not simply include bits of research-like activities; rather, the course was designed to fully immerse students in biological research.

Following the ancient Chinese proverb, “Tell me and I will forget, show me and I will remember, involve me and I will understand,” we tell our students very little in this first course in biology. Instead, we show them the scientific literature, an organism or groups of organisms, some experimental techniques and methods for analyzing and presenting scientific data, and then, most importantly, we involve each student in a novel research project for the duration of the semester.

All students who wish to study biology at Grinnell College, both prospective majors and non-majors, must first take Bio 150. To meet the demands of approximately 200 students, we offer eight or nine sections of Bio 150 each year, with enrollment limited to 24 students per section. Each section is taught by a member of the biology department who has created a unique course centered on a topic that is typically related to the faculty member’s primary research interest. This leads to a rich and diverse selection of courses from which students may choose, including “Animal Locomotion,” “Prairie Restoration,” “Biological Responses to Stress,” “The Effects of Climate Change on Organisms,” “Survivore,” “Sexy Beast,” “The Language of Neurons,” “The Sex Life of Plants,” “Plant Genetics and the Environment,” and “Cell Fate: Calvin or Hobbes.”

By limiting student enrollment to 24, each section can fit into one of our teaching laboratories, which allows considerable flexibility in scheduling class times. Sections are usually offered in either two three-hour or three two-hour blocks of time per week. This permits laboratory work to be seamlessly mixed with more formal didactic methods, hopefully mitigating the disconnect students often experience between lab and lecture. In every section of Bio 150, students spend most of the class time at the lab bench or field station trying to answer a “real” question (that is, a question to which no one, not even the instructor, knows the answer). Each semester culminates with a joint poster session in which...