A writing-intensive course improves biology undergraduates’ perception and confidence of their abilities to read scientific literature and communicate science

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Brownell SE, Price JV, Steinman L. A writing-intensive course improves biology undergraduates’ perception and confidence of their abilities to read scientific literature and communicate science. Adv Physiol Educ 37: 70–79, 2013; doi:10.1152/advan.00138.2012.—Most scientists agree that comprehension of primary scientific papers and communication of scientific concepts are two of the most important skills that we can teach, but few undergraduate biology courses make these explicit course goals. We designed an undergraduate neuroimmunology course that uses a writing-intensive format. Using a mixture of primary literature, writing assignments directed toward a layperson and scientist audience, and in-class discussions, we aimed to improve the ability of students to (1) comprehend primary scientific papers, (2) communicate science to a scientific audience, and (3) communicate science to a layperson audience. We offered the course for three consecutive years and evaluated its impact on student perception and confidence using a combination of pre- and postcourse surveys and coded open-ended responses. Students showed gains in both the perception of their understanding of primary scientific papers and of their abilities to communicate science to scientific and layperson audiences. These results indicate that this unique format can teach both communication skills and basic science to undergraduate biology students. We urge others to adopt a similar format for undergraduate biology courses to teach process skills in addition to content, thus broadening and strengthening the impact of undergraduate courses.

undergraduates; writing; communication; primary literature; curriculum; Likert-scale surveys; neuroimmunology

two of the most important skills that we can teach as part of an undergraduate biology curriculum are effective communication and comprehension of primary scientific literature. Communication as a core competency for undergraduate biology students has been emphasized in reports such as Vision and Change in Undergraduate Biology Education: a Call to Action (1), Scientific Foundations for Future Physicians (2), and BIO2010: Transforming Undergraduate Education for Future Research Biologists (26). Important communication skills for biology undergraduates include verbal and written communication to a wide variety of audiences, including other scientists (21, 29, 30) as well as the lay public (4, 15, 23, 27). An equally important and related skill is the ability to critically read and comprehend primary scientific papers. Primary scientific literature is the gold standard by which scientists communicate their results to other scientists, so exposure to and practice dissecting primary literature are important corollaries to communication skills (16). Although some published literature suggests that primary research papers are too difficult for undergraduates (24, 28, 32), there is a significant body of literature that suggests that reading primary scientific papers can help undergraduates develop scientific process skills (9, 18, 20, 25) and improve self-confidence in scientific thinking (25).

While the overall importance of communication skills is generally accepted, undergraduate biology courses infrequently offer opportunities for students to improve on these skills (5). Even fewer biology courses focus on improving communication as an explicit goal of the course. To address this gap in the undergraduate curriculum, we developed a novel undergraduate neuroimmunology course that uses a writing-intensive format to improve students’ abilities to comprehend primary scientific literature and communicate scientific concepts to diverse audiences. This course is an upper-level basic science course, which is taken after the basic requirements of introductory biology have been completed. It covers the same amount of biology content as a typical upper-level course, but does so with an emphasis on improving science communication.

Specifically, our research questions were as follows: Does our writing-intensive neuroimmunology course have an impact on undergraduate students’:

1. perception of their ability to read primary scientific papers?
2. confidence in their ability to communicate to other scientists?
3. confidence in their ability to communicate to a layperson audience?

Here, we describe the structure and format of a writing-intensive course that was taught for three consecutive years through the Immunology Program at Stanford University. We also report the evaluation of this curriculum from the second and third year, including results from pre- and postcourse surveys and coded open-ended questions.

METHODS

Course Content and Structure

Course goals. The course objectives were threefold: 1) to improve the ability of students to understand primary scientific papers, 2) to improve the ability of students to communicate science to scientists, and 3) to improve the ability of students to communicate science to laypeople. An additional goal of the course was to convey basic scientific principles of neuroimmunology, but assessing scientific content was not the focus of this evaluation; we chose to evaluate only process skills, not content.
Notably, the course was not designed for students interested in pursuing careers in journalism but rather as a basic science course for students interested in careers directly related to science (e.g., medicine, research, academia). Demographic data indicated that, indeed, the majority of undergraduates enrolled in the course were biology majors interested in pursuing careers in medicine or research (Table 1). The majority of students enrolled in the course based on their interest in neuroimmunology, as opposed to an interest in writing or communication (Table 1). This was our desired target population of students: those not predisposed to an interest in science communication and more representative of practicing scientists and physicians. In addition to our desire to explicitly teach science communication skills, we believed that a writing-intensive format would be a more effective way to assess content mastery rather than traditional exams based on the writing-to-learn literature (3, 11, 13, 30, 31). Thus, writing exercises served dual purposes: to test the students’ understanding of the material and to encourage students to read primary scientific papers deeply and convey the material in a thoughtful way (21, 30).

Course content. The course was an upper-level undergraduate neuroimmunology course with a prerequisite of introductory biology. This course focused on the molecular and cellular interactions between the immune system and the brain and is composed of two lectures and one discussion section every week. Although a fairly nascent field, an upsurge of neuroimmunology research over the past 20 yr has laid a solid foundation on which to base a curriculum. Many of the experts in the field are resident faculty members at Stanford (University of California-San Francisco (UCSF), Prof. Richard Daneman, Paul Costello, Natalie DeWitt, Bruce Goldman, Professor Donald Kennedy, Jonathan Rabinovitz, and Evelyn Strauss. Prof. Ben Barres, Prof. Ajay Chawla (UCSF), Prof. Firdaus Dhabhar, Prof. May Han, Prof. David Julius (UCSF), Prof. Emmanuel Mignot, Prof. Theo Palmer, Prof. Robert Sapolsky, Prof. David Schneider, Prof. Carla Shatz, Prof. Lawrence Steinman, and Prof. Tony Wyss-Coray).

Course assignments and structure. The weekly course assignments were composed of four core components: 1) attending a lecture presented by an expert that provided background information, 2) reading a primary scientific paper related to the lecture, 3) writing a one-page summary of the paper in the style of articles found in the New York Times (NYT style), and 4) discussing the paper in depth during a small discussion section (Fig. 1). While lectures provided background information in neuroimmunology that was critical for understanding the scientific papers, the writing assignments and discussion sections were focused exclusively on the primary scientific papers and how to best convey that information.

Every week, students attended two 75-min lectures taught by experts who specialize in neuroimmunology topics, as previously mentioned. Each iteration of the course included one lecture featuring a panel of professional science writers and scientists involved in science communication. These panelists gave students an expert perspective on how to communicate complicated scientific concepts to a lay audience, drawing examples from the students’ own writing excerpts. During the course, students also attended at least one mandatory informal lunch or dinner discussion with one of the lecturers. This gave students the opportunity to ask questions about the lectures or primary scientific papers as well as become more comfortable talking with professors outside of the classroom.

The hallmark assignment of this course was a Science Tuesday NYT-style summary of a primary scientific paper. We asked students to translate the main findings of a primary scientific paper into a one-page summary directed toward a layperson audience. As topics

### Table 1. Demographics of students enrolled in this course in 2010 and 2011

<table>
<thead>
<tr>
<th>Sex</th>
<th>Class Year</th>
<th>Major</th>
<th>Future Plans</th>
<th>What Was the Primary Reason for Taking the Course?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medical School</td>
<td>Graduate School in Basic Science</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Biology</td>
<td>Other</td>
</tr>
<tr>
<td></td>
<td>Sophomore</td>
<td>Junior</td>
<td>Senior</td>
<td></td>
</tr>
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</table>

For majors, Human Biology is an interdisciplinary biology major; “other” majors included German Studies, Anthropology, and Bioengineering.

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1 Lecturers (resident faculty members at Stanford University unless otherwise noted) over the 3 yr included Prof. Ben Barres, Prof. Ajay Chawla [University of California-San Francisco (UCSF)], Prof. Richard Daneman (UCSF), Prof. Firdaus Dhabhar, Prof. May Han, Prof. David Julius (UCSF), Prof. Emmanuel Mignot, Prof. Theo Palmer, Prof. Robert Sapolsky, Prof. David Schneider, Prof. Carla Shatz, Prof. Lawrence Steinman, and Prof. Tony Wyss-Coray.
for these summaries, we chose primary research papers written by guest lecturers published within the last 5 yr that we deemed reasonably accessible to undergraduates. The purpose of this exercise was not to have students produce a polished piece of science journalism but rather to use this style of writing as a means to assess their understanding of the paper and their ability to communicate science to a layperson audience. We provided specific guidelines for these assignments (Table 2), which standardized student summaries and enabled us to use them as a proxy for student ability to communicate science rather than to assess their basic writing ability or their ability to editorialize about a scientific issue.

The ~15 students that enrolled in the course each year wrote a total of five NYT-style articles based on primary scientific papers over the duration of the course. Students submitted all assignments by e-mail. We gave students specific written feedback on each article by graduate student TAs, both via edits within the document and one to two paragraphs of general suggestions at the end of each paper. We gave each summary a grade of either a check minus, check, or check plus and allowed students who received either a check or a check minus to rewrite the assignment, implementing our suggestions for a regrade. We observed that the majority of students (~95%) who received lower scores revised and resubmitted their assignments.

Students also attended a 60-min discussion section once a week led by a graduate student TA. Only five to eight students were in each section; the small size encouraged student participation. TAs led a discussion about the primary scientific paper during section. We required students to submit the NYT-style summary electronically before the beginning of the section. This ensured that they had read and thought about the paper before coming to the section and led to a productive discussion about the specifics of the paper. During the discussion, students interpreted each figure, identified the main points, and discussed the broader significance of the paper as it related to the field of neuroimmunology.

As a final assignment for the course, students wrote both a scientific review-style article and a NYT-style article on any topic of their choosing in neuroimmunology (Fig. 2). The review article was a three-page summary of primary scientific research in a given area and was directed to other scientists as an exercise of formal scientific writing. Throughout the course, students read review articles pertaining to broader topics in neuroimmunology as examples of this style of writing. Students received written feedback from graduate student TAs on both an outline and first draft of their review article, which allowed them to make iterative changes to it.

In tandem with the review article, students wrote a NYT-style summary of one of the more recent primary scientific articles described in their scientific reviews. TAs only provided guidance about which primary article to select; students did not receive any feedback on their writing from TAs on this assignment. However, students both gave and received peer critiques on their drafts. Additionally, we required students to give their draft summaries to two laypeople who had not taken introductory college biology for a “layperson critique,” a more authentic measure of how effective the student was in communicating the science to the target audience. Laypeople were selected by the students and were often family or close friends. They gave oral feedback to the student on the summary, which the student then synthesized in a one-page written report that he or she turned in. Thus, the final version of their NYT-style summary was a synthesis of both peer critique and layperson feedback. Students submitted the final versions of the review article and the NYT-style summary for grading by the TAs.

Course Evaluation

This course was offered to 12 undergraduates in 2009, 15 undergraduates in 2010, and 14 undergraduates in 2011. The writing-
intensive format with extensive feedback and iterative assignments limited the size of the class.

To evaluate the effectiveness of the course, we used an approach combining open-ended postcourse questions, pre- and postcourse surveys, and analysis of student writing. In 2009, we used traditional teaching evaluations (data not reported). We assessed the course through pre- and postcourse surveys and open-ended questions for 2010 and 2011.

Open-ended questions. In 2010, we gave students a postcourse assessment with the following questions related to our objectives for the course:

1. Do you think your ability to understand primary scientific papers has improved as a result of this course? Please explain why or why not.
2. Do you think your ability to communicate science verbally to other scientists has improved as a result of this course? Please explain why or why not.
3. Do you think your ability to communicate science verbally to other scientists has improved as a result of this course? Please explain why or why not.
4. Is it important for research scientists to be able to communicate their conclusions to a layperson audience? Please explain why or why not.
5. What is the most important thing you learned in this class?

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3. Do you think your ability to communicate science verbally to other scientists has improved as a result of this course? Please explain why or why not.
4. Is it important for research scientists to be able to communicate their conclusions to a layperson audience? Please explain why or why not.
5. What is the most important thing you learned in this class?

Closed-ended questions. The precourse survey consisted of three Likert-style blocks of questions that focused on student confidence in communication skills, student perceptions of reading comprehension of primary scientific literature, and student attitudes toward communication of science to the public (22). Students answered questions on a five-point scale from “strongly disagree” to “strongly agree.” The precourse survey also gathered demographic information.

We recorded student responses to these questions, and two independent raters coded the responses using grounded theory (10). We established interrater reliability to be over 80%. For coding disagreements, discussion between the two raters determined a consensus code.

Pre- and postcourse surveys. The precourse survey consisted of three Likert-style blocks of questions that focused on student confidence in communication skills, student perceptions of reading comprehension of primary scientific literature, and student attitudes toward communication of science to the public (22). Students answered questions on a five-point scale from “strongly disagree” to “strongly agree.” The precourse survey also gathered demographic information.

The postcourse survey included the same three Likert-style blocks of questions as well as a block of questions asking about the impact of different writing assignments on improvement of student writing and a block of questions pertaining to the overall impact of the course.

We developed pre- and postcourse surveys by performing think-alouds with three undergraduate students (6) and piloted the surveys with students in this course in 2010. After making revisions to the surveys, we piloted the final surveys with another four students using think-alouds before we administered the final versions to students in 2011. Data presented in this report on the pre- and postcourse surveys are from 2011; the preliminary data from 2010 using an earlier version of the survey were in agreement with the results presented here (data not shown). Students took the precourse survey on the first day of class and the postcourse survey on the final day of class. We matched and compared pre- and postcourse surveys by question to show the changes over the course of the quarter using paired-sample (pre/post) t-tests.

RESULTS

Here, we present seven major findings that support our claim that a writing-intensive format improves students’ perceptions of their ability to understand primary scientific papers, communicate science to scientists, and communicate science to laypeople. Much of these data are interrelated, illustrating how the key elements of frequent evaluation, revision, and practice work together to improve student processing skills.

Finding 1: Students Showed Gains in the Perception of Their Understanding of Primary Scientific Papers

One hundred percent of the students (15/15) in 2010 thought their ability to read primary scientific papers improved as a result of this course (Table 3). We coded students’ open-ended responses explaining the reasons why they improved using grounded theory (Fig. 3).

Many of the students cited the need to identify the main points of the primary scientific paper to effectively write the NYT-style summary. One student stated, “I am probably 100X better at understanding primary papers because the assignments forced me to understand the papers.” Another student echoed this theme by saying, “Taking the time to explain each [primary scientific paper] in my own words has helped me look for the main points and critical information while I read.” Finally, a student said, “I am more able to look and find important details in a paper and know what is important and what is not important. I understand how to go through figures and get the big picture from them.”

Additionally, students highlighted the change in their confidence in understanding figures of primary scientific papers. Responses included: “I have gained a better appreciation for focusing on the figures rather than the dense explanatory text,” “I also pay more attention to figures because I know how to read them better,” and “My knowledge in science has increased greatly through the demystifying of complex papers in section. Now I know–go straight to the figures!”

We gave students in 2011 a series of Likert-scale questions focused on reading primary literature. We saw statistically significant gains in response to questions regarding confidence in understanding figures, why a particular experiment was conducted, and the main findings of a paper (P < 0.05; Table 4). The

Table 3. Closed-ended questions about students’ ability to understand primary scientific papers and communicate science

<table>
<thead>
<tr>
<th>Question</th>
<th>Agree</th>
<th>Disagree</th>
<th>Maybe</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you think your ability to understand primary scientific papers has improved as a result of this course?</td>
<td>15/15 100</td>
<td>0/15 0</td>
<td>0/15 0</td>
</tr>
<tr>
<td>2. Do you think your ability to communicate science verbally to other scientists has improved as a result of this course?</td>
<td>14/15 93</td>
<td>1/15 7</td>
<td>0/15 0</td>
</tr>
<tr>
<td>3. Do you think your ability to communicate science verbally to other scientists has improved as a result of this course?</td>
<td>13/15 87</td>
<td>2/15 13</td>
<td>0/15 0</td>
</tr>
<tr>
<td>4. Is it important for research scientists to be able to communicate their conclusions to a layperson audience?</td>
<td>13/15 87</td>
<td>2/15 13</td>
<td>0/15 0</td>
</tr>
</tbody>
</table>

n = 15 students total. Postcourse survey responses to the following questions were analyzed on an “agree,” “disagree,” or “maybe” scale for students in 2010.
gains seen on the postcourse surveys compared with the pre-course surveys corroborated with the open-ended results from the students in 2010 (Table 3).

**Finding 2: Students Perceived Improvements in Their Ability to Write NYT-Style Articles**

Ninety-three percent of the students (14/15) in 2010 thought their ability to communicate science to laypeople through writing improved as a result of this course, and one student (1/15) was “not sure” if his ability improved (Table 3). We coded the open-ended responses regarding student explanations for their answers to these questions (Fig. 4).

The most frequent reasons for improvement in written communication included practice and feedback (Fig. 4). Students wrote a total of five NYT-style articles and peer critiqued at least two articles. TAs gave detailed feedback on every weekly assignment, after which students had the opportunity to revise and resubmit their articles. This iterative process appears to have strongly influenced students’ perception of improvement in their writing, as illustrated by one student’s response: “Practice, feedback, and examples helped me. The entire process of writing the [NYT-style summary] and having people read them was great.”

Additionally, students indicated that understanding the main points of primary scientific papers was important for their ability to write about them. As one student said, “Understanding a paper is instrumental in simplifying it to the level of a layperson. Reading papers and then discussing the main points has improved my ability to synthesize understandable explanations of complex ideas.” Another student mentioned, “I’ve gotten every NYT article proofread by my friends all quarter and I definitely feel like they were less confused at the end. I learned how to focus on the main points [of the primary scientific paper] and not try to discuss everything.” What perhaps best illustrates the importance the students placed on understanding the main points of the paper was one student’s response: “I think once I understand the concept thoroughly myself, describing it in simpler details becomes easier. Really I have realized that this particular form of writing is a testament to how well I understand the concept myself.”

Students in 2011 had high scores on the postcourse survey for questions related to their perception of their improvement in writing skills. All responses fell between “agree” and “strongly agree” on the Likert scale (Table 5), which also supported the data from 2010 (Table 3).

**Table 4. Reading primary-source scientific papers**

<table>
<thead>
<tr>
<th></th>
<th>Precourse</th>
<th>Postcourse</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I have difficulty understanding why a particular experiment was performed in a primary scientific paper. (Reversal)</td>
<td>2.43 (0.228)</td>
<td>1.64 (0.133)</td>
<td>0.786*</td>
</tr>
<tr>
<td>2. After I read a primary scientific paper, I can think of future experiments that should be done.</td>
<td>3.43 (0.202)</td>
<td>3.79 (0.155)</td>
<td>0.357†</td>
</tr>
<tr>
<td>3. I do not feel confident in my ability to understand the main findings/conclusions of a primary scientific paper in my field. (Reversal)</td>
<td>2.21 (0.261)</td>
<td>1.36 (0.133)</td>
<td>0.857*</td>
</tr>
<tr>
<td>4. I feel confident in my ability to understand figures in a primary scientific paper in my field.</td>
<td>3.76 (0.261)</td>
<td>4.50 (0.139)</td>
<td>0.714*</td>
</tr>
</tbody>
</table>

Data are precourse and postcourse survey results as means (SE) as well as mean gain scores for responses to the question “What is your level of agreement with the following statements?” for students in 2011; n = 14 students total. Reversal questions are those that are stated in the negative, so the sign of the gain is changed. Results were scored with the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. *Precourse vs. postcourse significance, based on a paired-samples t-test (P < 0.05); †precourse vs. postcourse significance, based on a paired-samples t-test (P = 0.055).
Finding 3: Students Thought That They Improved Their Ability to Communicate Science to Scientists

Ninety-three percent of the students (14/15) in 2010 thought their ability to communicate science verbally to other scientists improved as a result of this course (Table 3). One student did not think that her ability improved. We coded the students’ open-ended responses regarding their explanations for perceived improvement (Fig. 5).

In addition to perceived improvements in identifying the main points and having an overall deeper understanding of neuroimmunology, some students thought that the process of writing NYT-style articles helped them with their verbal communication. One student said, “Practicing writing doubles as practicing thinking, organizing, and articulating concepts. These are essential to verbal communication as well.”

Additionally, students thought that the discussion of the scientific paper in the section helped them become more comfortable communicating. One student mentioned, “I have had a lot of practice communicating with scientists and peers in the class, especially in section,” and another student echoed this sentiment, saying “I have gained valuable experience in discussing cutting-edge research with peers in a small group setting.”

Eighty-seven percent of the students (13/15) in 2010 thought their ability to communicate to other scientists through writing improved as a result of this course (Table 3). This lower percentage is not surprising given that the only assignment that specifically addressed written communication to other scientists was the review article that was directed to a scientist audience. Interestingly, the two students who did not think that the course improved this ability had previously written review articles. One of these students said, “I’ve written reviews before. Practice always leads to improvement, but this definitely was not a huge learning experience compared to the rest of the course.” However, for those students who had not previously written review articles, this course seemed to improve this skill. One student’s comment exemplified this: “I had never written a review before, so simply the act of finding and reading primary papers and then synthesizing a coherent article has improved my science writing.”

Table 5. Improvement of writing skills

<table>
<thead>
<tr>
<th></th>
<th>Postcourse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I think that the TA feedback on weekly NYT-style articles improved my writing.</td>
<td>4.57 (0.173)</td>
</tr>
<tr>
<td>2. I think that being able to rewrite my weekly NYT-style articles and submit them for a regrade improved my writing.</td>
<td>4.36 (0.225)</td>
</tr>
<tr>
<td>3. I think that being able to rewrite my weekly NYT-style articles and submit them for a regrade improved my writing.</td>
<td>4.36 (0.169)</td>
</tr>
<tr>
<td>4. I think that having my final NYT-style article peer reviewed by another student improved my writing.</td>
<td>4.57 (0.137)</td>
</tr>
<tr>
<td>5. I think that having laypeople critique my final NYT-style article improved my writing.</td>
<td>4.64 (0.133)</td>
</tr>
</tbody>
</table>

Data are postcourse survey results as means (SE) for responses to the question “What is your level of agreement with the following statements?” for students in 2011; n = 14 students total. Results were scored with the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. TA, teaching assistant.
Table 6. Communicating science

<table>
<thead>
<tr>
<th></th>
<th>Precourse</th>
<th>Postcourse</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I feel confident in my ability to verbally communicate to laypeople the scientific information I learn in class.</td>
<td>3.857 (0.206)</td>
<td>4.571 (0.137)</td>
<td>0.714*</td>
</tr>
<tr>
<td>2. I feel confident in my ability to write a NY Times-style article directed towards a layperson audience on scientific information I learn in class.</td>
<td>3.143 (0.294)</td>
<td>4.5 (0.139)</td>
<td>1.357*</td>
</tr>
<tr>
<td>3. I feel confident talking to peers who are science majors about scientific information that I learn in class.</td>
<td>4.071 (0.266)</td>
<td>4.714 (0.125)</td>
<td>0.643*</td>
</tr>
<tr>
<td>4. I feel confident in my ability to write a review style article directed to a scientific audience on scientific information I learn in class.</td>
<td>3.286 (0.286)</td>
<td>4.214 (0.214)</td>
<td>0.929*</td>
</tr>
<tr>
<td>5. I feel confident explaining scientific information that I learn in class to graduate student TAs.</td>
<td>3.643 (0.248)</td>
<td>4.429 (0.137)</td>
<td>0.786*</td>
</tr>
<tr>
<td>6. I feel confident explaining scientific information that I learn in class to science professors.</td>
<td>3.286 (0.194)</td>
<td>4.071 (0.195)</td>
<td>0.786*</td>
</tr>
</tbody>
</table>

Data are precourse and postcourse survey results as means (SE) as well as mean gain scores for responses to the question “What is your level of agreement with the following statements?” for students in 2011; n = 14 students total. Results were scored with the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. *Precourse vs. postcourse significance, based on a paired-samples t-test (P < 0.05).

Finding 4: Student Confidence in Communicating Science Improved

Notably, student confidence in communicating science also improved as a result of the course. We observed significant gains on the postcourse survey compared with the precourse survey from students in 2011 for every question (P < 0.05; Table 6). Student scores on the precourse survey fell between “neutral” and “agree,” whereas they fell between “agree” and “strongly agree” on the postcourse survey. These gains were observed in every category, regardless of whether the question asked about student confidence talking with laypeople, peer science majors, graduate student TAs, or professors in science.

Finding 5: Student Attitudes Toward Science Communication to Laypeople Showed a Ceiling Effect

On both the pre- and postcourse survey, 100% of the students (15/15) in 2010 thought that it was important for research scientists to be able to communicate their conclusions to a layperson audience, illustrating a ceiling effect.

To better assess student attitudes toward science communication, we designed a broader series of Likert-scale questions regarding attitudes toward science communication to laypeople. Surprisingly, student responses in 2011 using a Likert scale also displayed a ceiling effect in their attitudes toward science communication to laypeople. There were no differences between pre- and postcourse survey to the question “I think it is important for research scientists to be able to communicate their conclusions to a layperson audience” (Table 7), as students had a mean of 4.79 on a 5.0 scale for both the pre- and postcourse survey.

Table 7. Attitudes toward science communication to laypeople

<table>
<thead>
<tr>
<th></th>
<th>Precourse</th>
<th>Postcourse</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I think that most laypeople are interested in learning scientific information.</td>
<td>3.64 (0.225)</td>
<td>3.86 (0.143)</td>
<td>0.214</td>
</tr>
<tr>
<td>2. I think that most laypeople are not equipped with the skills or knowledge to be able to understand scientific concepts. (Reversal)</td>
<td>3.14 (0.294)</td>
<td>2.36 (0.248)</td>
<td>0.78*</td>
</tr>
<tr>
<td>3. I think that most scientific concepts are too complicated to explain to laypeople (Reversal)</td>
<td>2.29 (0.244)</td>
<td>1.93 (0.221)</td>
<td>0.357</td>
</tr>
<tr>
<td>4. I think it is important for research scientists to be able to communicate their conclusions to a layperson audience.</td>
<td>4.79 (0.114)</td>
<td>4.79 (0.114)</td>
<td>0</td>
</tr>
</tbody>
</table>

Data are precourse and postcourse survey results as means (SE) as well as mean gain scores for responses to the question “What is your level of agreement with the following statements?” for students in 2011; n = 14 students total. Reversal questions are those that are stated in the negative, so the sign of the gain is changed. Results were scored with the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. *Precourse vs. postcourse significance, based on a paired-samples t-test (P < 0.05).

One question that showed statistically significant differences between the precourse survey and the postcourse survey was “I think that most laypeople are not equipped with the skills or knowledge to be able to understand scientific concepts.” This reversal question showed a much lower score on the postcourse survey, indicating that after taking the course, students positively changed their perception of layperson abilities to understand science.

Finding 6: Students Explicitly Indicated That This Course Impacted Their Overall Ability to Communicate

Because students may have been exposed to other courses or activities that could have impacted their perceptions, we surveyed whether students thought that this course, specifically, had an impact on their ability to read primary scientific papers and communicate science. Students in 2011 had high scores on the postcourse survey for questions asking about the impact of this course on their abilities and understanding. All responses fell between “agree” and “strongly agree” on the Likert scale (Table 8). This supports the idea that this course taught students these valuable communication skills and understanding of neuroimmunology.

Finding 7: Students Perceived That the Course Was Successful at Teaching Both Science Content and Science Communication

We intended this course to be an upper-level basic science course. While the assignments focused on communication skills, the content was neuroimmunology. We asked students in 2011 an open-ended question on the most important thing they
learned in the course. Responses were coded, and the majority of responses fell into two categories: neuroimmunology content and science communication skills. Six responses indicated that science communication skills were the most important, whereas four responses highlighted that neuroimmunology content was most important. Four additional responses included both neuroimmunology and science communication skills as being equally important. The fact that many students felt that basic scientific content was the most important aspect of the course provides support for the assertion that teaching process skills does not negatively affect a course’s standing as a basic science course.

**DISCUSSION**

Here, we describe a course that uses a unique format to teach basic science and communication skills to undergraduate biology students. The evaluation data indicated that the course met its goals that focused on process skills. The course had a positive impact on student perceptions of and confidence in their abilities to read primary scientific papers and communicate science to both laypeople and other scientists.

Students were given numerous opportunities to hone their writing skills in a low-stakes way through iterative drafts and the opportunity to revise and resubmit their work, the effectiveness of which has been previously reported (7, 8). Not only did this give students the chance to refine their writing skills, but we believe it also encouraged them to think more deeply about the course material. For example, if students misinterpreted a figure in the primary scientific paper on which they were writing a NY Times-style summary, they were able to clarify this during the discussion and correct it in their summary. Additionally, a higher frequency of writing, in this case on a weekly basis, has been shown to improve both writing skills and thinking, serving dual pedagogical purposes (14).

An important feature of the course was the interdependence of the assignments. The combination of reading a primary scientific paper, writing a NY Times-style summary of the paper, discussing the paper in the section, and revising the NY Times-style summary led to gains in student perceptions of reading comprehension and communication that likely could not be independently ascribed to any one type of assignment. As the students themselves noted, the assignments as a whole met the course goals in a complementary manner, which supports previous literature linking reading, writing, and thinking (11).

Our target students were those interested in careers in science research and medicine rather than journalism or science policy. We aimed to train future physicians and scientists in the skills of science communication so that they are better able to communicate with scientists and nonscientists alike. According to demographic data, we served our desired population of students, those who were overwhelmingly biology-focused majors and interested in obtaining either a MD or PhD degree in basic science. By housing this course in a science program of study (immunology), we attracted a cohort of students interested in taking this course primarily due to its subject matter in neuroimmunology and not those students predisposed to an interest in science communication or writing. Interestingly, given a population of students not intrinsically interested in science communication, we had a ceiling effect for their positive attitudes toward science communication. On the precourse survey, all of the students in 2010 thought that research scientists need to be able to communicate their results to nonscientists. Additionally, students in 2011 answered close to “strongly agree” on the precourse survey Likert-scale questions. We asked graduate students in biology-focused PhD programs the same question and saw a very similar trend (data not shown). It would be interesting to see if practicing scientists and doctors also think that communication is important but feel ill equipped to be effective communicators to a lay public. This would have important implications for policy work, which has been perhaps too focused on trying to convince scientists that science communication is important. If researchers and clinicians already know that good communication skills are important, then we might want to shift the emphasis to providing avenues to practice these skills, starting in undergraduate and graduate programs.

The one question related to attitudes toward science communication to laypeople that significantly changed was “I think that most laypeople are not equipped with the skills or knowledge to be able to understand scientific concepts.” This reversal question shifted to a lower score on the postcourse survey, which suggests that students changed their perception about who is responsible for the lack of effective communication between scientists and laypeople. This result indicates that giving our students the opportunity to develop skills in science communication shifted their perception about the basic ability of laypeople to understand complex scientific concepts, an important result that we speculate could have wide-ranging implications for the acknowledged communication gap between science professionals and the lay public.

A small number of graduate students also enrolled in this course each year and completed all the assignments (their data is not included in this analysis). Although we do not have large enough sample sizes to do a more detailed study of their experiences, preliminary data showed that they also benefited from the course. This suggests that this course format might be effective for both undergraduates and graduate students, since both populations are not currently taught communication skills in their typical curricula.

Although previous studies have indicated the positive impact of courses that focus on reading primary scientific papers (18, 32) and scientific writing (21, 30), our curriculum uniquely combines those process skills with the added emphasis of communicating to a nonscientist audience. There have been a few studies (23, 27) that have described having students
communicate to a layperson audience, but we know of none that have been as extensive as our course.

**Limitations**

A limitation of this study is the small sample size. Only a small number of students enrolled in the course, and the amount of time and work that it took TAs to grade each assignment limited maximum enrollment. Given the iterative nature of the writing, feedback, and revision associated with the assignments in the course, we would have needed many more graduate student TAs to increase the course size. We have plans to adopt this format in a larger course with more peer feedback and less TA feedback to see whether similar gains are found despite less one-on-one attention to each student.

Second, another limitation is that we cannot separate the impact of the curriculum from the impact of the specific instructors of the course. Although we think that this course is successful due to the curriculum, a teacher effect could be responsible for some of the gains. We have plans to have other instructors teach the course to see if similar gains can be achieved using the same curriculum but different instructors.

Another potential limitation for expanding this course format for other upper-level undergraduate courses would be the recruitment of qualified TAs. The two graduate students who served as TAs (S. E. Brownell and J. V. Price) were codevelopers of the course goals, curriculum, and format, and thus not typical TAs. It might be difficult to formally train graduate students to serve as TAs for this type of course because they may not have previously taken a similar course. Our recommendation is for instructors interested in implementing a course such as ours to prepare for a considerable time commitment, and if recruiting graduate student TAs, to find individuals with a strong interest in teaching who can dedicate significant amounts of time to giving high-quality feedback to course participants in a timely fashion.

Although we do not have data to support this claim for this class, we suspect that the writing assignments improve not only student communication skills but also overall content knowledge, as suggested by the writing-to-learn literature (3, 11, 13, 30, 31). We cover an equivalent amount of information as traditional lecture-based upper-level courses, but hypothese that students will gain better mastery of the material using this writing-intensive format, based on science communication to a diverse audience. Additionally, having students learn how to use layperson’s language to describe complicated scientific ideas might even help them negotiate learning new material where they are unfamiliar with the terms (12). The lack of this data is a limitation of this study, but we are developing methods to formally test this hypothesis in future iterations of the class. We do, however, strongly feel that it is possible to teach both content and skills simultaneously, and we urge others to consider developing similar course formats for upper-level biology classes.

**Conclusions**

We focused on teaching science communication to a layperson audience for a number of reasons. There has been a call for scientists to engage with the lay public (17, 19), but there seems to be an absence of explicit instruction of these skills in the undergraduate biology curriculum. In particular, we know of no other existing course so focused on science communication taught in the context of basic science. Explaining complicated scientific information to a nonscientist audience is difficult and, like most communication skills, improves with practice. If we as a scientific community feel as though this is an important skill, then it is a skill that we need to explicitly teach.

**DISCLOSURES**

No conflicts of interest, financial or otherwise, are declared by the author(s).

**AUTHOR CONTRIBUTIONS**

Author contributions: S.E.B., J.V.P., and L.S. conception and design of research; S.E.B., J.V.P., and L.S. performed experiments; S.E.B. analyzed data; S.E.B. interpreted results of experiments; S.E.B. prepared figures; S.E.B. drafted manuscript; S.E.B. and J.V.P. edited and revised manuscript; S.E.B., J.V.P., and L.S. approved final version of manuscript.

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