Extended Problem-Based Learning Improves Scientific Communication in Senior Biology Students

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This article describes a model of extended problem-based learning that instructed upper-level undergraduate students to focus on a single biological problem while improving their critical-thinking, presentation, and scientific-writing skills. This course was developed in response to students' requests for formal training in oral presentation methods and hypothesis development. The goal for each student was not to learn a set of facts related to their biological problem. Instead, the goal was to teach the students that they could become experts in any biological problem through a cooperative process. To encourage this process, students learned about internet and library research of primary-scientific literature, strategies for reading literature, tips on presentation skills, and strategies for hypothesis development. Although this pilot course was done with a small cohort of students, direct and indirect assessments demonstrated an increase in the students' confidence to master material and in their comfort with oral and written presentation of scientific data over the course of the semester.

There is a general consensus in the science-education community that traditional lecture-based teaching is insufficient to prepare undergraduate students for careers in science (Dehaan 2005; Knight and Wood 2005). To supplement lecture, a variety of alternative-teaching techniques, including cooperative-learning and problem-based learning (PBL) approaches, have been developed (Prince and Felder 2007). Students working in a cooperative environment outperform lectured students (Crouch and Mazur 2001; Knight and Wood 2005; Prince and Felder 2006) and gain additional skills that are useful in careers in science (Oliver-Hoyo and Allen 2004). An alternative teaching technique that has a long history of success is the PBL model originally developed in the 1960s (Barrows and Tamblyn 1980).

In courses with PBL, students encounter problems that require critical analysis, in-depth research, and solution development. PBL has been successfully used to teach students in a variety of areas including physics, chemistry, and biology (Dahlgren 2003; Prince and Felder 2006). Interestingly, although PBL students do not perform better on exams compared with lectured students, the PBL students do have longer-term retention of the material, have a better ability to apply the material, and develop additional problem-solving skills (Prince 2004). The success of the PBL approach has led to experimentation with longer-term PBL models (Wankat 1993, 2002; Palmer 1998). These "super" PBL models involve only a single problem that is developed over the course of the entire semester through writing assignments. In the past, most students in science did not receive formal instruction in written and oral communication of science. Universities and colleges relied on general education requirements to prepare their students for professional communication (McDonald and McDonald 1993), which because of the specialized nature of scientific discourse was insufficient for science majors. A growing trend in science education is the incorporation of writing-intensive courses (Moore 1992; Yore, Bisanz, and Hand 2003; Greene 2010) designed specifically for formal training in scientific writing. Courses dedicated to experiential learning provide students with additional access to scientific knowledge, strengthen traditional approaches, and provide training in scientific discourse (Debburman 2002).

To further develop the communication skills of students, a "super" PBL model (called extended PBL in this article) was developed for use with upper-level undergraduates. This extended PBL model was based on a previously described approach (Wankat 1993, 2002) with a number of notable differences. This new course was conducted with undergraduate students, and the course incorporated oral presentations and a proposal-writing assignment. Student performance on oral presentations, written assignments, and surveys undertaken across the semester suggest that this model was effective in achieving these stated goals.

Course format

This new course included six fourth-year undergraduate students (all pre-med/predental) and met once per week in the spring of 2010. Stated course goals were to introduce students to the scientific process through research-based problem solving, develop students' reading skills for primary-scientific literature, improve students' scientific-presentation (oral and written) skills, and develop cooperative-work skills. Briefly, students were organized into two teams of three during the second week of class. Each group was tasked with becoming experts in a unique neurobiological problem and was assessed with attitudinal surveys, peer evaluation, graded-oral presentations, and graded-written assignments (see Table 1 for syllabus and the Assessment Tools section for evaluation details; see Figure 1 and the Appendix (which is available online at *www.nsta.org/college/connections.aspx*) for examples of neurobiological problems). The semester was divided into a discovery phase and a subsequent analysis phase.

In the discovery phase, assignments centered on developing skills necessary to research, read, and un-

TABLE 1

Course syllabus.

Week	Activity	Assessment during current week	Assignment (week due)
1	Introduction to course; lecture: "Tips on Online Research, How to Read a Scientific Paper"	Preterm repeated survey; intellectual property notebook (maintained throughout semester)	
2	Lecture: "How to Give a Scientific Presentation"; review chapter assignment described		Problem list received; work as group to pick a topic (week 3)
3	Lecture: "Tips on Scientific Writing"		Read "The Science of Scientific Writing" by G. Gopen and J. Swan (1990; week 4)
4	20 min. Group 1 and 2 presentation on problem; discuss reading assignment	Instructor/peer evaluation of oral presentation	
5	10 min. individual presentation on a primary article	Instructor/peer evaluation of oral presentation	
6	40 min. Group 1 presentation on overall review chapter	Instructor/peer evaluation of oral presentation; 1st group peer evaluation	Rough draft of review chapter (week 7)
7	40 min. Group 2 presentation on overall review chapter	Instructor/peer evaluation of oral presentation	Peer critique of review chapter (week 8)
8	Receive review chapter critique; experimental proposal assignment described	Midterm repeated survey; peer critique of written assignment	Final review chapter (week 9)
9	Lecture: "Introductory Discussion of Grant Writing and Hypothesis Development"	Instructor grading of review chapter; 2nd group peer evaluation	Prepare rough hypothesis for experimental proposal (week 10)
10	Go over hypothesis with group and instructor; watch and critique a professional scientific presentation		
11	15 min. individual presentation of experimental proposal	Instructor/peer evaluation of oral presentation	Rough draft of experimental proposal (week 12)
12	Rough draft of experimental proposal due	Peer critique of written assignment	Peer critique of experimental proposal; revised review chapter (week 13)
13	Receive experimental proposal critique	Instructor grading of experimental proposal; 3rd group peer evaluation; end-of-term repeated survey; overall course evaluation	Final experimental proposal (week 15)

derstand primary-scientific literature with the midterm goal for each small group to write a 30-page review chapter. This review-chapter assignment was designed to encourage students to summarize the known literature about the problem and highlight questions that remained unanswered. During this phase of the course, students received lectures on online research, reading scientific papers, giving scientific oral presentations, and scientific writing. Oral-presentation assignments included a group presentation that introduced each group's biological problem to the class, an individual presentation on a single research article, and a final lecture summarizing the group's written review chapter. Class periods between oral assignments were focused on small-group work and short meetings between the instructor and the individual groups.

The analysis phase centered on the development of a novel-experimental proposal to address a hypothesis related to each group's biological problem. The experimental proposal was developed with a single oral presentation assignment that allowed students to receive feedback on their proposed hypothesis and experiment; the proposal was finalized in the form of a 20-page NIH-style grant proposal. The final document contained a group-written introduction as well as individual experimental sections written by each student. During this phase, students participated in a discussion on hypothesis development that covered grant-writing techniques and experimental design. In addition, students observed and critiqued a professional-scientific lecture to help develop their presentation skills. For both of the written assignments, the groups met with the instructor to discuss the outline for the documents. Students then turned in rough drafts to be peer edited by the other group before the final draft was due. All peer reviews were read by the instructor, and tips for editing were provided to the peer editors. For the review-chapter assignment, students were additionally allowed to respond to the instructor's comments on the final draft to write a revised version.

FIGURE 1

Examples of biological problems.

Alzheimer's Disease (AD) is a serious age-related disorder affecting hundreds of thousands of people. In AD, neurons in the hippocampus are preferentially destroyed. Why does this occur? What is special about the hippocampus related to AD? Other neurological disorders have isolated anatomical specificity (e.g., Parkinson's disease affects dopamine cells in the substantia nigra). Why do these diseases affect specific populations of cells? What implications does this have for treatment of these diseases?

Over the past hundred years, modern society has made dramatic strides in creating equal opportunities for women. One outstanding issue for both opponents and proponents of equal rights for women is the extent to which women (XX genotype) are biologically distinct from men (XY genotype). Obviously, there are reproductive differences between the genders. Nonetheless, it's unclear what other differences might exist between the genders. Recent work using human imaging techniques (PET, fMRI) has discovered gender differences in activation of various anatomical areas during a variety of cognitive and sensory tasks. What examples of gender differences have been discovered? What are the cellular components of these gender differences? What (if any) are the societal implications of any biological gender differences?

Assessment tools

To assess student learning in this course, a combination of direct and indirect assessment techniques were used. There was direct assessment of the two group oral presentations, the two individual oral presentations, the written-review chapter, and the written-experimental proposal. Evaluation forms for oral presentations (filled out by the instructor and the students) focused separately on presentation style (20% of grade; e.g., enthusiasm, speaking clarity/speed, eye contact with audience, distractions, and appropriate diction), formatting (20% of grade; e.g., slide design/aesthetics, graphic/figure formatting, and balance of text and figures), and content (60% of grade; e.g., logic and organization of presentation and clarity of results). Analytical evaluation criteria of written documents were developed from published examples (Bean 2001) and focused on quality of ideas (60% of grade; e.g., depth of argument, logic of argument, critical analysis of primary literature, etc.), organization and development (30% of grade; e.g., clear arrangement of ideas, clarity of thesis statement, proper reference citation, adherence to instructions, etc.), and style (10% of grade; e.g., readability, word choice, sentence syntax, appropriate language for a scientific document, etc.).

Indirect measures of this extended PBL course included a beginning, midterm, and end-of-term survey; an overall course evaluation; three within-group peer evaluations that occurred during the semester; and an "intellectual property notebook" (used to track time spent working on course). The beginning, midterm, and end-of-term surveys analyzed students on scientific content, scientific-presentation skills, and group work (Table 2). The overall course evaluation was developed from a standard end-of-semester evaluation and focused on the overall course, including the organization and structure of the course (Table 3). The within-group peer evaluation forms were designed to provide personalized feedback to each student regarding his or her contributions to the group. These evaluations were a modified form of a previously described evaluation (Wright and Boggs 2002) and included a section that only the instructor could see. The "intellectual property notebook" was used to track students' work outside of class and was developed through an example kindly supplied to the instructor by Robin Wright (University of Minnesota; Wright and Boggs 2002). Throughout the semester, students were instructed to record, in individual and team logs, the amount of time spent working on the assignments and the type of activity done. The instructor confirmed recording in notebooks throughout the semester and analyzed final notebooks at the end of the course.

Results

As measured by direct assessment, students' oral presentations and scientific writing improved across the

TABLE 2

Beginning, midterm, and end-of-term surveys of students.

	1 Strongly disagree · 2 · 3 Neutral · 4 · 5 Strongly agree	Beginning of term mean ± SD	Midterm mean ± SD	End of term mean ± SD
Scientific knowledge	I am comfortable reading primary scientific literature.**	3.5 ± 0.5	4.2 ± 0.4	4.4 ± 0.5
	I am familiar with the typical sections (e.g., abstract, methods, results, discussion) of a primary journal article.	4.3 ± 0.8	5.0 ± 0	5.0 ± 0
	I am comfortable analyzing and critiquing scientific articles.*	3.2 ± 0.9	3.9 ± 0.9	4.2 ± 0.7
	I understand basic human imaging techniques.***	1.5 ± 0.8	3.5 ± 1.4#	3.3 ± 1.2#
	I understand what makes a good scientific hypothesis.**	3.7 ± 0.5	3.8 ± 0.4	4.8 ± 0.4#
	I am comfortable using online search engines to search for scientific scholarly articles.**	3.5 ± 0.8	4.7 ± 0.5	4.7 ± 0.5
	I am unfamiliar with basic molecular biology laboratory techniques.	1.7 ± 0.5	1.7 ± 0.5	1.5 ± 0.5
	I think that I could become an expert in a scientific field (or subfield) if given enough time.	4.3 ± 0.5	5.0 ± 0	5.0 ± 0
Presentation skills	I get nervous while giving presentations in front of others.**	4.0 ± 1.3	2.5 ± 1.0	2.3 ± 1.0
	I don't understand the difference between a scientific writing style and a writing style that I might use in a humanities course (e.g., American Literature class).**	2.5 ± 0.8	2.5 ± 1.6	1.0 ± 0##
	I think I am a good presenter of scientific data.*	3.0 ± 1.1	3.7 ± 1.0	4.0 ± 9.6
	I understand how to use the basic tools/features in PowerPoint (or other presentation software).	4.5 ± 0.5	4.8 ± 0.4	4.7 ± 0.5
	I know the best way to organize a scientific oral presentation.	3.3 ± 1.6	4.3 ± 0.5	4.3 ± 0.5
Group work	I worry that group work often allows some people to slack off.*	3.1 ± 0.9	2.0 ± 0.6	2.8 ± 0.9
	I worry that I don't work well in groups.	2.5 ± 0.5	2.0 ± 0	2.0 ± 0.6

Note: Friedman's Test *$P < .05$, **$P < .01$, ***$P < .001$; Dunn's Test #$P < .05$, #$P < .01$, compared with beginning survey.

semester (Figure 2). For oral presentations, this improvement was first seen in presentation style. Although the early presentations were characterized by a fast pace, numerous distractions (e.g., tapping of one's pen on the desk), and little eye contact, these issues were almost completely absent in the last presentation. Second, the improvement in student performance was also evident in the organizational content of their presentations. At the end of the semester, students were better at leading the audience to the hypothesis through simple introductions that started broadly and then focused in on the question. They also exhibited considerable improvement in their ability to clearly present experimental results by discussing the basics of the appropriate research methods. To evaluate the independence of scoring criteria, students were asked to grade each other's oral presentations. Peer evaluations of oral presentations closely mirrored instructor evaluations indicating consistent, identifiable strengths and deficiencies (Figure 2).

Also, students demonstrated improvement on the writing assignments across the semester (Figure 2). Students initially struggled in the general formatting of the document (e.g., number of pages and figures), on the proper citation of scientific literature (e.g., where to put citation in paragraph, when to use quotation marks, etc.), and in defining jargon, but improved with subsequent assignments. In addition, for the review chapters (titled "Alzheimer's Disease and the Role of the Hippocampus" and "Men Are From Mars, Women Are From Venus: A Review of Why Biological Sex Differences Matter for the Brain"), students struggled to consolidate information without losing the flow of their argument. Specifically, students failed to use effective transition sentences between subsections in the document. Interestingly, this issue was identified first through the peer-editing process. In the experimental proposals (titled "Amyloid-beta: Friend or Foe. Investigating the Properties of Amyloid-Beta as an Antimicrobial Peptide" and untitled), students demonstrated impressive ingenuity in their writing and experimental designs. For example, one of the groups used side boxes called "Spotlight on Technology" to introduce methods used throughout the document. This technique was borrowed by the other group, after the peer-editing process, and led to the development of a "Spotlight on Treatment" section. Ingenuity in the experimental design was best exemplified by the use of a variety of methods and model systems (e.g., cell culture, rodent experiments, human imaging) to gain a broad perspective on the biological problem. Another improvement seen between the rough and final drafts was in the logic of the proposed experiments. This suggests that through the peer-editing process students were able to critically analyze the feasibility and utility of the experiments.

As measured by indirect assessment, student surveys demonstrated significant improvements in the understanding of scientific literature and the communication of scientific concepts (Tables 2–3). Beginning, midterm, and end-of-term surveys were given to the students to evaluate the effectiveness of the course in modulating students' comfort level reading scientific literature, doing scientific presentations, and working in groups (Table 2). As these statistical comparisons are only with a small group of students, they should be viewed as potential evidence of the success of this course model rather than as a comprehensive quantita-

TABLE 3

End-of-term course evaluation.

1 (strongly disagree) 2 3 4 (neutral) 5 6 7 (strongly agree)	Mean + SD	% agree/ strongly agree
The material in the intro lecture on "presentation techniques" was useful.	6.5 ± 0.5	100
The material in the "scientific writing" lecture was useful.	6.2 ± 0.7	83
The material in the "grant writing" lecture was useful.	5.8 ± 0.8	67
I enjoyed working with a single group for the entire semester.	5.5 ± 1.8	50
I enjoyed working on a single biological problem for the entire semester.	6.2 ± 2.0	83
I thought the "review chapter" assignment was useful and interesting.	5.7 ± 1.0	67
I thought the "experimental proposal" assignment was useful and interesting.	6.3 ± 0.8	83
I learned a lot about scientific writing in this course.	6.5 ± 0.8	100
I learned a lot about scientific presentations in this course.	6.7 ± 0.5	100
I learned a lot about grant writing in this course.	6.3 ± 0.8	83

tive analysis of the course. Friedman's test (with post hoc Dunn's tests; McCrum-Gardner 2008) found statistically significant differences across the semester demonstrating perceived improvements in a number of areas. Most important, students perceived an increase in understanding what makes a good hypothesis, confidence in oral presentations, and understanding of the difference between scientific writing and that seen in humanities courses. In the overall course evaluation, students gave high remarks for the utility of lectures on presentation skills, scientific writing, and hypothesis development (Table 3). In addition, students reported satisfaction with the written and oral assignments and greater knowledge of scientific oral and written communication.

To facilitate a cooperative-learning process, students filled out peer evaluations at three points during the semester. As part of the evaluation, students also reported on their own perceived effectiveness in the group. The evaluations were positive for most group members and indicated an equivalent amount of work among the members. An issue that was identified with the peer evaluations was the tendency of certain group members to procrastinate and come to group meetings unprepared. These issues were dealt with internally with the instructor's guidance as they arose.

The final indirect assessment tool was the intellectual property notebook in which students recorded the time they spent reading journal articles, working on oral presentations, working on written assignments, and critiquing their peers. Overall, students spent 45 $\pm$ 8 hours working individually and 16 $\pm$ 1 hours working in groups over the course of the entire semester. By area, students spent the most amount of time working on oral presentations, followed by journal article reading, writing the review chapter, writing the experimental proposal, critiquing their peers' work, and performing other undefined activities (Figure 3).

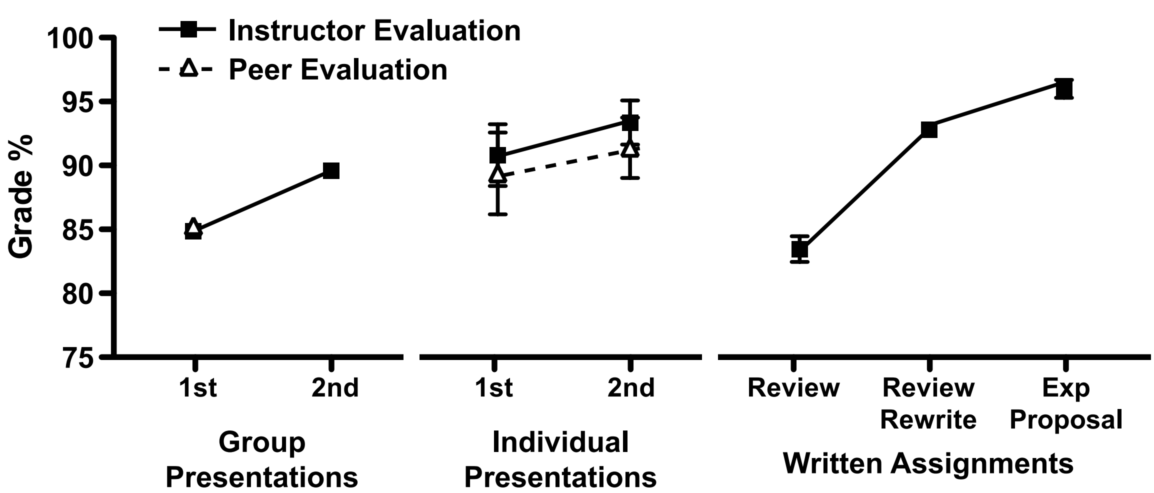
Discussion

The extended PBL approach described here can be easily implemented in a variety of scientific fields. Furthermore, although this example was done with only six students broken into two groups of three, the model could be adapted, with only minor changes, to larger groups and with class sizes of up to 18 students (Wankat 2002). With a larger group, there may be time for only one individual presentation per student, and the peer-review process could be done in pairs to facilitate the incorporation of suggestions in the drafts. The results presented here are consistent with other reports of "super" PBL models (Wankat 1993) but extend this approach to undergraduate students and incorporate primary data analysis followed by hypothesis and experimental-design development with written and oral presentation of that analysis.

An important component of this course was to increase the students' ability to read and understand primary journal articles. To this end, students reported significant improvements in their ability to find, read, and understand primary literature. This improvement likely occurred through an increase in familiarity of the specialized jargon of the biological problem and a deeper understanding and analysis of the material. The impact of scientific reading in this

FIGURE 2

Scores on oral presentations (group and individual) and written assignments. Data represented as mean $\pm$ SEM.



course was further illustrated by the students' intellectual property notebooks, which gave an indication of what areas the students struggled with the most in this course. Students reported spending 25% of their time outside of class researching scientific articles. This is not surprising as all of the students were relatively new to these problems. Interestingly, no significant improvement was reported in the students' familiarity with the typical sections of a journal article, suggesting that these upper-level students had prior experience reading primary literature.

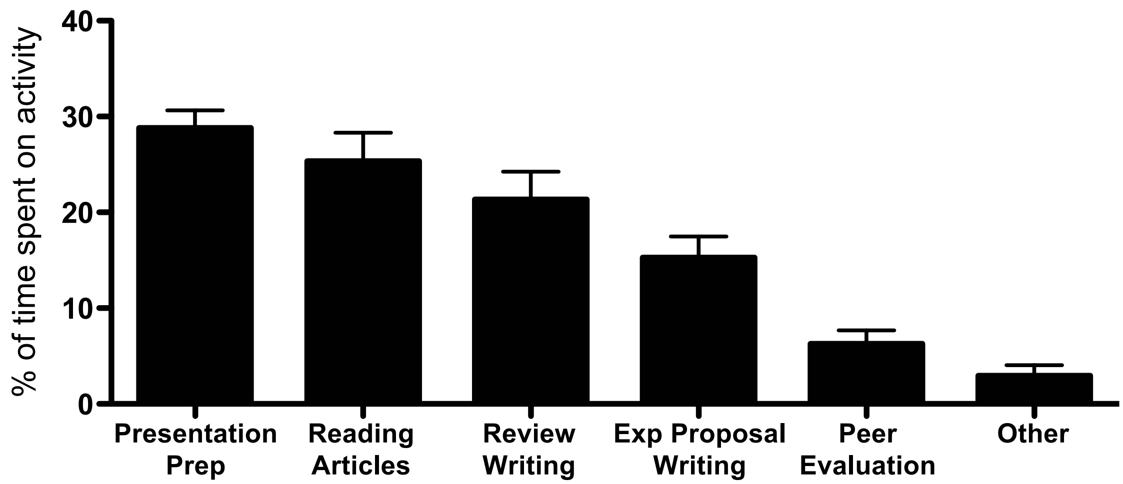
Another goal of this course was to instruct students on the effective techniques for the oral presentation of scientific data. Students spent 30% of their time working on the group presentations and practicing their own presentations, suggesting that the oral presentation component of this course was challenging. Students showed improvements over the semester in their comfort speaking in front of the class and in the intellectual depth of their presentations. Students demonstrated a qualitative reduction in nervousness and increase in overall enthusiasm and comfort with each presentation that they gave. In addition, students also showed a remarkable improvement in their ability to communicate a coherent and thoughtful scientific story as measured by grades in the content portion of their presentations. Although this could be a practice effect, it is more likely due to the repeated peer-editing process that was instituted. As students critiqued each other, they were more direct and astute in their observations for improvement. These observations may have then extended to the students' own work. Furthermore, consistent with the improvement of scores on oral presentations, students reported a significant decrease in nervousness while presenting and a feeling that they were better at presenting after taking this course.

This improvement in scientific communication extended to the written presentation of primary data. Some of this improvement is likely attributable to a gradual alignment of the students' work with grading expectations of the instructor. Consistent with the improvement of scores on the written assignments over the semester, students reported an increase in confidence regarding the presentation of scientific data and an increase in knowledge about scientific writing in contrast to writing in the humanities. The overall evaluation given to the students suggested that students were generally satisfied with the lectures related to scientific writing and felt that their knowledge of scientific communication was improved by taking this course.

Intellectual property notebooks allowed a further analysis of the amount of time that students spent working on different aspects of the class. As an evaluation tool, the notebooks provided the instructor with an indication of areas that students struggled with so that future versions of the course could be adjusted accordingly. The overall number of hours spent outside of class for the students (as individuals or groups) was consistent with general guidelines of two to three hours per credit hour per week and suggests that the time commitment for this extended PBL course was manageable. Although students were encouraged to record work time as it occurred, it is possible that the students underreported the amount of time they spent outside of class working on the writing assignments. Notably, this course provided a significant amount of time (not reported in the notebook) for students to work on assignments inside class. The amount of time spent outside of class

FIGURE 3

Breakdown of time spent outside of class by subject area. Data represented as mean ± SEM.



varied widely throughout the semester with peaks of activity occurring before all of the major assignments. Interestingly, despite the emphasis on cooperative learning in this course, students reported spending three times as much time working individually (reading literature and practicing presentations) as in the group. Although this could be interpreted as a failure of cooperative learning, it could also be viewed as a benefit of this course model in preparing students for real-world cooperative writing where groups of scientists writing a joint review might initially break an article into separate pieces.

Conclusion

Overall, this extended PBL model appeared to be successful in achieving the stated goals of the course. Specifically, students were successfully introduced to the scientific process through research-based problem solving, demonstrated improvements in their presentation skills, reported increased comfort reading scientific literature, and had the opportunity to develop their skills working in groups. This course model should be of immediate use with upper-level students, can be adapted to teach specific subject areas in science, and could be used with students beginning in-depth independent-study programs. Future studies will be needed to evaluate the effectiveness of this course model in comparison to other types of PBL courses. ■

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