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Research

Prop Demonstrations in Biology Lectures Facilitate Student Learning and Performance †

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Science students can benefit from visual aids. In biology lectures, visual aids are usually limited to tables, figures, and PowerPoint presentations. In this IRB-approved study, we examined the effectiveness of the use of five prop demonstrations, three of which are at the intersection of biology and chemistry, in three community college biology courses. We hypothesized that students' performance on test questions is enhanced by the use of prop demonstrations. Consistent with our hypothesis, we showed that students learn more effectively and perform better on questions that relate to demonstrations than on questions related to lessons that do not have a demonstration component.

INTRODUCTION

In most biology courses, the use of demonstrations is limited to lengthy and often expensive experiments conducted in the laboratory component of the courses (3, 5). Because these activities typically require equipment, reagents, and other resources that are not readily available outside of a laboratory setting, students cannot replicate them on their own. In lectures, most visual aids are in the form of figures on PowerPoint slides (or similar support) with very limited or nonexistent demonstrations or kinesthetic learning activities. Interestingly, the effectiveness of using PowerPoint presentations not accompanied by engaging methodologies such as active note taking has been questioned. For example, Lakrim (6) showed that lecturing with PowerPoint presentations and providing students with copies of PowerPoint presentations, without active note taking on the part of the students, provided no significant advantage to the students. By extension, the importance of applying active learning and interdisciplinary activities to promote learning in undergraduate biology courses was emphasized by Bonney (2). The effectiveness of a writing component in lectures in facilitating student learning, for example through the use of microthemes, has been supported as well (8).

Students often find demonstrations help them understand and remember new concepts. This is especially evident when teachers try to convey complex topics such as those that occur in sequential steps. In our opinion, the best demonstrations are those that are inexpensive, brief, convey the information thoroughly, and are also available outside of the classroom to allow students to repeat the demonstration independently if necessary. In addition, activities that require and allow students to actively take notes are particularly engaging and valuable.

Here we analyze five student-oriented active learning activities that use props for demonstrations, three of which are interdisciplinary with a chemistry component. We assessed the effectiveness of these props using student scores on relevant test questions as a measure of learning. Our hypothesis was that students will perform better on test questions that relate to prop demonstrations than on test questions that do not.

METHOD

Kingsborough Community College (KCC) is a campus of the City University of New York (CUNY) serving undergraduates from diverse ethnic and socioeconomic backgrounds. This study was conducted in the Department of Biological Sciences at KCC between summer 2012 and fall 2013. In this study we assessed the effectiveness of prop demonstrations in facilitating learning of five key concepts in the biological sciences. Props as pedagogical tools were used in the lecture component of three biology courses: BIO 13 (General Biology I for majors; 52 students), BIO 59 (Genetics for majors; 18 students), and BIO 37 (Human Genetics for nonmajors; 20 students).

Demonstrations

The demonstrations are summarized in Table 1. These topics were chosen as targets of the demonstrations because the instructors had indicated that they represent half

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†Supplemental materials available at http://jmbe.asm.org

TABLE 1.
Summary of the demonstrations used in class.

Demonstration	Learning Objective	Description
1	Describe how biological polymers are made from monomers and provide examples of the monomers, polymers, and the chemical bonds involved	Use a necklace to show how repeating units are linked into a long chain
2	Describe the steps, cellular components, and molecules involved in DNA replication	Use headphones and fingers to show how two strands can be unwound and acted upon by other objects
3	Describe the steps, cellular components, and molecules involved in translation	Use student volunteers, markers, and drawing on board to illustrate the process of translation in a ribosome
4	Describe the appearance, function, and bonds associated with each level of protein structure (primary, secondary, tertiary, quaternary)	Use a necklace to demonstrate 1) Joining of monomers for the primary structure, 2) Manipulation of the chain into helices and pleated sheets to illustrate secondary structure, 3) Further manipulation of the entire chain to demonstrate tertiary structure, 4) Use of two chains to show quaternary structures.
5	Recognize the concept of gene linkage and organize and reorganize alternative gene orders through drawings	Use a pen/pencil and fingers to illustrate the concept of gene linkage

of the ten most difficult main topics covered in the course; the other five of these topics were used as non-prop demonstration control lessons for comparison. The instructor performed each demonstration during lecture as part of a usual teaching activity that complemented the presentation and discussion of each designated topic. Demonstrations one (monomers), three (translation), and four (protein structure) (Table 1) have a chemistry component and are therefore interdisciplinary in nature. The description of two of the demonstrations is published in the Tips and Tools section of this issue, and a complete description for the other three can be found at: https://sites.google.com/site/tamarif26.

Assessment and data collection

Data were collected by two instructors for BIO 13 during two 12-week sessions (fall and spring) and one 6-week session (winter). All data for BIO 59 and BIO 37 were collected during the 12-week semesters (fall and spring, respectively) by a single instructor.

Each lecture exam included short-answer questions related to the course learning objectives covered by each demonstration (Table 2) as well as short-answer questions of a similar format, difficulty, and point value related to course learning objectives not covered by the demonstrations that were used as controls. To minimize variation in instructional technique and assessment design, the instructors involved in the study thoroughly discussed how prop demonstrations would be conducted and how assessment questions would be designed prior to commencing the study. All questions were graded according to a pre-determined, standardized rubric. Students' scores were used as a measure of student learning. Meticulous records of student attendance were kept for each demonstration day, with a plan to use grades for students who were absent for any particular demonstration as a second control. However, the total number of student absences being too low to conduct appropriate statistical analysis, these data were not used as a separate control. Test scores for students who did not provide any response to the prop- nor the non-prop questions (scores of zero for both questions) were omitted from this study. At the end of the course, students also completed an anonymous survey on the effectiveness of the prop demonstrations in helping them grasp and remember concepts. Data collection for student attitudes on the helpfulness of the props for conceptual learning and memory was based on a Likert-type survey. Five questions were asked on the survey that prompted the students to indicate whether they strongly agree, agree, show indifference, disagree, or strongly disagree with the statement that each prop: 1. Helped the student learn the material and 2. Helped the student remember the material (Appendix 1).

Statistical analyses

All data collection and preliminary analyses were performed using MIRCROSOFT EXCEL 2013. All parametric and nonparametric analyses used SIGMAPLOT version 12, SPSS for Windows (Release 11.5.0), or MIRCROSOFT EXCEL 2013. Students' scores on questions which were collected for prop vs. non-prop questions were anonymized by removing all identifying information from raw-score data before compiling class data for analysis.

Institutional Review Board (IRB) approval

This study was reviewed and approved by KCC's Human Research Protection Program and IRB of the City University

TABLE 2.
Sample test questions used to assess performance on prop questions.

Demo	Topic	BIO 13 Sample Test Question	BIO 37 Sample Test Question	BIO 59 Sample Test Question
1	Monomers	Complete a chart providing the following information for each monomer: name of monomer, type of polymer formed by monomers, name of bond that joins monomers together, and an example of the polymer formed by these monomers.		Using knowledge you gained from demonstrations conducted in class, explain how monomers are joined together to create polymers in macromolecules.
2	DNA Replication	Draw a replication fork and label the following: 3', 5', leading strand, lagging strand, Okazaki fragments, helicase, DNA polymerase, and single-strand binding proteins. To clarify what your drawing is showing, write a brief description of the function of helicase, DNA polymerase, and single-strand binding proteins.	In the space provided below, draw a diagram showing DNA replication (show a replication fork). In the diagram, show the location of all of the components involved in DNA replication, including enzymes and other proteins involved, DNA directionality, continuous vs. discontinuous replication, etc.	In the space provided below, draw a diagram showing DNA replication (show a replication fork). In the diagram, show the location of all of the components involved in DNA replication, including enzymes and other proteins involved, DNA directionality, continuous vs. discontinuous replication, etc.
3	Translation	Describe the process of translation. In your description, be sure to correctly use each of the following words: amino acid, anticodon, codon, mRNA, peptide bond, ribosome, tRNA, and 5' to 3'.	Draw the ribosomal assembly during translation. On it, label the following: large ribosomal subunit, small ribosomal subunit, mRNA, tRNA, amino acid(s), codons, anticodons, E site, P site, A site.	Draw the ribosomal assembly during translation. On it, label the following: large ribosomal subunit, small ribosomal subunit, mRNA, tRNA, amino acid(s), codons, anticodons, E site, P site, A site.
4	Protein Structure	Describe the four levels of protein structure and indicate which bonds are important for maintaining each level of structural organization.	In the boxes below, name and draw four levels of protein structure after polypeptides are produced.	In the boxes below, name and draw four levels of protein structure after polypeptides are produced.
5	Gene Linkage	Describe the concept of gene linkage. Discuss what makes two genes likely to be linked and how to tell whether two genes are linked by examining phenotypes.		Using a minimum of three diagrams, show three alternative orders for three genes (A, B, and C) on a segment of DNA.

Demo = demonstration.

of New York (CUNY IRB reference 340325-4, KCC IRB application #: 12-06-097-0138).

RESULTS

Comparison of overall means

To determine whether the use of prop demonstrations improved student performance on test questions, a *t*-test was performed to compare the mean score on all test questions that assessed knowledge of topics covered by prop demonstrations (Fig. 1, prop questions, P) with the mean score on an equal number of similarly formatted questions that assessed knowledge of topics for which there was no corresponding prop demonstration (Fig. 1, non-prop questions, NP). This comparison revealed that there was a significant difference ($p < 0.0001$) between the mean score on prop (P) questions ($\bar{x}_P = 76.2$, $SD_P = 27.8$, N = 370) and on non-prop (NP) questions ($\bar{x}_{NP} = 52.0$, $SD_{NP} = 34.3$, N = 349), indicating that students performed better overall on test questions about lessons for which a prop demonstration was used.

Comparisons of means for specific prop and non-prop questions across all courses

To determine which prop demonstrations generated the greatest increase in student performance, a one-way analysis of variance (ANOVA) was used to compare student performance on individual prop questions versus non-prop questions. The mean score on each prop question was higher than the mean score on the corresponding non-prop questions used for a control (Table 3). The biggest difference between prop vs. non-prop performance was observed for DNA replication ($\bar{x}_P - \bar{x}_{NP} = 36.6$), while the smallest difference was observed for gene linkage ($\bar{x}_P - \bar{x}_{NP} = 16.0$).

A pairwise comparison of the means was conducted using a post-hoc (Tukey) test. Overall student performance on test questions corresponding to the use of props for teaching about monomers, DNA replication, translation, and protein structure was statistically higher than performance on control questions, but the use of a prop for teaching about gene linkage did not result in a statistically significant difference in mean score compared to control non-prop questions (Table 3).

Comparisons of prop and non-prop questions in different courses and sessions

To determine whether students from different courses benefit from prop demonstrations differentially, a two-way analysis of variance was performed on student performance data using course (BIO 13, General Biology; BIO 59, Genetics; and BIO 37 nonmajors Human Genetics; Table 4) and treatment (prop vs. non-prop) as factors. A statistical difference due to both course and treatment was observed between subjects in terms of student performance on prop vs. non-prop questions ($p = 0.036$). The interaction of course and treatment (Table 4, row 5) is also statistically significant ($p < 0.001$). A similar analysis comparing taking the courses in the 6-week session vs. the 12-week session indicated no significant statistical difference ($p = 0.33$) (Table 4).

To delineate which prop demonstrations resulted in greater student scores in each course, a one-way ANOVA was used to compare the means for prop vs. non-prop questions followed by a pairwise comparison of the means using a post-hoc (Tukey) test in each course.

Figure 2A shows the means and standard deviations for BIO 13. For all five concepts studied, the mean student performance on test questions related to concepts for which there was a prop demonstration was higher than for test questions related to concepts for which there was not a demonstration. However, in only one instance was the difference statistically significant. Figure 2B shows the means and standard deviations for BIO 59. The mean scores on prop questions were higher than on non-prop questions for all five concepts. There was a statistically significant difference in student performance following all prop demonstrations ($p < 0.0001$), except for gene linkage ($p = 0.238$). Figure 2C shows the means and standard deviations for prop and non-prop questions for BIO 37. Student performance for only three of the concepts was assessed in this course. Similar to BIO

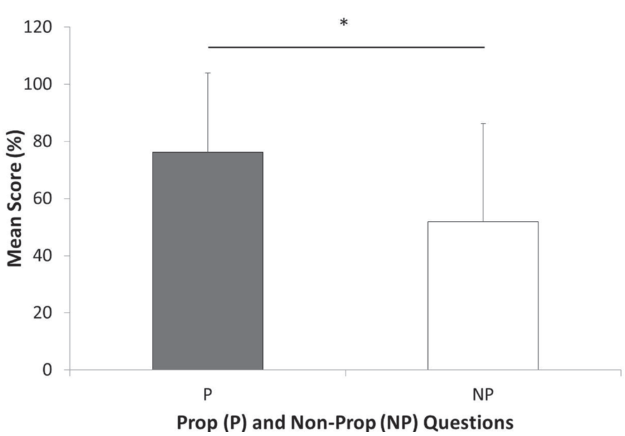

FIGURE 1. Comparison of student performance on prop and non-prop test questions. * Indicates a statistically significant difference. P = prop questions; NP = non-prop questions.

TABLE 4.
Comparison of student performance on prop and non-prop questions in different courses and sessions.

Source	Type III SS	df	F	*p* value
1. Corrected model	211634.5	34	7.2	<0.001
2. Prop vs. non-prop	138537.2	9	17.9	<0.001
3. Course	5735.4	2	3.3	0.036
4. 6-week vs. 12-week session	816.3	1	1.0	0.33
5. Interaction of 2*3	51055.7	13	4.6	0.001
6. Interaction of 2*4	21269.9	9	2.8	0.004
7. Error	587488.5	684		
Total	3784905.7	719		

ss = sum of squares; df = degrees of freedom.

TABLE 3.
Comparison of student performance on individual prop and non-prop questions.

Question	$\bar{x}_P$	SD_P	N_P	$\bar{x}_{NP}$	SD_{NP}	N_{NP}	*p* value
Monomer	80.0	29.9	62	58.0	31.6	62	<0.01
DNA Replication	79.8	23.0	86	43.2	39.0	86	<0.001
Translation	71.0	27.0	77	48.3	34.0	56	<0.001
Protein Structure	71.9	33.1	81	50.1	28.8	81	<0.001
Gene Linkage	79.4	23.8	64	63.4	33.4	64	0.094

$\bar{x}$ = mean, SD = standard deviation, N = sample size, P = prop question, NP = non-prop question.

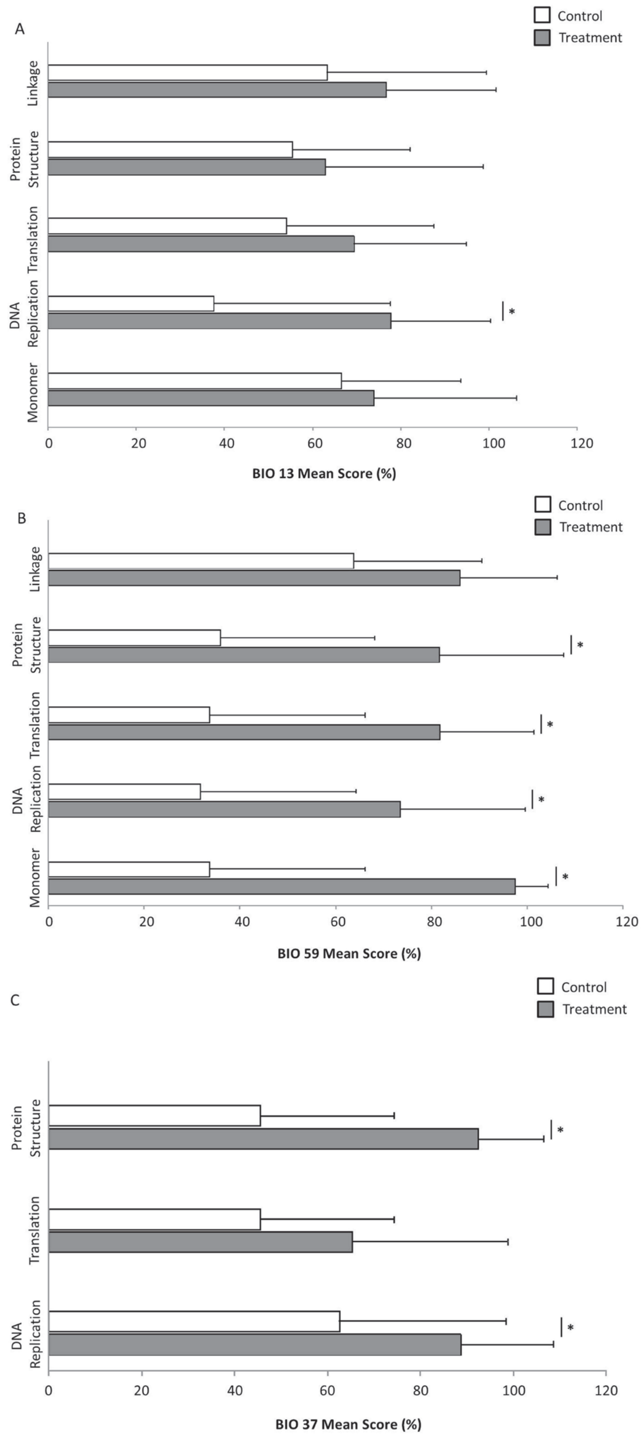

FIGURE 2. Comparisons of prop and non-prop questions in BIO 13, BIO 59, and BIO 37. Mean scores for each demonstration and its control are shown (treatment gray bars, control white bars). (A) Data for BIO 13 are shown. *p* values for each comparison are as follows: monomers ($p = 0.98$), DNA replication ($p < 0.001$), translation ($p = 0.45$), protein structure ($p = 0.96$), gene linkage ($p = 0.56$). (B) Data for BIO 59 are shown. *p* values for each comparison are as follows: monomers ($p < 0.0001$), DNA replication ($p < 0.0001$), translation ($p < 0.0001$), protein structure ($p < 0.0001$), gene linkage ($p = 0.238$). (C) Data for BIO 37 are shown. *p* values for each comparison are as follows: DNA replication ($p < 0.05$), translation ($p = 0.26$), protein structure ($p < 0.001$). * Indicates a statistically significant difference.

13 and BIO 59, the mean for student performance on prop questions was consistently higher than that of the controls (in BIO 37 the same control was used for translation and protein structure); however, there was a statistical difference for DNA replication ($p < 0.05$) and protein structure ($p < 0.001$) but not for translation ($p = 0.26$).

Student sentiment about the effectiveness of the prop demonstrations in facilitating learning and remembering the topics appears to be positive, with most students strongly agreeing or agreeing that the props helped them understand and remember the concepts better (Fig. 3). A Kruskal Wallis analysis of the overall data showed that students strongly agree or agree that the prop demonstrations allow them to learn and remember the concepts more effectively ($p < 0.0001$). As predicted, independent χ^2 analyses on each of the prop questions, for both learning the concepts and remembering the concepts, yielded the same results. χ^2 values ($\alpha = 0.05$, df = 4) ranged from 26.8 to 55.3 for the Likert-type survey questions, showing that in each question a statistically significant proportion of respondents strongly agreed or agreed that the props helped them learn and remember the concepts ($p < 0.005$ in all cases).

DISCUSSION AND CONCLUSIONS

Our study shows that prop demonstrations are a valuable tool to promote active and interdisciplinary learning, along with other activities. Important applications of active learning activities and interdisciplinary learning strategies were described in Bonney (2). Engaging lecture activities are effective pedagogical tools that allow students to understand, remember, and apply concepts that they learn in the classroom. One example of an engaging activity was proposed by Polizzotto and Ortiz (7), who used an assignment-oriented strategy in anatomy and physiology. Another example of an engaging lecture activity is the use of demonstrations, such as the ones used in our study. These prop demonstrations are physically and cognitively engaging and interactive (4, 9) because they require contributions to the discussion from the students and provide an opportunity for students to easily visualize concepts that may otherwise be difficult to comprehend.

To determine the effectiveness of these demonstrations on student learning of five key concepts in three different biological science courses, we conducted an IRB-approved study. Comparison of the overall mean scores on exam questions for all demonstrations in all courses indicated that students learned more and performed better on exam questions when prop demonstrations were used than when prop demonstrations were not used (Fig. 1). Comparison of the mean scores for prop and non-prop questions for each individual demonstration indicated that, overall, students seem to benefit from four of the five demonstrations used (Table 3). It is important to note that there was substantial heterogeneity in the data due to a somewhat bimodal distribution of scores, with some students receiving a score of

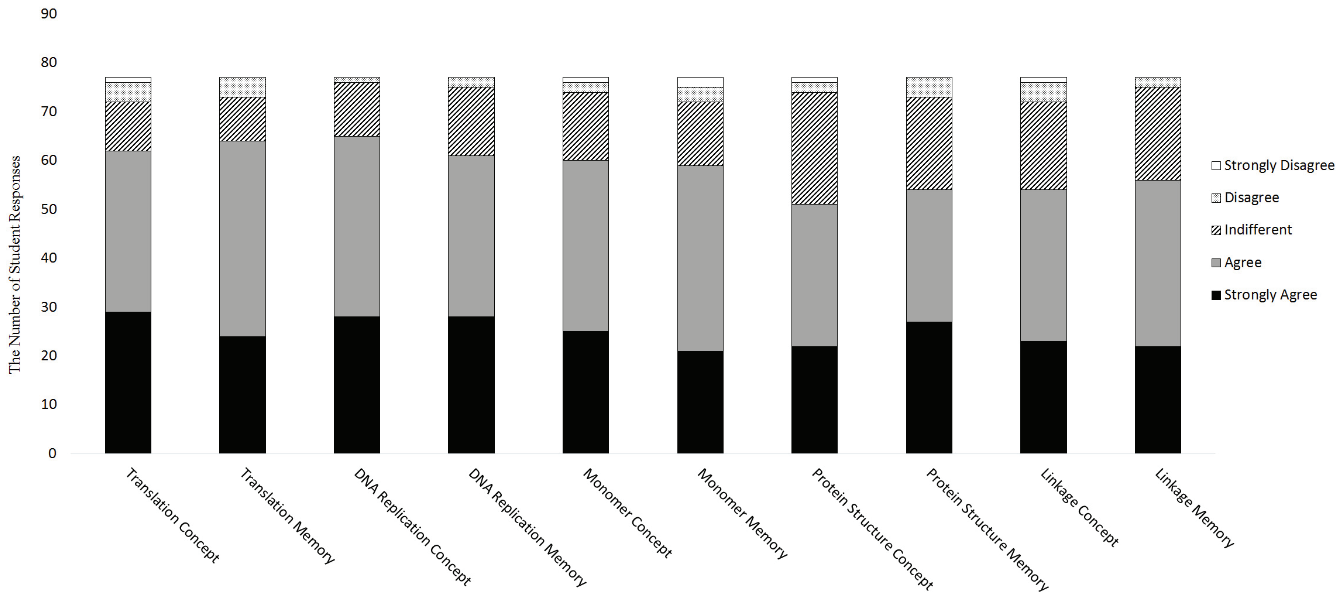

FIGURE 3. Students' sentiments about whether prop demonstrations did or did not help them learn the material (concept) and remember the material (memory) that had a prop demonstration component. Data compiled for BIO 13, BIO 59, and BIO 37.

zero, while most responses that were recorded resulted in a score of at least 50% of the possible points. This resulted in relatively high standard deviations that may have obscured trends toward statistical significance in some comparisons (Table 3). A small number of students did not answer any of the prop or non-prop questions that were analyzed in this study, so data for those students could not be included in any of the comparisons. Although it was not possible to obtain IRB approval to collect data from classes in which no prop demonstrations were used to serve as a baseline control for this study, our experience teaching this course many times suggests that the differences in performance on prop questions compared with non-prop questions is due to the use of the props and is not an artifact due to the control questions being more difficult than the prop questions. We can report anecdotally that scores have been similar in previous iterations of these courses.

Our results indicate that student learning and performance are influenced differently depending on the course in which the demonstrations are performed. Even though BIO 13 students appear to benefit from all prop demonstrations, the difference was only statistically significant for DNA replication (Fig. 2A). In BIO 59 (Fig. 2B) and BIO 37 (Fig. 2C), the students also appear to benefit from all demonstrations, but the differences are statistically significant for four of the five demonstrations for BIO 59 and two of the three demonstrations for BIO 37. We suggest that prop demonstrations may increase student learning more in higher-level courses, as evidenced by better student performance in BIO 59 than in BIO 13 (Fig. 2). This result could be attributed to greater effectiveness of demonstrations for students with a more advanced understanding of the subject due to reinforced learning of topics. It may be that students who have already been exposed to concepts in a previous course have a stronger framework on which to expand their understanding of those concepts. In other words, building upon previous knowledge may provide a context for the demonstration and make it more meaningful than it would be on first exposure. Alternatively, as BIO 13 is one of the prerequisites for BIO 59, the differences may be due to unsuccessful BIO 13 students not advancing to BIO 59. This, however, does not explain why the demonstrations were also effective in the BIO 37 nonmajors course. There is also a possibility that there are slight differences in demonstrations between the two instructors who performed them (although both instructors used the same text describing each demonstration to prepare for their use). BIO 37 and BIO 59 were taught by one instructor, and both were small classes (20 and 18 students, respectively). BIO 13 (three classes with a total of 52 students) was taught by two different instructors. This factor, in addition to the potential for minor differences between the instructors in the design of their questions, was not tested in our study and was assumed not to contribute to the differences that we found. Interestingly, whether the demonstrations are performed during the six-week session or the regular twelve-week session has no effect (Table 4). In the future, it would be desirable to conduct the study with larger sample sizes in order to achieve greater statistical power.

Finally, for BIO 37 the mean for student scores for translation, for which no significant difference was found between the prop vs. non-prop questions, was lower than the mean scores of all the other prop demonstration topics. It is possible that the lack of an observed difference was due to the complexity of the topic, which discourages nonmajor students. For biology majors, knowing that they must learn the topic in order to succeed in their major may provide extra motivation.

It was important to ascertain the students' perception of the effectiveness of the prop demonstrations, since their attitudes toward the demonstrations may influence their level of motivation for learning. Positive student attitudes toward the demonstrations might increase their engagement in the activities, which in turn will promote learning. Student survey data suggested that the prop demonstrations do increase students' abilities to understand and to remember the concepts. For each individual demonstration, between 66% and 84% of students responded that they "agree" or "strongly agree" that the demonstrations helped them to grasp and remember concepts. The number of students who "strongly disagreed" was only 0 to 3%. All differences were statistically significant.

The use of visual pedagogical tools such as demonstrations has been shown to enhance learning (4, 9). The prop demonstrations that we propose, or other appropriate demonstrations, require students to actively engage in the learning experience. We believe that this physical and cognitive engagement, together with the "writing to learn" (1) component of the learning experience as the students take notes on the demonstrated concepts, significantly enhances acquisition and retention of the material. Additionally, the props and the demonstrations that we used require everyday items and therefore can easily be repeated by students independently. Thus the demonstrations might provide a benefit beyond the classroom.

In summary, based on both quantitative data (Figs. 1 and 2) and student sentiment (Fig. 3) we suggest that demonstrations, especially interdisciplinary ones (see Table 1, demonstrations 1, 3, and 4) at the intersection of biology and chemistry, should be incorporated into biology classes since they help students to learn the material better and to perform better on assessments. In the future, it would be worthwhile to examine the use of prop demonstrations in other contexts (including non-biology courses and interdisciplinary learning communities), and to elucidate differences in the effectiveness of teaching with prop demonstrations when different student populations are involved (for example, majors compared with nonmajors, low-GPA students compared with high-GPA students, English language learners compared with native speakers).

SUPPLEMENTAL MATERIALS

Appendix 1: Survey on student sentiment

ACKNOWLEDGMENTS

The authors declare that there are no conflicts of interest.

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