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Virtual Lab Demonstrations Improve Students' Mastery of Basic Biology Laboratory Techniques

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Biology laboratory classes are designed to teach concepts and techniques through experiential learning. Students who have never performed a technique must be guided through the process, which is often difficult to standardize across multiple lab sections. Visual demonstration of laboratory procedures is a key element in teaching pedagogy. The main goals of the study were to create videos explaining and demonstrating a variety of lab techniques that would serve as teaching tools for undergraduate and graduate lab courses and to assess the impact of these videos on student learning. Demonstrations of individual laboratory procedures were videotaped and then edited with iMovie. Narration for the videos was edited with Audacity. Undergraduate students were surveyed anonymously prior to and following screening to assess the impact of the videos on student lab performance by completion of two Participant Perception Indicator (PPI) surveys. A total of 203 and 171 students completed the pre- and post-testing surveys, respectively. Statistical analyses were performed to compare student perceptions of knowledge of, confidence in, and experience with the lab techniques before and after viewing the videos. Eleven demonstrations were recorded. Chi-square analysis revealed a significant increase in the number of students reporting increased knowledge of, confidence in, and experience with the lab techniques after viewing the videos. Incorporation of instructional videos as prelaboratory exercises has the potential to standardize techniques and to promote successful experimental outcomes.

Teaching biology to undergraduate students most often includes lecture-based and laboratory classes. Recent studies have suggested that students are more engaged when presented with active-learning strategies (5). The laboratory provides one of the best opportunities for active learning as laboratory classes are designed to teach concepts through experiential learning. Most laboratory sessions are taught onsite, however with advances in multimedia and online delivery, all or portions of lab sessions can be taught virtually. Recent reports from the Boyer commission (2) and the National Academies of Science BIO 2010 commission (3) recommend the use of appropriate technology in instruction to improve student understanding. One method of technology-assisted learning is the use of computer simulations to instruct students in the use of lab equipment and procedures. For example, the University of California at San Diego has developed a virtual "Interactive Lab Manual" (7) for students to experience laboratory exercises through computer simulation before performing them in the lab. Another approach discussed here is the use of videos to enhance preparation for laboratory sessions.

Virtual biology lab courses have met with varying success. While Leonard (8) reported that video delivery was equivalent to in-class courses with regard to standard learning outcomes and the video learning approach was more time efficient, Stuckey-Mickell (11) reported that students considered the face-to-face lab courses to be more effective than virtual labs. There are few, if any, studies that assess the effectiveness of using multimedia to prepare students for a face-to-face biology laboratory class. In this study, we developed videos of laboratory techniques to provide prelaboratory instruction for students and to be used as a teaching resource for Teaching Assistants (TAs). We assessed the success of preclass video instruction using a Participant Perception Indicators (PPI) survey, which gauges students' perceptions for each technique.

Students who have never performed a technique must first be guided through the process; thus a visual demonstration of laboratory procedures is a key element in teaching pedagogy. Current practice in our General Biology Laboratory Class I & II at Johns Hopkins University (JHU) has students observe demonstrations of lab techniques in the teaching lab. Under those conditions, viewing is inadequate because of space constraints and there is limited opportunity for review of the technique. The success of laboratory learning is directly related to how well the experiment is performed using a standard laboratory protocol; therefore preparation for the laboratory can increase the success rate of the experiment as well as result in active-learning outcomes. While students can read about a procedure before class, typically there is no resource available to view the technique or procedure beforehand.

In addition to the value for student preparation, videos of basic techniques provide resources for graduate TAs who

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will demonstrate the procedure to the class. The skill sets of TAs are variable and many TAs require training. Dickey et al. (4) reported in their survey of biology lab instructors that while almost all hold weekly meetings, few offer opportunities for hands-on training and none use a multimedia approach to review and standardize techniques across laboratory sections.

Assessing student satisfaction can be accomplished by a variety of means, including formal surveys, focus groups, and anecdotal information. We (10) and others (11) have used the PPI first developed by the University of Michigan (11) to determine the value of techniques and approaches to student learning. This survey instrument assesses students' confidence, knowledge, and experience with laboratory techniques and is scored on a Likert (9) scale of one to five.

In this study, we developed and assessed the value of 11 short laboratory technique videos, which provide preparation for hands-on lab courses and serve as a resource for TAs. In this report we present data on the effectiveness of laboratory videos using student's perception queries of these preparatory materials.

MATERIALS AND METHODS

Filming of lab techniques. Laboratory techniques to be videotaped were selected from several teaching laboratory techniques used in General Biology, Genetics, Biochemistry, and Biotechnology classes at JHU. Outlines of the elements of the videos were written and scripts prepared to guide in the filming process. Techniques were filmed in the undergraduate biology laboratories on the Homewood campus and the graduate laboratories on the Montgomery County campus using a Canon GL2 DV cam. Raw footage was rendered into digital form with a Sony Mini-DV Deck and imported into iMovie. The footage was then edited with iMovie; narrative voiceovers were recorded with a line-in microphone and edited with Audacity v. 2.2.6 (General Public License), then added to the footage. All video editing was done at the Center for Educational Resources computer lab, Johns Hopkins University. Videos were uploaded to the Johns Hopkins Advanced Academic Programs server, and links were posted on the Johns Hopkins Biology website (http://www.bio.jhu.edu/undergrad). Table 1 lists the videos that were created. The videos produced are used in both undergraduate and graduate laboratory classes in the Krieger School of Arts and Sciences. The undergraduate laboratory classes using the videos are the Introductory Biology labs and Biochemistry lab. The graduate laboratory classes using the videos are Emerging Infectious Diseases, Biotechnology Lab Methods, and Recombinant DNA lab. Students were able to view the videos as often as needed. In this study, we only report on the effectiveness of the videos for the undergraduate General Biology Lab 1 course.

TABLE 1. Videos of lab techniques

Lab techniques	
Basic	Advanced
Lab safety	Use of an inverted microscope
Micropipetting	ELISAs
Macropipetting	Agarose gel preparation and electrophoresis
Spectrophotometry	
Light microscopy	Agarose gel documentation
Centrifugation	SDS-PAGE

Analysis of student performance. In order to assess the impact of the videos on student performance in class, two PPI surveys were administered to students in the undergraduate General Biology Lab 1 course. The PPI surveys were constructed using a Likert scale and administered to students through Zoomerang (www.zoomerang.com), a Web survey site. The student survey responses were collected anonymously. The first PPI survey was given at the beginning of the semester, after the first week of lab sessions and before any of the videos were viewed. The second was given later in the semester, after a number of videos were viewed as a part of required, graded, online prelaboratory assignments. The assignments were designed with questions that students should only have been able to answer after viewing the videos.

A total of 203 and 171 students completed the first and second PPI surveys, respectively. Each survey was linked to a regular online prelab assignment in order to promote participation. The rates of PPI survey participation represent 94% and 84%, respectively, of the students enrolled in the course.

In the PPI survey, the students were asked to rank their knowledge of, experience with, and confidence in performing a lab technique on a scale of one to five, with one as the lowest and five as the highest. Students were asked a total of 10 questions related to techniques performed during the course (Table 2); a sample question is provided as Fig. 1. The negative control, question 2—working in a biological safety cabinet, was a technique that was neither covered in lab nor by one of the videos. The positive control, question 5—accurately pipetting volumes less than 1 ml, was a technique that students had practiced in lab before the first PPI survey was administered and before the students had viewed the related video. The negative video controls, questions 1—use of sterile technique at the lab bench, 3—importance of sterile technique, and 7—move bacteria to a new petri plate, related to techniques students had performed before the first PPI survey and for which there were no related videos. The test techniques included questions 4—use of a centrifuge, 6—pipette volumes greater than 5 ml, 8—pour an agarose gel, 9—use a gel documentation system (Gel Doc), and 10—explain the purpose of gel electrophoresis. Question 4 asked about techniques for which the students saw a video and performed the technique in between the administration of the first and second PPI surveys. Questions 6, 8, 9, and 10 included techniques for which students viewed a video but had not performed the task in class at the time of the second PPI survey.

The results from the two PPI surveys were compared using a chi-square test. Scores of one to three (low) and three to five (high) on the Likert scale (9) were combined for analysis. A value of three was included in both sets of scores (high

TABLE 2. Relationship of PPI survey questions to timing of video viewing

Type of variable	Question	Performed technique before first PPI	Viewed related video before first PPI	Performed technique before second PPI	Viewed related video before second PPI
Positive	5. Accurately pipette volumes less than 1 ml	Yes	Yes	Yes	Yes
Negative	2. Use sterile technique while working in a biological safety cabinet (also known as a laminar flow hood)	No	No related video	No	No related video
Negative video	1. Use sterile technique while working at a lab bench	Yes	No related video	Yes	No related video
	3. Explain when it is important to use sterile technique	Yes	No related video	Yes	No related video
	7. Move bacteria to a new petri plate without contaminating them with other bacteria or fungi	Yes	No related video	Yes	No related video
Test	4. Use a centrifuge	No	No	Yes	Yes
	6. Accurately pipette volumes greater than 5 ml	No	No	No	Yes
	8. Pour an agarose gel	No	No	No	Yes
	9. Use an electronic documentation system (such as the Gel Doc) to visualize an agarose gel under UV light and print a picture of it	No	No	No	Yes
	10. Explain the purpose of agarose gel electrophoresis	No	No	No	Yes

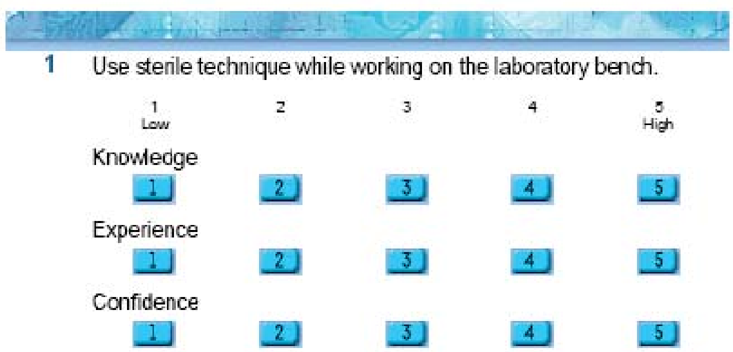

FIG. 1. Sample PPI survey question. Students were asked to rank their knowledge of, experience with, and confidence in their ability to carry out a particular technique using a Likert scale, with one as the lowest rank and five as the highest.

and low) and analyzed with a 2 × 2 chi-square test without Yates' correction using Graphpad QuickCalcs (http://www.graphpad.com/quickcalcs/index.cfm). A P value of less than 0.05 was considered statistically significant.

RESULTS

Eleven videos were produced introducing students to both basic and advanced techniques (Table 1). Each video is several minutes long and students may view them multiple times prior to class. The videos are hosted on the JHU Advanced Biotechnology Studies server and are available to the public at the JHU Biology Department website, http://www.bio.jhu.edu/Undergrad/Default.html.

The results of the chi-square analysis of the PPI surveys are shown in Table 3. Question 2—sterile technique in a biological safety cabinet, the negative control, indeed shows no significant change in students' ranking of their knowledge or their confidence. However, there are significant differences when students are presented with a video but no hands-on experience with the technique between the initial and final PPI surveys, as demonstrated by student responses to questions 8—pour an agarose gel, 9—use a Gel Doc, and 10—explain

TABLE 3. Chi-square analysis of differences between initial and final PPI survey results

Type of variable	Question	Category	*P* value	Statistical significance[a]
Positive controls	5. Accurately pipette volumes less than 1 ml	Knowledge	0.5078	Not significant
		Experience	0.0032	Significant
		Confidence	0.3995	Not significant
Negative controls	2. Use sterile technique while working in a biological safety hood (also known as a laminar flow hood)	Knowledge	0.0738	Not significant
		Experience	0.0088	Significant
		Confidence	0.053	Not significant
Negative video controls	1. Use sterile technique while working at a lab bench	Knowledge	0.2489	Not significant
		Experience	0.0144	Significant
		Confidence	0.0389	Significant
	3. Explain when it is important to use sterile technique	Knowledge	0.0816	Not significant
		Experience	0.003	Significant
		Confidence	0.003	Significant
	7. Move bacteria to a new petri plate without contaminating them with other bacteria or fungi	Knowledge	>0.0001	Extremely significant
		Experience	>0.0001	Extremely significant
		Confidence	>0.0001	Extremely significant
Test variables	4. Use a centrifuge	Knowledge	0.0546	Not significant
		Experience	>0.0001	Extremely significant
		Confidence	0.0239	Significant
	6. Accurately pipette volumes greater than 5 ml.	Knowledge	0.6942	Not significant
		Experience	0.0408	Significant
		Confidence	0.6035	Not significant
	8. Pour an agarose gel	Knowledge	>0.0001	Extremely significant
		Experience	0.0039	Significant
		Confidence	0.0013	Significant
	9. Use an electronic documentation system (such as Gel Doc) to visualize an agarose gel under UV light and print a picture of it	Knowledge	>0.0001	Extremely significant
		Experience	>0.0001	Extremely significant
		Confidence	>0.0001	Extremely significant
	10. Explain the purpose of agarose gel electrophoresis	Knowledge	>0.0001	Extremely significant
		Experience	0.0055	Significant
		Confidence	0.0001	Significant

[a] Key to statistical significance: not significant, $P > 0.05$; significant, $0.0001 < P < 0.05$; extremely significant, $P < 0.0001$.

the purpose of electrophoresis. There are also significant differences when students are presented with hands-on experience with the technique but no video between the initial and final PPI surveys, as shown in student responses to questions 1—use sterile technique, 3—explain the importance of sterile technique, and 7—move bacteria to petri dish.

Question 5 represents the positive control where students had already viewed the video and performed the technique before the initial PPI survey. No change is seen between the initial and final PPI surveys for knowledge or confidence. Questions 6, 8, 9, and10 represent techniques for which students viewed a video as a prelab assignment between the initial and final PPI surveys. For these queries, there is a shift towards higher Likert scores (closer to five) in each category (knowledge, experience, and confidence). This shift is represented graphically using the data for question 10 (Fig. 2).

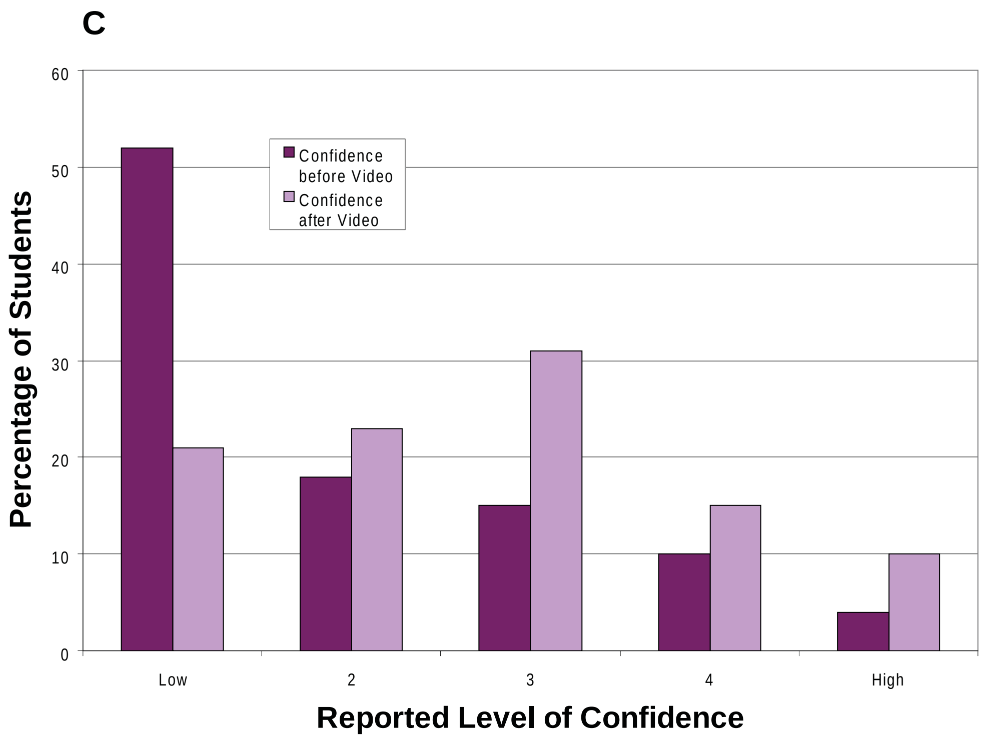

FIG. 2. Student-reported levels of knowledge (A), experience (B), and confidence (C) regarding the purpose of an agarose gel (PPI survey question 10). The first PPI survey was administered before students had seen the agarose gel videos or performed the technique in lab. The second PPI survey was administered at the end of the semester, after the students had seen the videos but before they had performed the technique in lab. The data are expressed as percentages to account for the different number of responses to each PPI survey.

DISCUSSION

Viewing videos of basic laboratory techniques increases students' self-reported knowledge, experience, and confidence with specific techniques. These videos can be used in a wide variety of laboratory courses, ranging from introductory undergraduate courses to specialized graduate courses. Although these videos were not meant to be substitutes for actual lab work, we did find that the video alone showed as strong an effect as performance of the lab technique alone. Our data indicate that the combination of both the video and the actual laboratory skill is best for maximal knowledge, confidence, and experience. In aggregate, 70% of students (Table 3) responded positively that the lab videos were effective in increasing student knowledge, experience, and understanding of lab procedures. Analysis of the responses demonstrated that for the higher-level techniques such as Gel Doc and gel electrophoresis, there was a greater difference in students' confidence, knowledge, and experience after viewing the videos than for more basic techniques such as centrifugation and micropipettes.

Anonymous feedback about the demonstration videos was collected from the General Biology 1 students using an online survey tool via the WebCT course management system. A few representative comments are reproduced here:

"The videos were very helpful in teaching techniques to students before the actual lab assignment. Seeing these skills performed provided a much more accessible and clear means by which to understand the technique. Reading the same list of instructions from a textbook or written source would have caused unnecessary confusion and wasted time."

"The demonstration that helped me the most was the demonstration on how to set up and cast an agarose gel. I had never done one before, and seeing the process before lab made actually doing the lab much faster."

"I thought the videos were very helpful especially because they saved time when performing the lab. We didn't have to waste time going over how to do all the techniques and use all the instruments during lab, instead we were able to jump right into the experiment. I thought all the videos were great!"

Although the General Biology 1 course surveyed for this study does not incorporate a laboratory practical where students are tested on performance of techniques, future studies of the impact of such videos could incorporate this metric as well.

The introductory chemistry laboratory at JHU also uses a similar method of introducing students to basic lab techniques, and anecdotal reports indicate a similar level of success (L. Pasternak, Dept. of Chemistry, JHU, personal communication). Incorporation of instructional videos as prelaboratory exercises has the potential to standardize techniques and to promote successful experimental outcomes.

Another benefit of the videos was the standardization of techniques as demonstrated by TAs and across sections. As TAs often vary in laboratory skills, the video collection serves as a resource for review and standardization. Training the next generation of instructors is crucial for improving science literacy in the United States (6). In addition, the technology fellows who produced the films learned valuable skills in making complex laboratory procedures accessible to students. This project was a first step in their training as future educators.

As the data indicated that videos for higher-level techniques were the most beneficial, future videos on additional topics are planned, covering sterile technique, microarray technology, real-time PCR, cell culture, and high-throughput robotics. Perhaps other fields of laboratory science could benefit from such videos in the teaching laboratory.

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