



Preparation of Biology Review and Virtual Experiment/Training Videos to Enhance Learning in Biochemical Engineering Courses

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Abstract

Two major challenges are inherent in any biology-related engineering subject (e.g. biochemical engineering, biomechanical engineering, or civil/environmental engineering) – (1) the student must have a good understanding of fundamental biology concepts to fully comprehend the advanced engineering concepts and (2) most of the techniques discussed in these courses are too time-consuming, hazardous, or expensive to demonstrate in a classroom setting. We have addressed these issues by preparing a series of videos that review basic biology concepts and demonstrate several common biochemical engineering (BioChE) techniques and experiments. The primary goal of the review videos is to ensure that students have a firm grasp on basic biology concepts to help them fully understand the more advanced BioChE topics discussed in class. These videos can also be assigned before class, allowing us to spend more class time discussing new and advanced BioChE concepts. The goal of the experiment videos is to help us expose the students to state-of-the-art experimental techniques in lecture-based classes or to help them better prepare for the experiments that they conduct in lab-based courses. We have also used these videos to streamline the training process for undergraduate and graduate students performing research in our labs. Some of the review and experiment videos have already been utilized in our BioChE courses and we have evaluated their effectiveness with student surveys. The feedback from these surveys is highly positive and indicates that the videos help to enhance student learning.

Introduction

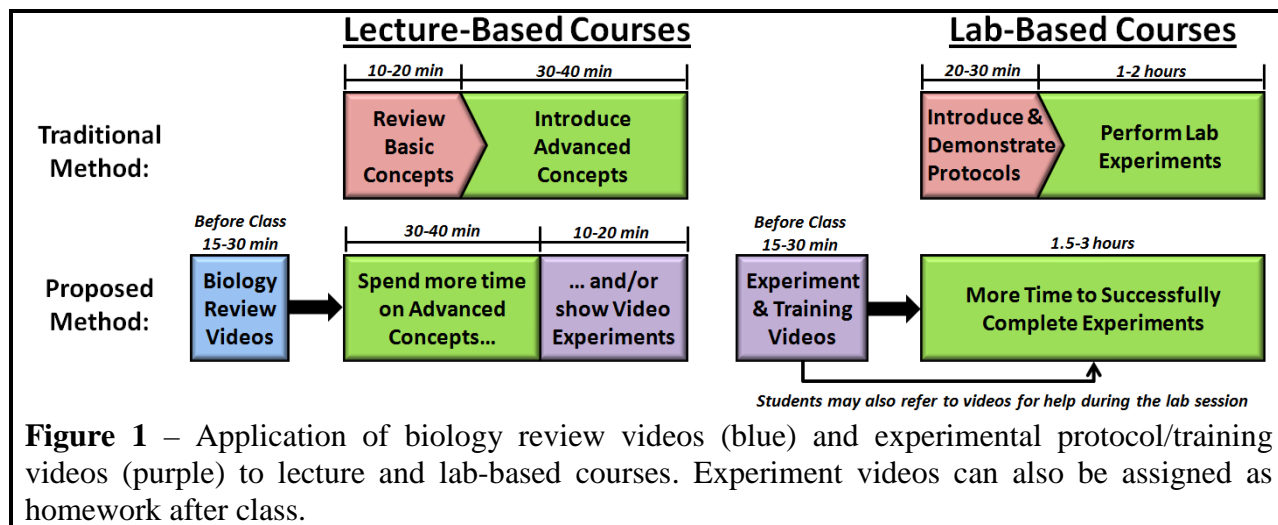
Since the advent of broadband internet provided on-demand video capability to students in the late 1990's, instructors have been experimenting with the use of online lessons and videos to enhance student learning both inside and outside of the classroom (e.g. flipped classrooms¹ and distance learning²). Online videos and animations have been shown to be especially effective for teaching molecular biology concepts^{3,4}, which are often too small to see with the naked eye and difficult to conceptualize.⁵ Several organizations have already created full length online videos for biology topics that are available free of charge, including the BioVisions series from Harvard⁶, Khan Academy⁷, Open Courseware at MIT⁸, TED⁵, and several others^{9,10}. These videos allow students to learn and study at their own pace outside of the classroom or can be used to supplement lessons in the classroom. In addition, online videos are a useful reference material that students can review as needed later in their careers.

Videos have also been used to demonstrate a wide variety of experiments and techniques. For example, the Harvard BioVisions series includes videos on aseptic technique and DNA microarray experiments.⁶ Several excellent experiment videos are also available on video sharing websites like Vimeo and YouTube (e.g. purification of green fluorescent protein by hydrophobic interaction chromatography¹¹). The largest library of video experiments is provided by the Journal of Visualized Experiments (JOVE), a peer-reviewed online scientific video journal. Each JOVE video begins with an overview of relevant fundamental concepts, followed by a demonstration of the experiment and any relevant data analysis. In contrast to the Materials

and Methods section of most journal articles, these videos show every step of the experiment in great detail to help scientists in other labs successfully conduct these experiments with high reproducibility. These videos can also be used in the classes to demonstrate applications of advanced concepts, thereby helping students to comprehend and appreciate the importance of such topics. Showing experiment videos is also much safer and costs much less than in-class demonstrations and especially appeals to students with a visual learning style.

The goal of this project was to develop three sets of videos: (1) reviews of fundamental biology concepts, (2) demonstrations of biological experiments, and (3) safety and basic skills training videos for students in lab classes. Each video was strategically designed to enhance student learning in lecture and/or lab-based courses by allowing students to review basic concepts and experimental protocols before class, thereby providing more time in class to discuss advanced concepts or perform experiments (see Figure 1). In addition, some of the experimental videos were also designed to enhance lecture-based classes by including experiment demonstrations that are typically too dangerous, time-consuming, or expensive to perform in a classroom. Two hypothetical applications of these videos are shown below.

- 1) In a lecture on recombinant proteins, an instructor may need to spend 10-20 minutes reviewing basic concepts like transcription and translation before introducing more advanced topics like fermentation. Our review videos for these basic concepts could be assigned before class to provide more time in class to discuss expression plasmids or demonstrate related techniques with short videos of actual experiments.
- 2) In lab courses, up to 30 minutes might be spent introducing or demonstrating how to conduct an experiment. Our experiment and training videos allow students to learn their protocols before class, thereby providing more time during the lab to actually conduct the experiments. In addition, students may also refer to the experiment videos during class to help them successfully complete the experiment or after lab while they are writing lab reports.



Preparation of Videos

Review Videos of Fundamental Biology Concepts: Each review video was recorded in a conventional distance learning classroom with a camera that simultaneously recorded the instructor, their PowerPoint slides, and any sketches or notes that were made in real time on the slides. All of the slides were archived and made available to students upon request. A comprehensive list of all the review videos and their content is shown in Table 1.

<i>Category</i>	<i>Video</i>	<i>Topics</i>
Molecular Biology	Biomolecules	Structure and functions of lipids, sugars, proteins, and DNA
	Gene Expression	Transcription, translation, and regulation of gene expression
	DNA	DNA replication and structure
	Proteins	DNA, RNA, Amino acids, and levels of protein structure
	Enzymes	Enzyme structure and reaction kinetics
Cell Biology /Physiology	Mitosis	An overview of the cell cycle and stages of mitosis
	Cell Structure	Structures and functions of various organelles
	Metabolism	Glycolysis and the Krebs' Cycle
	Cell Signaling	Receptors and signaling cascades (e.g. JAK/STAT)
Human Anatomy	General Anatomy	Cells, tissue, organ, and system organization/functions
	Immune System	Immune cells and activation pathways
	Cancer	Causes, effects, and treatments for cancer
Microbiology	Types of Cells	Bacteria, Fungi, Eukaryotes, and Viruses as well
	Plasmids	Elements required for recombinant protein expression

Table 1 – List of fundamental biology concepts covered in our review videos.

Experiment/Protocol Videos: Experimental procedures were recorded in a laboratory setting with a camcorder and tripod. Video clips were edited using Camtasia Studio (TechSmith) and integrated into PowerPoint presentation slides that included instructions for each step of the experiment, along with troubleshooting advice and other detailed notes. For example, one of the slides from the Restriction Digest experiment video is shown in Figure 2. While the video plays in the central panel, short step-by-step instructions are listed below it and more detailed notes are displayed in the panel on the right. In this case, the notes include a recipe for the digest reaction and important reminders about the buffers and times that should be used to optimize the reaction.

Video slides were also preceded by 1-2 introduction slides with computer animations that provided an overview of the experiment and any relevant concepts. The entire PowerPoint presentation was then narrated, converted to .mp4 video format, and uploaded to MediaSite. A list of the experiment and training videos that were produced is shown in Table 2.


<i>Category</i>	<i>Experiment/Topic</i>	<i>Description</i>
Training Modules	Biohazard Safety	Common biohazards & proper safety measures
	Basic Lab Skills	Pipetting, balances, centrifugation, etc.
	Aseptic Technique	Tips to avoid contamination of cell cultures
	Waste Disposal	Proper disposal of cells, liquids, and chemicals

Animal Cell Culture	Freezing & Thawing Cells	Freezing cells in DMSO and starting new lines
	Passaging Animal Cells	Trypsinization and counting cells
	CO ₂ Incubators and the BSC	Basic guidelines for culturing animal cells
Bacterial Cell Culture	Bacterial Culture Techniques	Media prep, inoculation, and incubation of cells
	Plasmid DNA Purification	Using a miniprep kit to isolate plasmid DNA
	Recombinant Protein Expression	Expression of the aeBlue protein in E. coli
Microscopy	Light Microscopes	Examining cells with an inverted microscope
	Fluorescent Microscopes	Imaging fluorescent animal cells
Molecular Biology	Overview of Cloning	Introduction to the molecular biology videos
	PCR	Amplification of a target gene for cloning
	Restriction Digests	Digestion of PCR products and plasmid DNA
	DNA Ligation	Joining DNA fragments to make a new plasmid
	Bacterial Transformation	Inserting a DNA plasmid into E. coli cells
	Agarose Gel Electrophoresis	Separation of DNA fragments on an agarose gel
	Agarose Gel Extraction	Recovery of DNA fragments from a gel
Protein Purification and Separations	Anion Exchange (AEX)	Purification of human hemoglobin
	Hydrophobic Interaction (HIC)	Purification of recombinant aeBlue protein
	Metal Affinity (IMAC)	Zinc affinity purification of human hemoglobin
	Precipitation and Desalting	Selective precipitation of hemoglobin by NiCl ₂
	Ultrafiltration	Purification of erythrocrucorin by 500 kDa filters
	PAGE	Separation of proteins by molecular weight
	Dialysis	Assembly of a device to remove salt from water

Table 2 – List of experiments and training videos prepared in our project

High Definition Video of Experiment

Restriction Enzyme Digests



Notes:

- Restriction enzymes require specific buffers, incubation temperatures, and incubation times. Refer to the manufacturer's instructions.
- Try to use restriction enzymes with similar requirements. Otherwise, you will have to do separate digests.
- DO NOT incubate digests for >2 hours. Enzymes may degrade non-target sequences (a.k.a. star activity).
- Example digest reaction (V = 50 uL):
 - DNA.....1 ug
 - Buffer.....dilute to 1 X
 - Enzymes....10 units

- 1.) Mix DNA, reaction buffer, and restriction enzyme(s) .
- 2.) Incubate the digest reaction at 37C for 20-60 minutes.
- 3.) Run an agarose gel to visualize the results of the digest.

Tips, Troubleshooting, Hazards, and other details

Step-by-Step Instructions for the experiment shown in the video

Figure 2 – Screenshot of Restriction Digest Experiment Video. In addition to the video, step-by-step instructions and detailed notes (troubleshooting advice and hazards) are also provided.

Note: All videos are available upon request - please contact the corresponding author (Dr. Jacob J. Elmer).

Student Feedback Surveys: A survey with 7 questions and a space for suggestions or comments was sent to students after they watched each video. Comments and the responses to each question were compiled, analyzed, and saved in Excel. Examples of questions include:

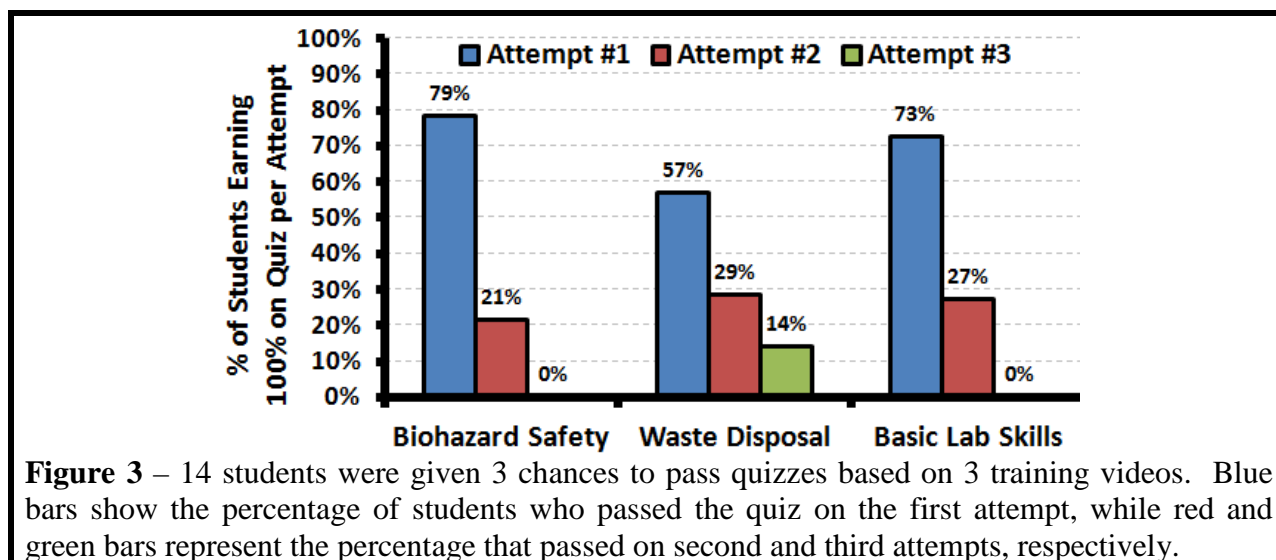
- Was the video enjoyable? (No, Somewhat, and Very Much)
- Did the video help you understand material presented in class? (No, Somewhat, Yes)
- How would you describe the length of the video? (Too short, Too long, Appropriate)
- Will you use this video to study for the test? (No, Maybe, Yes)
- Would you recommend that this video be used again in this class? (No, Maybe, Yes)

Applications of the Videos

Training Videos for Research Students

At the beginning of the 2014-2015 school year, all undergraduate and graduate students participating in research in our department were required to watch the *Biohazard Safety*, *Basic Lab Skills*, and *Waste Disposal* training modules shown in Table 2. The students were then given three chances to take quizzes based on each video and were informed that they would not be allowed to begin their research until they had earned a perfect score on each quiz.

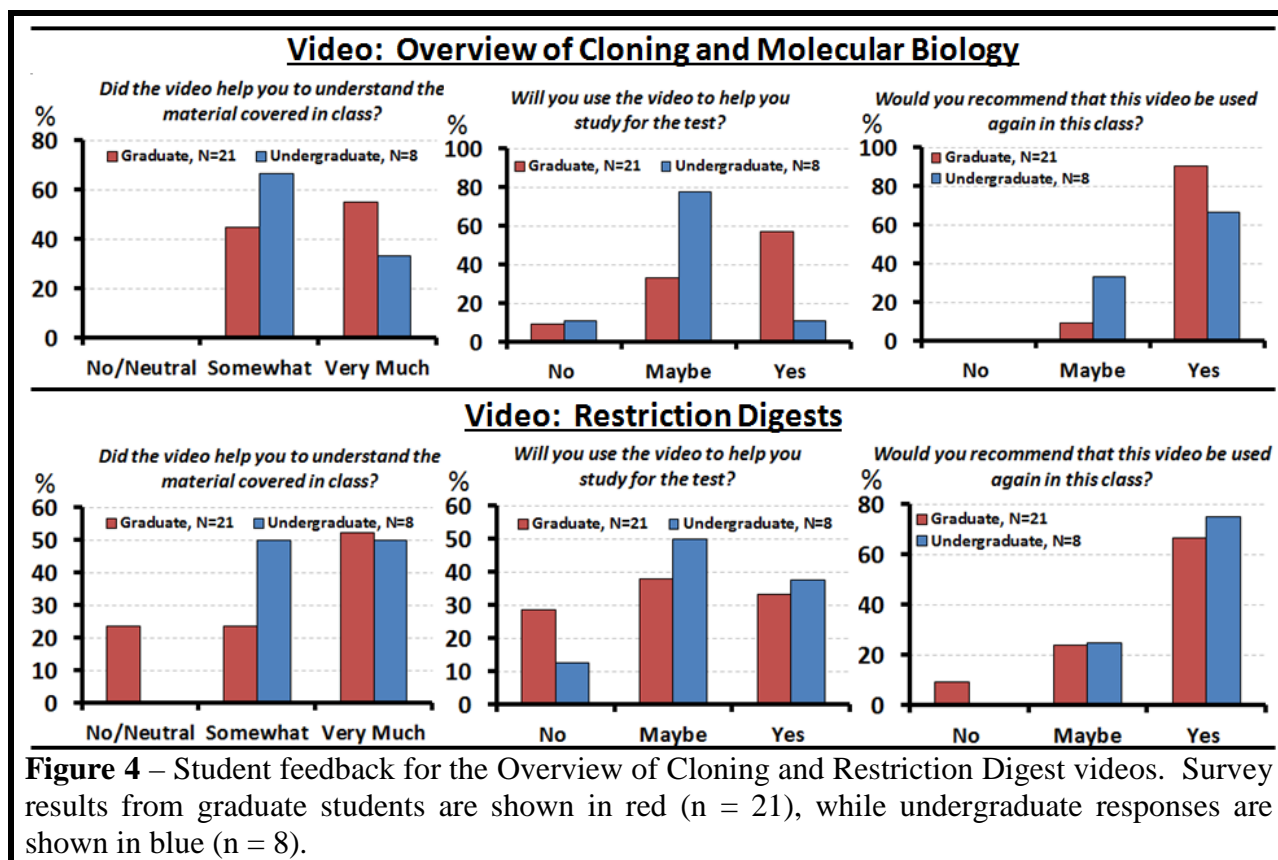
Most of the students passed each quiz on the first attempt (57-79%), as shown in Figure 3. The biohazard safety quiz had the highest first attempt pass rate (79%), while the waste disposal quiz had the highest amount of 2nd and 3rd attempts (29% of students had to take the quiz a 2nd time and 14% required a 3rd attempt). No 4th attempts were required on any quiz. There was a significant fraction of students that did have to make a second attempt on each quiz (21-29%), but it is important to mention that most (13/14) of the quizzes that were not perfect on the first attempt only had a single mistake (9 out of 10 correct) and the most common mistake was to select only one answer in multiple choice questions with multiple correct answers (two questions of this type were on the Waste Disposal quiz). Overall, these results suggest that these training videos are an effective tool for teaching students basic lab skills and safety guidelines.



While we found these training videos to be a convenient, consistent, and thorough way to train our students, it is important to mention that the videos are only a portion of our total training regimen. Once the students had passed their quizzes, we also gave them personal lab safety tours and demonstrated specific protocols to ensure that they were properly trained. Therefore, these training modules are not used to replace traditional training practices, but we have found them to be a good initial experience to start training our students before they begin working in the lab.

Experiment Video in Biotechnology Classes:

Two of the experiment videos – *Overview of Cloning* and *Restriction Digests* – were assigned as homework in an undergraduate elective course (Introduction to Biotechnology) and a required graduate course (Biochemical Engineering). These videos are specifically designed to show students how plasmids are prepared for recombinant protein expression and we assigned them as a supplement to in-class lessons that focused on bacterial fermentation and protein expression. This combination allowed students to see how plasmids are made in the videos and then discuss how to optimize protein expression from those plasmids during class.

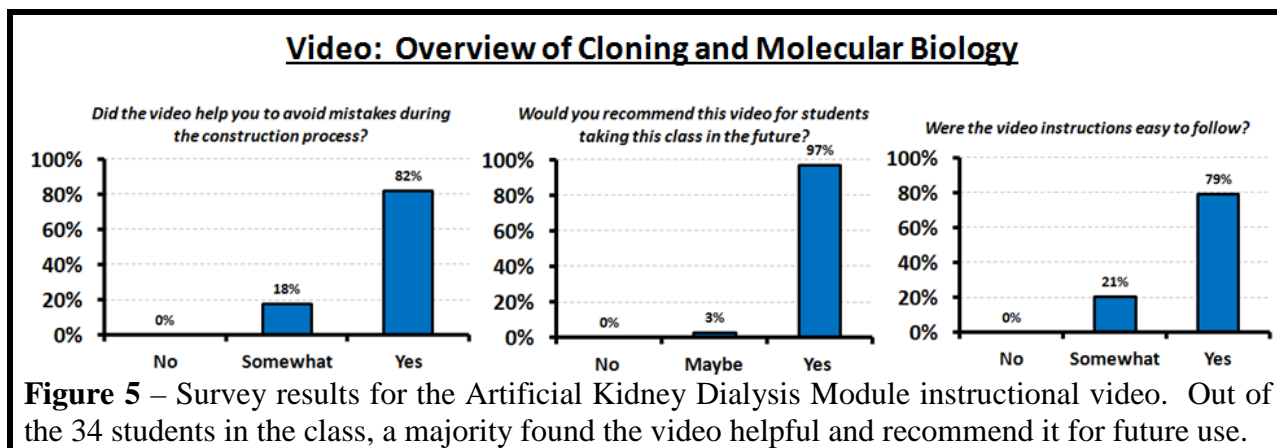


After the students had watched each video, they were asked to complete a brief survey with several questions and a space for comments and suggestions. The responses from graduate (red) and undergraduate (blue) students for three of the questions are shown in Figure 4. Students in both classes agreed that both of the videos helped them to better understand the

material covered in class (somewhat or very much) and the majority of students also reported that they would or may use the videos to help them study for the next test. The students also recommended that the videos be offered again in the class next year. However, there was a significant fraction of graduate students who commented that the restriction digest video was too long (23.8%, 5/21 students) and it did not help them to understand the material covered in class (23.8%). Therefore, we may need to streamline and revise the content of the digest video for the graduate class, but the overall opinion of both videos seems to be highly positive in both classes.

Protocol/Training Video in a Freshman Engineering Class

As part of our freshman engineering program, students are required to take two half-semester project-based courses in which they work on multi-disciplinary projects to design a product or system that addresses a real world problem. The goal of one of these projects is to construct a dialysis device using plastic tubing, a dialysis membrane, and 15 mL centrifuge tubes.¹² Although the design is fairly straightforward and the instructor demonstrates how to construct the device in class, the students’ devices frequently have leaks or blockages that require them to start over and lose valuable time that could be used to test their devices. To address this problem, we prepared an instructional video that showed them how to construct the dialysis device and highlighted helpful tips and common pitfalls in the assembly process. Interestingly, many students started bringing their laptops to class to watch the video as they were assembling the device. Compared to previous semesters, the students that were given the instructional video built devices that had fewer flaws and were able to spend more time testing and collecting data (instead of rebuilding their devices).



The results of student surveys for the instructional video were highly positive (see Figure 5). All of the students agreed that the video helped them to avoid mistakes during the construction process (82% entirely, 18% somewhat) and 97% of students recommended that this video be used again in future offerings of the class. However, there were several students (21%, 7 out of 34) who indicated the video was only “somewhat” easy to follow. One key difference between this video and our other videos is that there was no narration or audio to accompany the video and step-by-step instructional captions. Interestingly, five of the seven students who chose “somewhat” as their response to this question also indicated in the comments section that video would be more effective with narration. These results show that while video alone is a powerful

learning tool, audio or narration is also very important to some students (even though sufficient written instructions and captions are provided along with the video).

Review Video on Proteins in a Protein Engineering Course

The review video *Introduction to Proteins* was assigned to students before the first day of a graduate course on Protein Engineering. This review video is a brief (15 min) overview that discusses transcription, translation, amino acids, and protein structure (primary, secondary, tertiary, and quaternary). Assigning this video before class freed up extra time in our first lesson on advanced protein synthesis to discuss how tRNA's are charged with amino acids by amino acyl transferases and how this pathway can be modified to incorporate unnatural amino acids into proteins. While surveys (data not shown) indicated that only half of the class (6 out of 12 students) chose to watch the video, the students that did watch it all agreed that the review helped them to understand the content in class at least somewhat and that the video should be offered in again in future offerings of the course.

Future Work

Our current survey results indicate that our review and experiment videos are effective and well received by our students, but there is still much work to be done. Since a significant fraction of students have commented that they would prefer a shorter version of the experiment videos, we are currently preparing "abridged" versions of the experiment videos that are less than 5 minutes long and may be more appropriate for some classes that do not require the fine details of each experiment. Some of the shortened videos will also be converted into Graphics Interchange Format (GIF) files, allowing them to be easily incorporated into PowerPoint slides and shown in class as visual demonstrations. We may also disseminate these abridged videos and GIF's to high schools with advanced courses in biology or biotechnology to broaden the impact of these videos and increase interest in engineering and science.

Due to the success of these videos in our biochemical engineering courses, we are also planning experiment videos for other non-biological Chemical Engineering (ChE) courses like Unit Operations. These videos would show students how to operate several pieces of common equipment in our lab courses, including double-pipe heat exchangers, evaporators, and others.

Conclusion

Over the course of this project, we developed 14 review videos for fundamental biology concepts and 25 experiment videos showing a wide range of biological experiments and techniques. We have already implemented 7 of these videos in classes and labs over the past year and observed the following benefits:

- Assigning review videos before class provides more time for advanced concepts in class
- Students appreciate seeing real world applications of concepts in the experiment videos
- Experiment videos also help students to understand the related concepts covered in class
- Training and instructional videos help students to successfully complete and prepare for lab experiments

Since our survey data indicates that these videos are effective learning tools, we will continue assigning the remaining videos in Tables 1 and 2 throughout the rest of our curriculum. We will also continue collecting survey data to help us revise and optimize each video with the ultimate goal of creating a BioChE review/experiment video library that can be disseminated to other colleges and high schools. These videos will be made available upon request to the corresponding author (Dr. Jacob J. Elmer).

Bibliography

1. Herreld, C. F. & Schiller, N. A. Case Studies and the Flipped Classroom. *J. Coll. Sci. Teach.* **42**, 62–66 (2013).
2. Williams, S. L. The Effectiveness of Distance Education in Allied Health Science Programs: A Meta-Analysis of Outcomes. *Am. J. Distance Educ.* **20**, 127–141 (2006).
3. Stith, B. J. Use of animation in teaching cell biology. *Cell Biol. Educ.* **3**, 181–8 (2004).
4. Sanger, M. J., Brecheisen, D. M. & Hynek, B. M. Can Computer Animations Affect College Biology Students' Conceptions about Diffusion and Osmosis? *Am. Biol. Teach.* **63**, 104–109 (2001).
5. Animations of Unseeable Biology. at <o
http://www.ted.com/talks/drew_berry_animations_of_unseeable_biology.html>
6. BioVisions at Harvard University. at <multimedia.mcb.harvard.edu>
7. The Khan Academy. at <www.khanacademy.org>
8. MIT Open CourseWare - Courses in the Biology Department. at <<http://ocw.mit.edu/courses/#biology>>
9. Kyrk, J. Cell Biology Animation. at <www.johnkyrk.com>
10. Free Biology Animations. at <<http://www.learnerstv.com/animation/Free-biology-animations-page1.htm>>
11. BioNetwork. *Hydrophobic Interaction Chromatography (GFP Purification Part 4 of 6)*. (2014).
12. Comolli, N., Kelly, W. & Wu, Q. The Artificial Kidney: Investigating Current Dialysis Methods As A Freshman Design Project. in *Am. Soc. Eng. Educ.* (2010).