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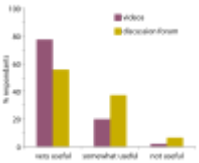
Teaching MIT Students to Think Like Cell Biologists: A Visual Approach

Abstract:

Imagine sitting in a lecture hall and hearing the phrase, "prepare Golgi membranes from CHO 15 B1 cells after infecting them with VSV." Can you visualize the process or molecular components involved? If you are an experienced biologist, then you likely performed an experiment similar to this, or at least are familiar enough with the ideas that you have no problem forming a picture in your brain of what this procedure would involve. Most of our undergraduate students are not experienced biologists, however, and have only a year or two of biology experience at Massachusetts Institute of Technology (MIT) when entering classes that discuss experiments at this level of detail. Most of the biology core courses do not have an associated lab component; therefore we need to develop teaching strategies to best support students learning these experimental concepts. During the fall of 2014, we, the MITx Biology team [1] partnered with Professors Frank Solomon and Adam Martin of the Department of Biology to create videos addressing experimental design to enhance the undergraduate learning experience in the sophomore-level cell biology course (7.06). We used the residential MITx platform, an online platform available only to those in the MIT community, based on Open edX, to distribute the content and create a place for discussion outside of class. Based on our survey data and the faculty's classroom experience, students responded very positively to this teaching approach for biology. Almost all (95%) of the students reported that they would like to see more experimental videos for other biology courses and think that future cell biology students will find the videos useful. The faculty also found the teaching tool valuable and observed differences in students' ability to discuss experiments. Based on this pilot, we will continue to expand upon teaching by this method.

Hide Figures



Who We Are

Our team consists of Mary Ellen Wiltrout, PhD, an Instructor and Digital Learning Scientist, and two MITx Postdoctoral Teaching Fellows, Nathaniel Schafheimer, PhD and Sera Thornton, PhD, all members of the Department of Biology and MIT Digital Learning Lab. We develop content for and manage all MITx projects from the Department of Biology. Our goal is to develop innovative teaching techniques to enhance the learning experience for MIT students by incorporating digital learning materials through the residential (used only on campus) MITx platform and in the classroom. We also want to share enthusiasm for biology with learners around the world through our free, non-credit courses that we publish through edX, a nonprofit company founded by MIT and Harvard.

On MIT campus, we work with the staff of a variety of biology courses – such as 7.06 Cell Biology, as discussed in this article, but also from Introductory Biology courses 7.012 and 7.013 to advanced courses like 7.28/7.58 Molecular Biology – to develop residential MITx sites. In total, we have

developed sites for about ten residential courses. These sites host content specific to the course and semester taught. The entire course does not have to go digital; instead, the faculty can select how much or little content (videos, problems, text) they want to host on the MITx site. The content on these sites is different from that of the MITx courses released on edX for the world audience, and these residential sites are not available to the public.

We also currently have developed and manage four courses that are available worldwide on edX.org: 7.00x Introduction to Biology - The Secret of Life [2], 7.QBWx Quantitative Biology Workshop , 7.28.1x Molecular Biology: DNA Replication and Repair , and 7.28.2x Molecular Biology: Transcription and Transposition (first released October 2015).

Why We Wanted to Try New Teaching Methods in Science Education

After almost 30 years of primarily teaching graduate-level courses, MIT Department of Biology Professor Frank Solomon faced the new adventure of teaching 7.06 Cell Biology, a course taken by nearly 100 undergraduates each semester. The students are mostly juniors and seniors majoring in biology or biological engineering. He wanted to explore more effective ways to engage his students both inside and outside the classroom. To that end, he became interested in active learning and blended learning techniques. Active learning strategies are supported by education research, as summarized last year by Freeman *et al.* in the *Proceedings of the National Academy of Sciences* [3]. The authors analyzed 225 studies of undergraduate classes in science, technology, engineering, and math (STEM) taught by traditional, instructor-centered lecturing versus an active learning approach. They found that active learning improved students' exam scores by almost half a standard deviation and decreased failure rates.

The introductory biology course taken by all MIT undergraduates does not have a lab component, which typically involves a more active learning process. How can we expect these students, who lack the necessary framework, to be able to visualize the complicated experimental steps from published research like the purification of Golgi membranes? Given a number of limitations, the Biology Department cannot have a lab associated with every residential course, and lab courses cannot give students practice with all techniques performed in research labs. Likewise, when the teaching staff of undergraduate courses assign a scientific paper as reading, the details of that paper are crucial. But without the experimental framework (usually not sufficiently explained in the published results because the reader is expected to have a certain level of expertise), they do not mean as much, and in fact are over the heads of many students, as observed by teaching staff in recitations or discussion. And yet our goal is to get our biology graduates to the level where they can read, understand, and critique a scientific paper, allowing them to be productive contributors to the field of biology. During their time at MIT, 89% of our undergraduates do participate in research [4].

To provide students with this necessary framework, instructors may discuss those experimental assays during lecture time or refer to a static image in a textbook or a video online, but it is rare that a resource exists that describes the concepts in the same depth or way that they want to teach them. Video is especially interesting as a teaching tool; many studies have been done to determine whether animated graphics offer a pedagogical advantage over still graphics, and a meta-analysis of 26 such studies suggests that they do [5]. There are many educational videos on the web, but very few animate the experiments with an emphasis on scientific thinking, as we want to teach in an MIT class. In our situation, we wanted to create an audiovisual resource so that the students could visualize – for example – the infection of the CHO cells by the virus VSV, all without having to spend hours of class time demonstrating these processes in a lab.

Collaboration between 7.06 Staff and the MITx Biology Team to Produce a Pilot Video Series

We worked with Professors Frank Solomon and Adam Martin to give students taking 7.06 Cell Biology during the fall of 2014 a different approach to learning experimental design and assays. We created the series entitled "Neat Experiments in Cell Biology," consisting of four 5-8 minute videos (Figure 1) based on the experiments that appear in research papers chosen for the class. The process of video creation involved scripting and editing the text for the video, recording the professor's narration, and animating the scientific concepts so that visual and auditory channels work seamlessly together to tell the story [6]. We then embedded the video in the 7.06 MITx site and posted follow-up questions for students to optionally answer on the discussion forum after watching the video. Before releasing the video to the class, the faculty would introduce the video topic in lecture and set up the questions to be addressed by the experiments in the video. After giving the students time outside of class to watch the video and reviewing and responding to student comments on the forum, the faculty would build upon the framework of the video in the next class by asking the students additional questions focused on experimental design related to the video content.

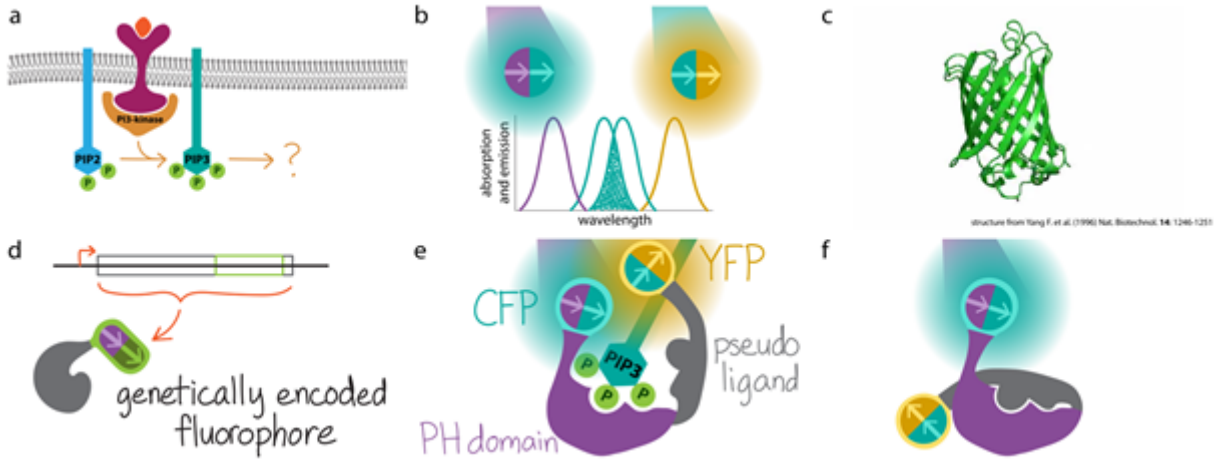


Figure 1 (a-f): A sampling of frames from the video "Neat Experiments in Cell Biology: Visualizing Signal Transduction in Living Cells." This video is available for viewing at http://youtu.be/GIH5ql7IzlM .

The staff did not use the 7.06 MITx site only for this video dissemination and discussion. Based on a technique first described by Frederick Mosteller [7], Professor Solomon also collected handwritten questions from students immediately following lecture to identify the "muddiest" part of the lecture. He addressed the most common issue or two in the next lecture and wrote the responses to other popular questions on the 7.06 MITx discussion forum. After considering the feedback from students that they do use these staff responses to study, as well as the benefits to the instructor in terms of understanding students' level of comprehension and confusions, Professor Martin has adopted the practice this year.

Result 1: Students Approve of and Want More Experimental Videos and Discussion Forums

Based on the anonymous survey results collected at the end of the semester, with about half of the 2014 7.06 class reporting (N=45), 100% of the students who completed the survey said that they

watched the first three videos, and all but two students reported watching the fourth video, even though the staff did not assign any points directly to watching the videos or using the discussion forum. Our click data from the MITx site – representing all of the registered students at the end of the semester (N=89) – also support that most students watched all four of the videos (94%, 93%, 97%, and 88%, respectively) and did so more than once (median 6, 13, 10, and 20 clicks per student, respectively). Clicks represent starting and stopping the video playback (for example, playing the video from the beginning all the way to the end without interruption would register as one click). For this 2014 data set, we did not have enough information on watching the video to separate out stopping and starting from complete watching. However, from the preliminary 2015 data collected so far, we do observe that about 90% of unique users watch a video to at least 95% completion. The students unanimously posited that they understood the concepts better with these videos (**100%**) than they would have had they needed to read the original literature papers, with most students categorizing the videos very useful or somewhat useful as a study aid (Figure 2). Almost all (**95%**) of the 7.06 students would like to see more experimental videos for other biology courses and think that future 7.06 students will find the videos useful.

The students had the ability to post questions or comments on any topic throughout the semester on the discussion forum, and to view staff and student comments and respond to them. Additionally, the staff posted the specific prompt questions to the discussion forum for each video, as well as the replies to mud slips. Most students (**95%**) reported reading the discussion forum posts and comments, even if they did not post. **88%** of the students found the answers to the post-lecture questions by Professor Solomon on the discussion forum helpful. The majority of students described the discussion forum as very useful or somewhat useful to understanding biological concepts (Figure 2), and **74%** of students would like to have discussion forums in other MIT biology courses.

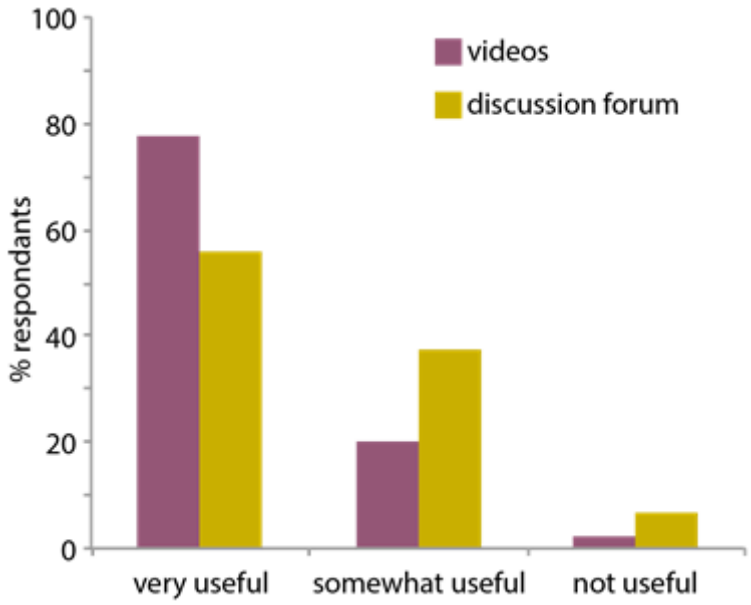


Figure 2

Most students categorized the “Neat Experiments in Cell Biology” videos and 7.06 MITx discussion forum as very useful or somewhat useful. The questions posed by the survey were: “Did you find the 7.06 MITx videos useful as a study aid?” and “Did you find that reading the questions, answers, and comments posted by other students or staff helped you study or understand 7.06 concepts?” N=43

These videos have advantages over standard lecture, such as flexibility of student learning – students can view the videos when and where they want at their preferred speed and as many times as they want. Supporting this, our click data did indicate that many students watched the videos

more than once. The videos also provide flexibility to the instructors. Making a video gives the faculty the opportunity to explain and demonstrate a complex concept in a succinct and well-organized manner, or to excite students by presenting a cutting-edge idea or technique that may not fit into limited lecture time. Also, given their modularity, the teaching staff can use the videos again for future offerings of 7.06 or in related courses without an additional time commitment. The spring offering of 7.06 – taught by different instructors – already started using one of these videos for their class as well. We believe that the videos provide an audiovisual means of learning that the students do not obtain from the delivery of content in person alone, which some students confirm in their comments. We even received several requests from students who were so inspired that they wanted to help in the creation of videos like these.

Excerpts from three students' comments:

> "I'm a visual learner, so seeing things in pictures rather than words was very useful to me. I think the concepts covered in the videos were the ones that have stuck with me the most."
>
> "I liked the style of the videos a lot. I think they really clarify the experiments we talk about in class, and I think they would be helpful in other biology classes as well."
>
> "These videos and the discussion questions help A LOT. I feel like I'm actually coming away with an understanding of the experiments and an improved ability to think about experimental design, controls, and how results can be interpreted."

Result 2: Professors Also See Improved Scientific Thinking in Students

Professor Frank Solomon notes an advantage – with respect to his particular goal of fostering a scientific thought process in the students – of the "Neat Experiments in Cell Biology" videos over the primary scientific papers themselves. "The videos represent an extract of the original paper," he says, "not all the details but enough of them and enough of a background to allow students to access how we know what we know. We wanted to give the students a chance to think about the elements of an experiment, including techniques, on their own, ask questions about it, and then bring that understanding to apply to material in lecture, and I think the videos are invaluable to that cause." As Professor Adam Martin describes, "the goal of our course is not only to get students to understand how a cell 'thinks', but to also understand how a cell biologist thinks. After using the videos on the MITx site, I noticed a big improvement in students' ability and willingness to suggest experiments that address a cell biological problem in lecture. They were thinking like cell biologists." For example, they could come up with multiple approaches to the discussion question, "Given your knowledge of actin binding proteins, how might you design an assay to look specifically at growth at either the barbed or pointed end in a filament population?"

Conclusion

In agreement with firsthand accounts from other MIT residential course staff, we have previously found in other biology courses that about 50% of students will view lecture videos posted to an MITx site. Compared to this baseline, the percentage of students viewing the 7.06 "Neat Experiments in Cell Biology" series is extremely high. We feel that course-specific implementation is key to motivating student use of content on the residential MITx sites. Simply posting content to a site does not guarantee its use or improve the quality of the learning. Effective use requires planning and alignment of that content with the in-person portion of the course and overall course learning objectives. We hypothesize that the style of video (short, narrated animations crafted by biology

PhDs) and direct applicability of the video content to tested concepts that are not thoroughly addressed in a textbook, as well as selection of intellectually engaging topics, thoughtful planning, and effort on the part of faculty, contributed to the high percentage of students viewing the videos. It is also worth noting that even though we received positive feedback from the students and had a high viewing percentage, they did not always watch the videos at the time suggested by the professor to prepare for productive conversations in class. Many students are still motivated mostly by points, and only the four exams counted toward the overall grade in 7.06. As such, although most students watched the first of the videos before the relevant class (as suggested), the majority of views of the second and third videos did not come until the night before the exams, as other demands on time became more immediate and pressing for students. (The fourth video was conceived of later in the semester and posted near the exam date.) We hope to use our observations from this pilot semester to design strategies to encourage more viewing *before the relevant class* in future years. In short, we find the positive student feedback and use of the MITx short videos and discussion forum encouraging and plan to continue the development of similar educational tools for this course and others in the future.

Acknowledgements

We would like to thank Professors Frank Solomon and Adam Martin for their enthusiasm about teaching and willingness to try something new. We would like to thank Professor Tania Baker for creating the MITx Biology team and the Office of Digital Learning and the Department of Biology for supporting the MITx Biology staff to make these projects possible.

Notes

[1] The MITx Biology team consists of Mary Ellen Wiltrout, PhD, an Instructor and Digital Learning Scientist, and two MITx Postdoctoral Teaching Fellows, Nathaniel Schafheimer, PhD and Sera Thornton, PhD, all members of the Department of Biology and MIT Digital Learning Lab. We develop content for and manage all MITx projects for the residential courses and edX courses from the Department of Biology. In addition to being involved in the scripting, Sera completed all of the animation and editing work for these videos.

[2] Seaton, Daniel Thomas and Reich, Justin and Nesterko, Sergiy O and Mullaney, Tommy and Waldo, Jim and Ho, Andrew Dean and Chuang, Isaac, 7.00x Introduction to Biology: The Secret of Life MITx on edX Course Report - 2013 Spring (January 20, 2014). MITx Working Paper #9. Available at SSRN:http://ssrn.com/abstract=2382325 or http://dx.doi.org/10.2139/ssrn.2382325

[3] Freeman, Scott, et al. "Active learning increases student performance in science, engineering, and mathematics." *Proceedings of the National Academy of Sciences* 111.23 (2014): 8410-8415.

[4] http://web.mit.edu/facts/undergraduate.html

[5] Mayer, Richard E., and Roxana Moreno. "Nine ways to reduce cognitive load in multimedia learning." *Educational psychologist* 38.1 (2003): 43-52.

[6] Höffler, T.N., and Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. Learning and Instruction 17, 722–738.

[7] Mosteller, Frederick. "The 'Muddiest Point in the Lecture as a feedback device." *On Teaching and Learning: The Journal of the Harvard-Danforth Center* 3 (1989): 10-21.

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