

# A Toolbox for Giving Your Biology Laboratory a Pedagogical Makeover

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Biology instructors should educate themselves in topics related to pedagogy, cognition, and student learning. Some of these topics can impart useful information for helping students learn in a post-secondary, biology laboratory environment. Our workshop included background information and discussion about the psychology of learning, encouraging students' critical thinking, clicker (Personal Response System) use, and PowerPoint® use. Particular tools that we discussed were the use of Socratic questioning, peer collaboration, and concept mapping as ways to encourage student critical thinking. Our technology section covered clickers, PowerPoint®, and the online resources provided by ABLE.

**Keywords:** clickers, classroom response systems, psychology of learning, PowerPoint®, learning styles, student motivation, self-regulated learning, concept map

## Introduction

Our workshop gave a venue to discuss topics, or tools, that we believe should be in each biology laboratory instructor's pedagogy toolbox. We left plenty of room for other tools, and by no means hoped to give a comprehensive set of tools or instructions for using them. Instead, we used our experiences at our own university, tools we've found useful,

and needs that surfaced through discussions with attendees at previous ABLE conferences to give us a framework for discussion of selected topics. We opened with some background and discussion of the psychology of learning, then followed with an introduction to techniques and tools that may help instructors meet deep learning goals.

## Notes for the Instructor

### Psychology of Learning

It is important for instructors to be aware of the current theories about how college students learn, so that they can structure college-level classes to give their students the best chance at academic success in their discipline. Our workshop didn't serve as a literature review of these theories of learning, nor was it a history of the research in that field (that would be a long workshop!). Instead, we framed our discussion around one author's taxonomy of significant learning (Fink, 2003), and sprinkled in some classic cognitive theory research by Piaget (1974) and Ausubel et al. (1978).

### *Student Motivation*

An important aspect of student learning is student motivation. We noted the variation in motivation levels of the students entering our labs: majors versus non-majors, freshman versus seniors, and 4-year versus 2-year institution students. Whatever the entry point, we agreed that helping students get motivated can have a positive impact on their learning and performance in our biology laboratories. Fink (2003) notes that students can be motivated by finding applications of biology lab material to other areas by integrating the content (being able to relate it to another subject), by giving the material a human dimension, and by seeking opportunities to help them care about the material. Miscellaneous tips included reward systems (e.g. candy for those who arrive 10 minutes or more before lab starts), scheduling and announcing breaks during long labs, and letting students know you care about them and their learning. Participants got into small groups to discuss how they'd seen, or how they thought they could apply, each of Fink's four areas. Table 1 shows the authors' and participants' (from both AM and PM workshops) ideas.

### *Self-Regulated Learning*

Another important aspect of student learning, and usually an overarching goal of colleges, universities, and individual courses, is making sure that students are self-regulated learners. That is, we hope that our students leave our biology courses able to learn biology on their own, without our curriculum and office hours. This usually means making sure they have basic (or course-specific) study skills, engaging them in inquiry learning, and allowing them to practice tools useful in deep learning.

Whether freshmen or seniors, students often need assistance learning or practicing study skills that will help them learn biology lab concepts. Most of us don't have the luxury of affecting institutional admissions requirements, so it is important to remember that your administration thinks each student in your class is capable of succeeding. Your job, then, is to take on the attitude of supporting each student's success in your biology lab. This could mean taking simple steps like adopting textbooks that include study tips (e.g. Hoefnagels, 2012) or mentioning the hours of your campus learning or

tutoring center. Or it could involve a little more effort and sacrifice like polling students for the best time to have your office hours, then advertising those heavily, or asking your learning/tutoring center if you could host a weekly tutoring/review session through them (in place of a couple of office hours). Another idea one of the authors shared was having successful students submit their own study tips. Instructors can post these on a corkboard or online (text or video), or the students can come back the following semester to talk during lecture about their success strategies. This advice may carry more weight from a peer than the same advice from the instructor.

Traditional labs have certain strengths, such as helping students to learn techniques, allowing easier setup across multiple sections, and allowing easier training of graduate teaching assistants. To help lab instructors reach course goals of critical thinking and teaching the process of science, investigative labs continue to be an invaluable tool. Labs set up in this manner require students to think independently and critically about their scientific questions, how to find an answer (using lab techniques and accounting for financial, time, and equipment limitations), and how to interpret data and results. Lest this approach sounds too daunting, the authors have found that existing traditional labs can be converted to investigative labs with some creativity and collaborative brainstorming with colleagues (Hoefnagels and Walvoord, 2005, 2008).

Finally, there are some graphical tools that students may find useful in becoming self-regulated learners. These tools include concept mapping, Venn diagrams, and timelines. We focused on concept maps during our workshop, as a tested method useful in science and other disciplines in both assessment and in deep learning. Although concept maps have been around since the 1970s (Ausubel et al., 1978), research continues into their best use, automated assessment setups, and the integration of new technology (e.g. SmartIdeas® concept mapping software). Maps are based on the theory that we all form a mental schema in our brains, connecting ideas and observations to each other (Piaget, 1974). As new observations are encountered, we work to integrate them into our existing schema. If this integration can't happen, we have to rebuild the schema or ignore the new observation. Concept maps are a graphical representation of how our brains are organizing information. So, they are useful for revealing misconceptions or hashing out how information is related (one definition of deep learning). They can encourage peer learning by assigning lab groups to build concept maps around 5-10 terms you provide, then switching with another group for critique (e.g. Preszler, 2004). This, and other graphical tools, can be used in other disciplines as a note taking, paper writing, or study and learning skill.

### *Socratic Questioning*

A final tool we discussed in our psychology of learning section was Socratic questioning. This is a technique used to help students think about material, learn it better, and be-

**Table 1.** Author and workshop attendee ideas on Fink's four areas of student motivation, as they relate to biology laboratory courses

Application	<ol style="list-style-type: none"> <li>1. Ask students a pre- or post-lab question such as, "What is another application of this technique or information in another area of biology we have covered?"</li> <li>2. Physiology class lab practical: build a working polygraph to integrate the individual labs from multiple physiological systems</li> <li>3. For the first lab in cell biology class, use problem-based learning to show why a year of general chemistry coursework matters in biology</li> <li>4. Have freshmen buy the same "current protocols" book that they use in all four years of college</li> <li>5. Human genetic disease and SNPs hit many of the topics in Student Motivation. Have students pick a disease that's important to them to study in depth.</li> <li>6. Service learning hits on all the student motivation bullets (e.g. air quality and asthma for immunology course; oyster restoration project for nonmajors marine biology)</li> </ol>
Integration	<ol style="list-style-type: none"> <li>1. Ask students to keep a journal and note any time they thought about or used the previous lab's content or application.</li> <li>2. Assign lab groups based on other courses (or majors) that students may have in common to encourage spontaneous discussion about the relationship of lab content to other subjects.</li> <li>3. Connect topics to environmental issues, such as connecting data on global climate change with student behaviors (e.g. personal transportation, recycling awareness); have students journal about their peers' recycling behavior in the cafeteria (relationship to food science and agriculture)</li> <li>4. Coordinate labs between two classes (e.g. organic chemistry students synthesize auxin, then biology students design experiments to test the effects on plant growth and send the results back to the organic chemistry students); expression constructs produced in molecular biology labs can be used in cell biology labs.</li> </ol>
Human Dimension	<ol style="list-style-type: none"> <li>1. Include a short story about the scientist that first discovered this topic or came up with this technique</li> <li>2. Personal stories about instructor's own experiences (or those of other people) or case studies on the particular topic</li> <li>3. For pre-health majors, relating a topic to human health makes it more real to students</li> <li>4. Give extra credit for student-selected service projects that build student relationships as well as reinforcing course content (e.g. donation drive for local hotel that houses relatives of cancer patients)</li> <li>5. Talk about authorship on papers from primary literature</li> </ol>
Caring	<ol style="list-style-type: none"> <li>1. In a post-lab question, ask students "What was your favorite part of today's lab?"</li> <li>2. Make sure students see that you, as the instructor, care about this material and/or are enthusiastic about it</li> <li>3. Give overachievers a challenge beyond what other students are doing, e.g. "Not everyone gets this technique" to appeal to their competitive sense; can also allow students to compete with the instructor (e.g. lung capacity)</li> <li>4. Trivia question unrelated to lab (with candy as prize) to encourage students to come to lab on time</li> <li>5. Create lab groups that enhance diversity, which builds relationships that help students help each other with content</li> </ol>

come more independent learners. It is based on the technique that the Greek philosopher, Socrates, used with his students to NOT answer their questions directly, but rather to ask them questions to guide them to finding the answer themselves. Following is a sample discourse using the Socratic method:

Student: When is nuclear DNA replicated for mitosis?

**Instructor: Do you remember why the cell needs another copy of DNA?**

Student: I think so that it can be split into the two new cells during mitosis.

**Instructor: Very good! Now can you draw on the board for me the steps of the cell cycle? That could help you visualize where replication happens.**

Student: I can't do it from memory, but I think I have it in my notes. [Student copies it from notes to board]

**Instructor: Good, now could you guess in which part of the cell cycle DNA would be replicated?**

Student: Sometime before mitosis, so I guess G2 phase?

**Instructor: That is a very good guess, but it turns out a cell needs that phase to check the replicated DNA to make sure it all worked correctly. So, do you have another guess?**

Student: I guess the S phase then?

**Instructor: That is true! So, please summarize what you just learned.**

Student: DNA replication happens in S phase, then the cell checks this in G2 phase, so it can start mitotic cell division. During Mitosis, these two copies of DNA split into the two new cells.

This is also a technique that biology lab coordinators may wish to train TAs or lab instructors to implement with their students. Table 2 shows a quick way that we practiced at our workshop.

Participants noted a few potential challenges. One is that TAs may not know the lab material well enough to use Socratic questions effectively. Another is that it is not as time-efficient as just telling students the answer. Suggestions from other participants to minimize these challenges included making sure the TAs get practice; brainstorming what questions TAs should expect from students in an upcoming week's lab activities (rely on veteran TAs to provide information here); have novice TAs view videos of other TAs doing Socratic questions, or require them to sit in on a veteran TA's lab section; make lab topics last 2-3 weeks to allow more time for deep learning and critical thinking using Socratic questioning in labs. Finally, someone in the afternoon workshop noted that weak students may get overly frustrated by this method. It does take some sensitivity to student needs on the part of the instructor, but letting the students work in pairs to answer questions could also be helpful.

#### *What about Learning Style Theory?*

There is a popular notion that, by subscribing to learning style theories, instructors can assist students in better learning

course material. The claim is that students have a particular way they learn best, independent of content and ability. For instance, a student's poor performance in biology lab could be attributed to that student not studying or working using his or her learning style. If he or she is an aural, kinesthetic, or visual learner, then he or she need only study using more aural, kinesthetic, or visual methods to learn the material and succeed. Though there are some elegant hypotheses centered around these theories, there does not yet appear to be research evidence to support learning theory claims. The assumptions that learning varies by student is supported, and from this we can gain application to our teaching. Varying teaching methods can help keep students' interest and motivate them. Within this variation, it may be wise to pick teaching methods and tools to match your course content and your goals, taking your audience and their background into account (Dembo and Howard, 2007; Riener and Willingham, 2010).

#### **Clickers**

Clickers (aka Personal, Audience, or Classroom Response Systems), like most educational technology, can be a powerful tool if used correctly. During our workshop, we shared a diverse set of uses for clickers in a biology lab setting. In order to inform participants of the capabilities of several popular systems, we introduced them and their features, along with strengths and weaknesses. We then practiced using one brand of clicker and multiple question types so participants could experience the student perspective.

Following is a non-exhaustive list of uses for clickers in lab.

- Take attendance
- Pop quizzes/check understanding before or after a lesson
- Give exams/lab practicals
- Collect homework
- Add active learning activities to class
- Predict results of an experiment
- Create "learning games" (e.g. game show format with teams)
- Collect data for use in the lab
- Collect anonymous opinions about controversial or embarrassing issues
- Peer review of student presentations or lab write-ups

One author described the clicker setup in her class and lab, to give participants one example of its use. She used Interwrite PRS clickers and software for many semesters, but recently switched to the i>clicker2. Approximately 16% of points in lab come from clicker questions, and several clicker quizzes can be dropped at the end of the semester to account for a forgotten clicker or dead batteries. Clicker questions are used to encourage discussion in this lab, so collaborating on quiz answers is encouraged. On exams or lab practicals, cheating seems no more likely with clickers as with paper (i.e. students answering with their peer's clicker

**Table 2.** A three-round Socratic questioning practice exercise

	<b>Person A (student)</b>	<b>Person B (instructor)</b>
Round 1	State Problem	Ask for clarification; summarize problem
Round 2	Answer, explain more	Questions to get them to come up with their own solutions
Round 3	Critical thinking to get their answer	Summarize and/or another round of questions to get them to best solution

and their own; or looking at other people's buttons/screens). Question types available on many clicker systems include multiple choice, choose all that apply, short answer, numeric (data collection, survey, sequencing), and self-paced mode for exams.

A given instructor's choice of clicker systems depends on many factors. Some schools have already adopted a single system. But for instructors who get to choose, here are some considerations:

- Does the publisher of your textbook have an agreement with a clicker company?
- Cost: will students purchase their own, or will the instructor purchase a classroom set?
- Is it possible to coordinate with other classes using clickers, so students don't have to buy multiple brands of clickers?
- Clicker versatility and flexibility: the choice of clicker depends in part on what sorts of questions the instructor plans to ask.

Beyond the technical side of choosing the hardware/software, assigning point values, and deciding on cheating policies, the real pedagogical advantage comes from the drafting of questions with learning objectives in mind. Rather than cover details of this aspect, we referred to the publication describing our 2010 ABLE presentation on writing good clicker questions (Walvoord and Hoefnagels, 2011). Finally, one participant noted that there are low-tech substitutes for clickers. For example, students could hold up fingers/hands or just vote with colored index cards to achieve many of the same results.

### **PowerPoint® Use in Lab**

Participants agreed that we have seen PowerPoint® used poorly, so we tried to highlight and give examples of good uses of presentation software in a biology laboratory setting. We realize some instructors use other presentation software (e.g. Keynote or Prezi), and we encourage instructors to explore all the tools available to make their laboratory the best learning environment possible. However, because of the popularity of MS PowerPoint®, we discussed it in particular.

Lab instructors can use presentation software to:

- Demonstrate procedures with simple animations of the setup/activity

- Embed videos of procedures or previous lab sections' (or semester's) experimentation
- Show photos of good/bad techniques or experimental results
- Add teaching flexibility (hyperlinks within presentation)
- Create hyperlinks to web resources (pictures, videos, animations, other explanations of concepts)
- Post lab outlines, pre-lab information, or review materials for students
- Integrate clicker questions
- Collect and display student data

Students can use presentation software to:

- Give oral presentations of results
- Make concept maps and other diagrams for assignments or presentations
- Show photos of their own results (e.g. a photo journal or electronic lab notebook)

There are several useful papers on the best use of presentation software (e.g. Clark, 2008), so we highlighted a few general tips to help make its adoption successful. To make slides readable and visually appealing, it is important to use contrasting colors for text and backgrounds. The font size should correspond to the size of the screen and room (stand at the back of the room to confirm proper sizing). Avoid placing too much text on one slide, and use animation tools to reveal each text item or illustration as it is discussed.

Next, we polled participants on what PowerPoint® tool(s) they felt deficient in, then we encouraged participants to discuss and practice these tools. Participants in both the morning and afternoon sessions seemed most interested in exploring embedding videos and in creating animated, custom motion paths.

### *Embedding Videos*

Participants agreed that embedding videos or linking out to videos on the internet (e.g. YouTube) from presentation software is a great use for biology lab. For instance, we envisioned showing safety procedures, clips of past students giving study tips, and videos explaining proper experimental procedures. Embedding greatly increases the size of the presentation file, and there is a limit to what types of files are acceptable. But, doing so, versus linking out, allows

the presentation to be self-contained—it can be used without mapping to a file elsewhere on a computer or requiring an internet connection. Rather than duplicate and risk giving out of date information on procedures for using this tool, we refer readers to online resources on this topic. Microsoft Office help articles like the one entitled “Embed in, or link to a video from your presentation” is useful if using MS PowerPoint® 2010 for Windows (<http://office.microsoft.com/en-us/powerpoint-help/embed-in-or-link-to-a-video-from-your-presentation-HA010374729.aspx>). For MS PowerPoint® 2011 for Macs, see <http://mac2.microsoft.com/help/office/14/en-us/powerpoint/category/2a464e65-aede-4fdf-92fe-ca355328640f> (checking the links to “Add a movie to a slide,” “Set the play options for movies in your presentation,” or “Insert media into your document”)

### Creating Animations

No matter which version of PowerPoint® you use, the process of creating animations begins with the animations tab. Once you click on that tab and see the animations menu, click on the item you wish to animate and choose an effect. “Entrance” effects are ways to make an item appear; “emphasis” effects allow you to highlight an item with color or movement; and “exit” effects offer ways to make an item vanish from the slide. PowerPoint® also allows you to create motion paths in predefined shapes or custom paths. Motion paths are very useful for creating simple animations of laboratory procedures.

In MS PowerPoint® 2010 for Windows, after you select the animations tab, your screen should resemble the image in figure 1. The dropdown menu shows where to find the entrance, emphasis, and exit effects, along with the motion paths.

In MS PowerPoint® for Mac 2011, the animations tab brings a set of options such as those shown in figure 2. The entrance effects are highlighted in this screenshot, but similar dropdown menus are available for emphasis effects, exit effects, and motion paths.

After you have selected your effects, click “Reorder” to tell PowerPoint® the order in which you want the effects to occur. You can also experiment with the “Start” options, which tell PowerPoint® whether you want each effect to occur automatically or when you click the mouse.

### ABLE Resources

The ABLE website (<http://www.ableweb.org>) contains pedagogically sound resources for direct integration into lab. The Proceedings include over 30 years of lab activities; the latest two volumes are available to members only, but all of the articles are rate-able and comment-able. This allows continuous assessment and suggestions for improvement of the labs. Also on the website are “Teaching Apps,” a forum for sharing electronic resources related to biology laboratory education. The annual ABLE conference is another source of information for lab pedagogy-philosophers. Workshops, vendor resources, and conversations with participants are always rewarding.

### Conclusion

We hope this article starts to build, or improves upon existing, tools in each biology laboratory instructor’s pedagogy toolbox. An understanding of some of the issues surrounding the psychology of college student learning should be a good start to finding and using tools that help students learn.

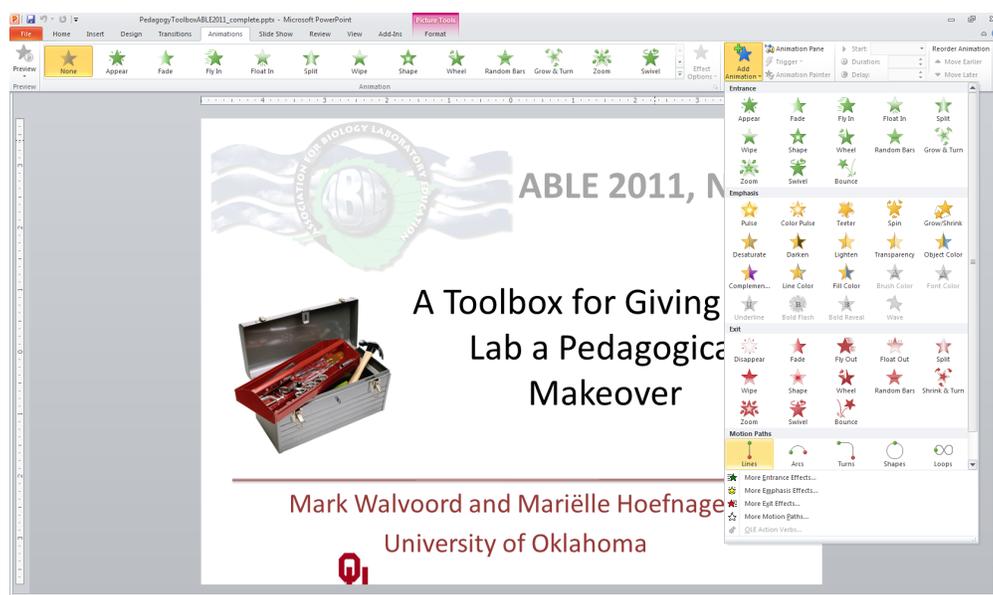


Figure 1. Screenshot showing MS PowerPoint® 2010 for Windows’ animation options

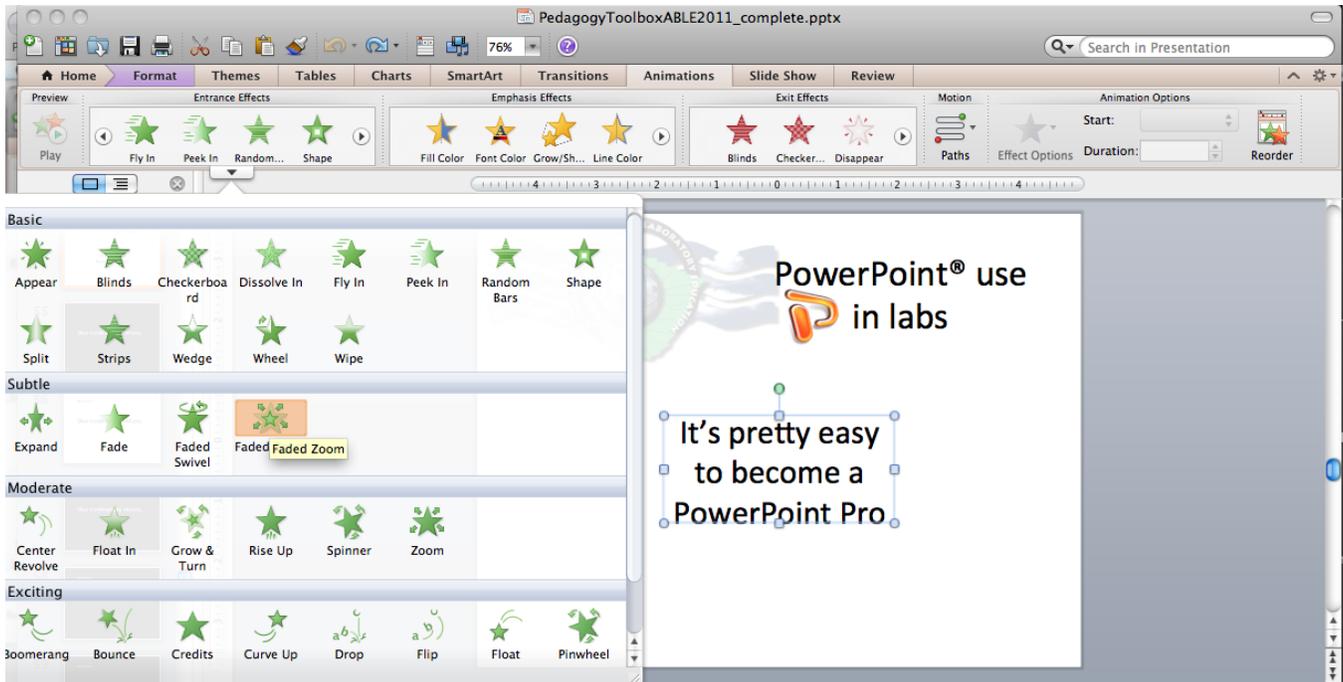


Figure 2. Screenshot showing MS PowerPoint® 2011 for Mac's animation options

## Acknowledgements

The authors are grateful for the participation of the workshop attendees in our morning and afternoon sessions at the 2011 ABLE conference at New Mexico State University in Las Cruces, NM, USA.

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### Citing This Article

Walvoord, M.E., and Hoefnagels, M.H. 2012. A Toolbox for Giving Your Biology Laboratory a Pedagogical Makeover. *Tested Studies for Laboratory Teaching*, Volume 33 (K. McMahon, Editor). Proceedings of the 33rd Conference of the Association for Biology Laboratory Education (ABLE), 390 pages. <http://www.ableweb.org/volumes/vol-33/?art=17>

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