OPEN ACCESS Freely available online

CourseSource

Teaching Tools and Strategies

Drawing Flowcharts of Lab Protocols Helps Students Prepare for Biology Labs

Katie Anne Szumlanski Burnette[1*]

[1]Department of Evolution, Ecology, and Organismal Biology, University of California Riverside

Abstract

With the publishing of the Vision and Change report, we know it is best practice to include authentic research experiences in our undergraduate science lab classes. One big challenge in teaching so-called "wet lab" classes is figuring out a way to make sure students come to lab prepared to successfully complete their experiments. Molecular biology protocols are particularly challenging as they are typically long, detailed, and have multiple steps to complete. The most successful teaching practice I have tried is having students prepare for lab by hand-drawing flowcharts of the lab protocols. Drawing is a proven way to increase scientific understanding and requires students to engage with the lab materials before class. These flowcharts are due when students walk in to lab and more importantly, students use their flowcharts during lab. This teaching tool is easy to teach to students, simple to assess, and does not rely on any pre-existing knowledge of molecular biology or artistic skill. I have had great success using flowcharts as a teaching tool in both upper division and lower division classes as well as with both life science major and non-major students. Flowcharts have many potential applications beyond undergraduate "wet lab" classes including discussion courses and graduate research projects.

Citation: Burnette KAS. 2020. Drawing flowcharts of lab protocols helps students prepare for biology labs. *CourseSource*. https://doi.org/10.24918/cs.2020.2

Editor: Lisa McDonnell, University of California San Diego

Received: 7/19/2019; **Accepted:** 12/08/2019; **Published:** 2/06/2020

Conflict of Interest and Funding Statement: The author does not have a financial, personal, or professional conflict of interest related to this work. No external or internal grant funds were used to support this work.

Supporting Material: Supporting File S1. Drawing Flowcharts - Student Examples.

***Correspondence to:** Department of Evolution, Ecology, and Organismal Biology, 1229 Spieth Hall, University of California, Riverside, Riverside, CA 92521 USA. Email: katie.clark@ucr.edu

INTRODUCTION

One of the main recommendations of the Vision and Change report is to engage all undergraduate students in an authentic research experience, regardless of their major (1). An obvious way to ensure that all students get the opportunity to do a research project is to incorporate research into the existing biology labs. There are several great examples of well-developed undergraduate courses that include a research project (2; reviewed by 3,4)

One challenge is how to ensure that students are prepared for lab. There is a variety of techniques that are shown to improve student preparation for their science labs including integrating a discussion of lab techniques during lecture (5,6), online pre-lab tests or quizzes (7,8), so-called "entry ticket" lab assignments (9), mandatory pre-lab training activities (10), and instructional videos (11). While all of these are effective, they all require advanced preparation and can take a lot of an instructor's time. An ideal lab preparation assignment would shift the burden of the work onto the student.

My particular challenge was figuring out how to prepare undergraduate students for a molecular biology lab project. Molecular biology lab protocols can be rather long or complicated or both, even more so if each student is doing their own project. I want students to understand both the specific details of a protocol (times, temperatures, volumes, etc.) and also the "Big Picture" purpose of the protocol in their research project (e.g., using PCR as a tool to amplify a region of a "barcoding gene"). I want students to be prepared for the non-linear way to follow a lab protocol efficiently (e.g., finding the next reagents they will need while waiting for their samples to chill on ice). My solution is to have students draw flowcharts of the protocols that they use in lab.

I give students a lab manual with all of the protocols at the start of the semester. Each week, students draw a flowchart of the protocol or protocols they will use in lab. The flowchart is due at the start of their lab section. For example, in my non-majors cellular and molecular biology class the first molecular protocol involves extracting DNA from a sample of gram-positive bacteria using a commercially available DNA extraction kit. I tell the students I do not want them to write a bullet-pointed list since this protocol is non-linear and has tasks that can be completed during longer steps (e.g., labeling new tubes while their samples heat for 30 minutes). I also do not want them to copy the protocol word-for-word because they have the lab manual available during lab. This is an authentic activity since many commercially available kits come with a simple flow-chart including the kit the students use (e.g., https://www.qiagen.com/us/resources/resourcedetail?id=6b09dfb8-6319-464d-996c-79e8c7045a50&lang=en).

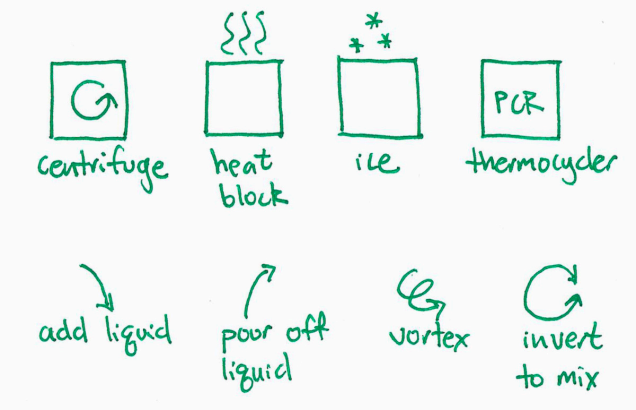

Figure 1. Suggested symbols for flowcharts. Common lab equipment is re-drawn as boxes and common actions shown as line drawings.

Drawing, whether it is graphing, illustrating, or creating a diagram has been shown to increase learning and retention of biological information (12,13).

One common concern from students is that they do not know what the equipment looks like so they are not sure what they should draw. Being able to draw an accurate detailed image of a centrifuge is not necessary to be able to draw a useful flowchart. Most molecular biology equipment (e.g., centrifuges, thermocyclers, and heat blocks) looks more or less like a box (Figure 1). So, I tell students to draw a box to represent any piece of lab equipment and write the key details (e.g., spin at 8,000 g for 3 minutes) so they know what the box represents. I have drawn an example flowchart showing a DNA extraction protocol from gram-positive bacteria cells (Figure 2).

The assigned flowcharts were due at the start of each lab class. I had the students show their flowcharts to either me or my lab TA. We quickly looked at the flowcharts, noted which students had completed a flowchart, and had students use their flowcharts during lab. Importantly, we encouraged students to make corrections or edits to their flowchart during lab and to cross off completed steps so they could track their progress.

Intended Audience

I have used this technique in several biology classes with great success. These included:

- An introduction to cellular and molecular biology lab for non-life sciences majors at a large research university. This class has 288-336 students in 12-14 lab sections of 24 students each. Graduate student TAs teach the lab sections.
- A genetics lab for biology majors at a small 4-year college. This class had 48 students in 2 lab sections of 24 students each. I taught the lab sections with the help of an undergraduate TA.
- A special topic upper division "DNA Barcoding" workshop style class for biology majors at a small 4-year college. This class had 12 students in a lab that met for 3 hours twice a week. I taught the workshop class.

SCIENTIFIC TEACHING THEMES

Active Learning

Students actively engage in learning by hand drawing a flowchart of the lab protocol before each of their lab classes. This ensures that they will read through and think through the lab procedures before coming to class.

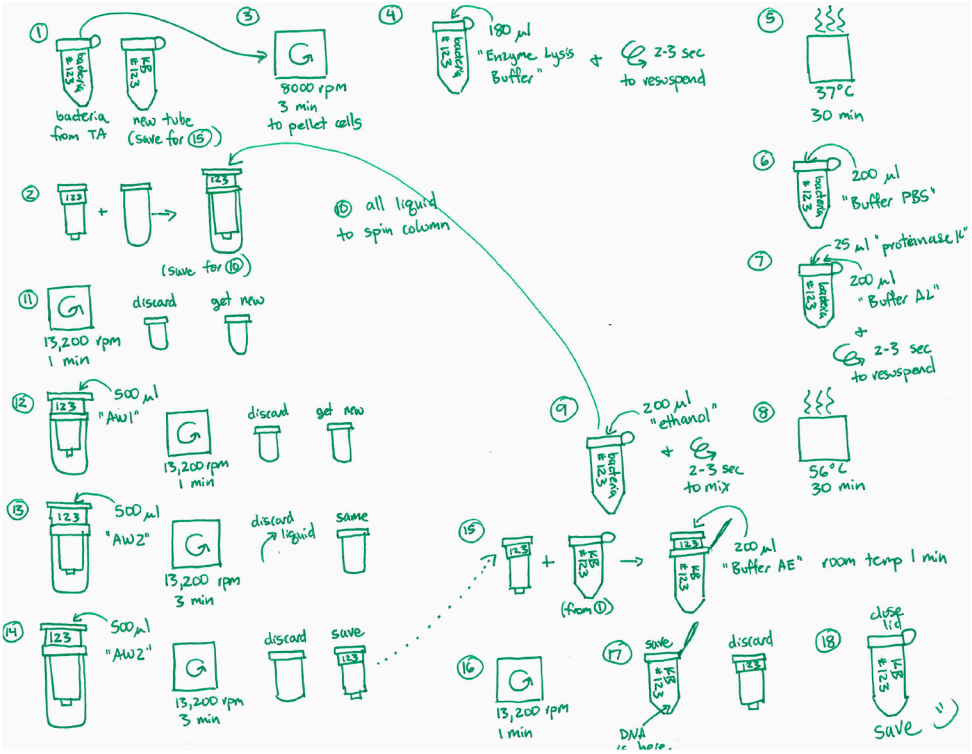

Figure 2. "DNA Extraction Flowchart." Hand-drawn flowchart of protocol for extracting DNA from bacteria cells.

Assessment

I made the flowcharts worth a modest portion of the students' lab grades (25 of the total 265 points). A complete or nearly complete flowchart earned full credit, a partially complete earned half credit, and a missing or barely started flowchart earned zero points. In practice, it took only a few minutes to grade flowcharts for a class of 24 students. Most students earned all or nearly all of these points. See Supporting Material (Supporting File S1. Drawing Flowcharts-Student Examples) for example flowcharts from students, ranging from functional and basic to detailed and artistic.

In my experience, my students were better prepared for lab when I asked them to draw a flowchart compared to previous quarters when I started the labs with a brief quiz. For example, in my genetics class, I would ask students to extract DNA and set up a PCR reaction in one three-hour lab class. Even though the quiz was rather short (5 minutes), students still had to rush to complete the lab on time. When I switched to flowcharts, students were able to complete the lab with time to spare. I was pleasantly surprised at how students asked fewer procedural questions when they had prepared for lab by drawing a flowchart. They were also better able to help each other with procedural questions (e.g., How long do we spin our tubes? Which buffer do we add next?). Overall, students were more prepared and were able to use their time in lab much more efficiently.

Students self-evaluated their preparation for lab by using their hand-drawn flowcharts during their lab class. Having their flowcharts out during the lab means the students could see what step they were doing in the protocol, record their data, and plan ahead. Realizing that they forgot to add key details like what volume of buffer to use or how long to put their tubes on ice means the students could edit as needed. Simply put, if a student could not use their own flowchart, then they knew that they needed to create a better one for the next class.

Inclusive Teaching

Having each student draw their own flowchart means that all students in the participate in this activity. The lesson is designed to include all participants because success does not depend on a student's familiarity with molecular biology or on their artistic skill. In fact, some students said they really enjoyed the ability to show their creativity and often drew portraits of themselves or their TA in the lab as part of their flowchart.

TIPS FOR SUCCESS

Give students explicit instructions on how to draw a flowchart. The first time I asked students to draw a flowchart, many of them wrote a bullet-pointed list that was a nearly word-for-word copy of the protocol from the lab manual. Now, I include an example protocol and flowchart in the lab manual, such as the flowchart shown in Figure 2. Also, I build in time during their first lab day to give students time to work on their DNA extraction flowcharts that they will use their next lab day. The TAs talk the class through the first few steps in the protocol and draw the start of a flowchart on the board. Seeing an example really helps alleviate a lot of the concern some students have about their drawing ability or how much detail is necessary.

Make the flowchart due at the start of lab. The point of drawing the flowchart is to help students prepare for lab. The flowchart is not as useful if the students do not draw it before class. Allow students to make edits during lab, as this is how they learn if their flowchart is accurate and complete. I had students show their flowcharts to their TA at the start of lab. Alternately, you could have students upload a picture of their flowchart to a class website or have students make a photocopy to turn in at the start of class and have the student keep their original.

Have students use their flowchart during lab. I encouraged students to write on their flowcharts to keep track of their progress by crossing out completed steps. You can also take a few minutes to chat about the protocol and give any needed adjustments. The first time I had students extract DNA from bacteria, I realized that I needed to increase the time they placed their samples at 37°C. So, I just told them to find step 5 on their flowchart and write that the time was now 30 minutes. Flowcharts are also a great way to ask students which step will take the longest to complete, set the pace for the class by giving timepoints to complete certain steps, and give students responsibility for knowing what they are supposed to complete in lab.

Re-write commercial protocols to condense the instructions and remove any mention of additional variations. Commercially available DNA extraction kits can often be used for several types of starting material (rodent tails, bacteria cells, fish blood, etc.) and have modifications depending on which type of sample you are using. I give my students just the portion for gram-positive bacteria. I would also suggest you standardize the language in the protocol, especially if you use protocols from multiple sources. Common lab equipment and supplies can have many different names. Experienced researchers know that 1.7 ml tubes, snap-cap tubes, microcentrifuge tubes, and simply "tubes" can refer to the exact same piece of plasticware. Help your students by choosing one term and being consistent. For my non-life sciences majors, I also simplify the language (e.g., change "discard supernatant" to "pour off the liquid") to make the protocols more accessible for students without a strong science background. Alternately, you could include a glossary of common lab terms.

There are many possible modifications to how you can use flowcharts in a "wet lab" class. You could use the flowcharts as an opportunity for students to reflect on the purpose of their lab. Have students write the "Big Picture" importance or goal of their project, the specific purpose of certain steps in the protocol (e.g.. lyse open cells, precipitate DNA, etc.), create data tables, or fill in their conclusions on their flowcharts. You could use them as a way for students to record their observations during the lab (e.g., what did your cells look like after you added the lysis buffer?). You could also use them to help students trouble-shoot if a protocol did not work as expected or to record any deviations from the original protocol (intentional or not).

Flowcharts are not just for undergraduate "wet lab" classes. I personally use flowcharts to plan steps in a large project and assign folks to specific tasks in that project. You could use flowcharts during discussion classes to map out the techniques used to create figures in papers. You could use

flowcharts in a graduate research lab as a way to teach or learn new techniques. You could incorporate flowcharts into your lab meetings or seminar presentations to help explain your methods.

SUPPORTING MATERIALS

- S1. Drawing Flowcharts – Student Examples

ACKNOWLEDGMENTS

I would like to thank my undergraduate and graduate Teaching Assistants for their help developing and refining this teaching tool, especially Cameron Chow from my Genetics class; Carina Edmondson, Amanda Hale, Monica McNamara, Alison Mills, Irma Ortiz, Jason Randall and Robert Prather from my Spring 2019 Biol002 non-majors molecular biology lab.

I would also like to thank the undergraduate students from my Biol002 Spring 2019 who generously allowed me to use their flowcharts as student examples in this publication.

REFERENCES

1. AAAS. 2009. Vision and change in undergraduate biology education: a call to action. Washington, DC. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2879380/
2. Caruso SM, Sandoz J, Kelsey J. 2009. Non-STEM undergraduates become enthusiastic phage-hunters. CBE Life Sci Educ 8:278-282. DOI: 10.1187/cbe.09-07-0052
3. Ballen CJ, Blum JE, Brownell S, Hebert S, Hewlett J, Klein JR, McDonald EA, Monti DL, Nold SC, Slemmons KE, Soneral PAG, Cotner S. 2017. A call to develop Course-Based Undergraduate Research Experiences (CUREs) for nonmajors courses. CBE Life Sci Educ 16:mr2. DOI10.1187/cbe.16-12-0352
4. Mader M, Beck CW, Grillo WH, Hollowell GP, Hennington BS, Staub N, Delesalle VA, Lello D, Meritt RB, Griffin GD, Bradford C, Mao J, Blumer LS, White SL. 2017. Multi-Institutional, Multidisciplinary Study of the Impact of Course-Based Research Experiences. J Microbiol Biol Educ 18(2):18.2.44. doi:10.1128/jmbe.v18i2.1317
5. Rollnick M, Zwane S, Staskun M, Lotz S, Green G. 2001. Improving pre-laboratory preparation of first year university chemistry students. International Journal of Science Education. 23(10):1053-1071. doi:10.1080/09500690110038576.
6. Smith AC, Stewart R, Shields P, Hayes-Klosteridis J, Robinson P, Yuan R. 2005. Introductory Biology Courses: A Framework To Support Active Learning in Large Enrollment Introductory Science Courses. Cell Biol Educ. 4(2):143-156. doi:10.1187/cbe.04-08-0048.
7. Whittle SR, Bickerdike SR. 2015. Online Preparation Resources Help First Year Students to Benefit from Practical Classes. Journal of Biological Education. 49(2):139-149. doi:10.1080/00219266.2014.914554.
8. Cann AJ. 2016. Increasing Student Engagement with Practical Classes Through Online Pre-Lab Quizzes. Journal of Biological Education. 50(1):101-112. doi:10.1080/00219266.2014.986182.
9. Howard DR, Miskowski JA. 2005. Using a Module-based Laboratory To Incorporate Inquiry into a Large Cell Biology Course. Cell Biol Educ. 4(3):249-260. doi:10.1187/cbe.04-09-0052.
10. Pogacnik L, Cigic B. 2006. How To Motivate Students To Study before They Enter the Lab. J Chem Educ. 83(7):1094. doi:10.1021/ed083p1094.
11. Schmidt-McCormack JA, Muniz MN, Keuter EC, Shaw SK, Cole RS. 2017. Design and implementation of instructional videos for upper-division undergraduate laboratory courses. Chem Educ Res Pract. 18(4):749-762. doi:10.1039/C7RP00078B.
12. Quillin K, Thomas S. 2015. Drawing-to-learn: a framework for using drawings to promote model-based reasoning in biology. CBE Life Sci Educ 14:1-16. doi: 10.1187/cbe.14-08-0128
13. Ainsworth S, Prain V, Tytler R. 2011 Drawing to Learn in Science. Science 333:1096-1097. DOI: 10.1126/science.1204153