Chapter 7
Teaching with Laboratories

Kirsten M. Brown

Abstract Laboratory-based teaching has been a foundation for medical education for decades. Although the time dedicated for laboratory teaching has declined for several reasons, the literature clearly outlines the many benefits that laboratory exercises can have on a student's professional development and growth. When done well, teaching with laboratories offers opportunities for students to explore concepts in more detail and apply what they have already learned. A fundamental aspect of laboratory teaching is the integration of principles of active learning and instructional design. By considering these factors, you will seamlessly incorporate structure, assessments, opportunities for feedback, and constant communication as you plan your exercise. With careful thought and attention to details you are well on your way to becoming a proficient laboratory instructor.

Introduction

This chapter presents basic information on how to implement laboratory teaching exercises. You may be reading this content as an expert, who is looking to find more information for how to better adapt your laboratory sessions in ever-changing curricula. On the other hand, you may be reading this content as a novice, who is looking for more formal guidance on implementing sessions. Regardless of your background, this chapter will guide you through laboratory teaching, including how to design a session, how to evaluate a session, and how to avoid pitfalls. After reading the chapter, you may also find yourself thinking less about a specific setting or space, and more about the concept of a laboratory. No matter how you approach the

K. M. Brown (✉)
School of Medicine and Health Sciences, George Washington University, Washington, DC, USA
e-mail: kmbrown@gwu.edu

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chapter, hopefully you will find the information here thought-provoking and valuable to use at your own institution.

Benefits of Laboratory Teaching

There are many benefits to teaching in a laboratory setting. First and foremost, laboratory teaching allows deeper exploration of concepts that have already been covered. For this reason, laboratory teaching is also an ideal setting to incorporate principles of adult learning.

Research has shown across multiple disciplines that laboratory teaching sessions are well received by students and result in greater understanding of content (Modell et al., 2004; Pizzimenti et al., 2016; Rae et al., 2016). Students have rated laboratory sessions positively because of the additional opportunities for exploring complex concepts (Horrigan, 2018). Moreover, sessions are most effective for knowledge transfer and retention when grounded or tied to clinical scenarios or cases (Jurjus et al., 2016). Laboratory teaching has also been shown to positively influence the development of psychosocial skills like teamwork (Huitt et al., 2015) and positive attitudes toward interprofessional roles (Alfaro et al., 2019; Hamilton et al., 2008). Laboratory exercises help students develop teaching skills (Bian et al., 2018) and reinforce ethical principles (Stephens et al., 2019). When modelled to mirror clinical handoffs, laboratory teaching can also provide a necessary link for incorporating clinical skills early in medical education (Lazarus et al., 2016). Overall, laboratory teaching can have a profound positive impact on the student's development into a healthcare professional.

Examples of Laboratory Teaching

A common theme you will notice throughout this section is the pressure to add more content in a curriculum without including any additional instructional time. For many of the standard laboratory experiences – gross anatomy, histology/pathology, and physiology – this pressure has resulted in a significant reduction in laboratory hours (Dee, 2009; McBride & Drake, 2018). With concurrent expansion of technologies for teaching, there has also been a shift from traditional laboratory experiences to more small-group and self-study exercises. Given these drastic changes, our definition of "laboratory" has also changed, to include multidiscipline activities and virtual options. Accordingly, the standard practical examination may have been phased out for specific disciplines. Should you find yourself wanting to include more of a traditional laboratory experience, you need to weigh all these factors and work with your colleagues to prioritize the laboratory, the assessments, and timing within the curriculum.

Gross Anatomy

One of the cornerstones of premedical education is the gross anatomy laboratory. Gross anatomy laboratory sessions can vary widely in time allocation and structure, but most include some aspects of student dissection, faculty-created prosection, and osteology and imaging. Instructors include graduate teaching assistants, anatomy faculty, and clinical faculty (e.g., surgeons). Students are traditionally assessed using a practical examination, although there are a variety of assessment opportunities. After dissection is completed for a given region, faculty select bodies to pin structures to identify or ask something about the structure's function. Given evolving curricular structures and time constraints, the traditional anatomy practical exam and laboratory setting continues to evolve to meet learners wherever they are. Recent examples include incorporating ultrasound (Jurjus et al., 2014), 3D models (Cui et al., 2017), and virtual reality (Birbara et al., 2020).

At many institutions, a proactive approach is applied to adapt the undergraduate medical laboratory sessions to curricular changes and resource limitations. If this is a need at your institution, you may use dissection as a primary teaching modality for first- and second-year students, and supplement sessions with prosections and ultrasound sessions. Instead of full-length practical examinations, team-based quizzes can be used periodically, and practical-based questions can be included on all written summative assessments. For those students who are interested in surgical specialties, you can also expand clerkship offerings to include more focused dissection opportunities. In this way, the anatomy laboratory sessions and the discipline can span all 4 years of undergraduate medical education.

Histology/Pathology

Like gross anatomy, histology and pathology have also undergone significant changes in their laboratory format over the past several years. Decades ago, both disciplines were taught with laboratory sessions organized around light microscopes and slides; however, with advances in digitization of slides, histology and pathology transitioned to virtual microscopy (Dee, 2009). Regardless of the format (virtual or light microscopy), histology and pathology laboratory sessions involve examining slides with an accompanying laboratory manual. Faculty could include cell biologists, system-or specific pathologists (e.g., dermatopathology), and residents. Disease process, epidemiology, and clinical presentation are emphasized where appropriate. Assessments in the laboratory setting include practical examinations, with questions targeting structure identification and/or function. More recently, some institutions have adopted virtual pathology (Eraña-Rojas et al., 2017) and histology laboratories (Jurjus et al., 2013). Others have combined their pathology laboratory materials with other disciplines to create integrated laboratory sessions

(Azer et al., 2013). Therefore, faculty have continued to adapt these disciplines and their assessments to better coincide with overall trends in medical education.

Another option to consider is administering histology laboratories as self-study modules for students to review on their own time. If you choose this option, synchronous live laboratory periods can be used for faculty to provide additional review in image identification and structure relationships. In this model, there are no practical examinations, but be sure to include practical-based questions on written exams. Similar models use virtual slides for pathology self-study modules with in-person case-based sessions on diseases and disorders.

Physiology

Although not as prominent as gross anatomy laboratory sessions, laboratories involving physiology also exist in medical education. These sessions are usually structured so students can work through physiological processes as they relate to complex clinical problems and concepts. Examples of physiology laboratories include sessions on heart rhythms, respiratory volumes, and acid-base balance. During laboratories, students work through protocols that involve either experimentation by generating *in vivo* data or using existing data to test various hypotheses. For sessions where drug interactions and effects are critical, pharmacology can be introduced as well. As Horrigan (2018) demonstrated, one of the major benefits of these laboratory sessions is that it allows students to visualize physiology and better translate basic science content to clinical scenarios. Accordingly, pathophysiologic data can be added to further emphasize clinical integration of concepts and aid in generating a diagnosis (Fris et al., 2010).

Educators continue to modify the above format to provide a greater emphasis on active learning (Modell et al., 2004) and peer teaching (Bian et al., 2018). At my institution, physiology laboratory sessions roughly follow the above format. For a session on respiratory volumes, students generate their own volume-time curves and flow-volume loops using a spirometer and computer program. They can also compare their own data to ideal computer controls. Finally, using computer data, students then compare control respiratory volumes to those in conditions like asthma and chronic obstructive pulmonary disease (COPD). Besides experimenting with the equipment, this exercise offers students practical application of foundational physiology concepts in pulmonology.

Online Laboratory Considerations

The rapid development of new technologies, curricular constraints, and educational research has resulted in many institutions adopting online learning strategies. Laboratory exercises have not been immune from these changes, with educators

opting for either fully or partially online components for laboratories. As with any educational intervention, there are advantages and disadvantages when considering online laboratory sessions.

From a performance perspective, student performance on written or practical examinations is equivocal when comparing online to face-to-face (F2F) course formats (Acosta et al., 2018; White et al., 2019). Students regularly rate the self-directed format and continued ability to review material at one own's pace as a benefit to the online format (Attardi et al., 2016; Eraña-Rojas et al., 2017). Similarly, data from Wilson et al. (2019) reinforced the idea that repeated exposure to content, particularly with computer-based platforms, is critical for student learning. However, students have also reported difficulty in communicating with instructors, a lack of kinesthetic learning opportunities, challenges with technology, and a failure for a true replacement for an interactive, face-to-face session in the online environment (Attardi et al., 2018).

Ultimately, it is up to the instructor to determine whether online laboratories are a realistic option for teaching content within their curriculum. External factors, such as faculty and financial support, are also likely to impact these decisions. Therefore, faculty should carefully consider the above when opting for an online laboratory session.

Assessment of Laboratory Teaching Techniques

Above all, assessment options must be tied to the instructional design and learning objectives of the laboratory session. Table 7.1 presents examples of assessments for relevant Bloom's cognitive processing dimensions and learning objectives (Engelhart et al., 1956). It should be noted the examples provided are not exhaustive or exclusive; there is likely some overlap between the assessments you could select for neighboring cognitive dimensions**.**

Without considering instructional design, it is easy for components of a hidden curriculum to overshadow the goals of the laboratory session. For example, in a dissection-based anatomy laboratory session, is the goal for your learners to

Table 7.1 Learning objectives, assessment options in a laboratory setting

Cognitive dimension	Learning objective verb	Assessment example
Knowledge	Define, list, repeat	Multiple choice tests, fill-in-the-blank worksheets
Comprehension	Describe, discuss, identify	Labelling exercises, multiple choice tests
Application	Apply, demonstrate	Skill demonstration
Analysis	Analyze, criticize	Open ended prompts, Oral examinations
Synthesis	Construct, create	Student-developed projects
Evaluation	Appraise, assess	Simulations

demonstrate good dissection techniques or to identify structures? If you ask anatomy faculty, they may say both! However, the way the sessions are organized and learning objectives are selected would suggest that is not necessarily the case. If good dissection technique is your objective, then you would want to consider designing an assessment that would target the skill. This could include assessing the overall quality of a dissection and any techniques necessary to complete the skill. If structure identification is your goal, then a multiple-choice quiz would be appropriate. It should be noted that the learning objectives and assessments need to be targeted to the level of the learner. You may have different assessments for different student populations.

Regardless of what type of assessment you choose, both formative and summative options should be provided to help learners navigate the topics. Formative assessments should be low-stakes, nonthreatening, and worthwhile. The nature of the formative assessment should also match that of the summative assessment. Therefore, you want to consider a formative assessment that is as similar in format and structure to the summative assessment as possible. You should also provide feedback to your learners for both formative and summative assessments. Feedback allows learners to identify any gaps in their knowledge or skill sets. For written assessments, that may include rationales to questions. For higher cognitive domain assessments, you may need to provide specific comments related to the assessment. In the scenario above, a debrief with the learner on the dissection quality and their technique would be appropriate for feedback for skill development. In the labelling example, detailed rationales for written questions would be appropriate feedback.

How to Set Up a Lab Exercise

By far the most amount of your time spent laboratory teaching will be spent designing and setting up your laboratory exercise. Successful laboratory sessions require thought, time, and coordination among all participants. This section will cover laboratory session design, setting expectations, and inclusive teaching in the design process. Although these topics are separated, they should be done in unison during the laboratory session development.

Laboratory Session Design

I employ a structured design process for my laboratory sessions known as the PLHET process because it includes the steps of Prep, Link, Hook, Engagement, and Transfer (Jurjus et al., 2013). This method incorporates principles of both adult learning and instructional design. An example of how we used the PLHET approach to structure clinically-oriented anatomy laboratory sessions for our third year

Obstetrics and Gynecology (OB/Gyn) clerkship students is included in Table 7.2 (Jurjus et al., 2016).

Once you have defined your learning objectives, outline how you want your laboratory session to run. A critical component of the model is the inclusion of preparatory work to be completed before your learners attend the session. If you include preparatory work, this needs to be communicated to the students prior to the session. In our example, we clarified the session format at the clerkship orientation and sent multiple reminder emails. At the onset of the session, you will review the learning objectives and general flow and timing of the session. To initiate the learning process, you "link" to what they already know or have covered. In the example above, this was done by referencing the preparatory work and their prior experiences in seeing patients. A practicing clinician led this discussion by getting students to discuss how in clinical situations, normal anatomical structures may not be readily visible. By anchoring or giving a "hook" for your session, you provide your learners with a foundation for how your content relates to their professional goals. In other words, how is what you are teaching them essential for clinical care? In the example above, the "hook" discussed the consequences of not correctly identifying anatomy in perineal lacerations for patient outcomes. Session engagement is where the bulk of the teaching and learning happens by leveraging prior knowledge and experiences to create new knowledge. In the example above, students rotated through several prosection stations focused on the gross anatomy for different clinical scenarios: laceration repair, intrauterine device (IUD) placement, hysterectomy, and cesarean section incisions. After learners have engaged with the material, you offer a "transfer" to reinforce what they learned. This can be done by repeating the

Table 7.2 Using the PLHET Model to plan a surgical reproductive anatomy laboratory session

Component of model	Definition	Example of design	Time allocated
Prep	How the learners prepare for the session	Three videos on relevant female reproductive anatomy	45 min
Link	How the learners can relate prior experiences to content	Outline of learning objectives and overview of timing Faculty-led discussion on why understanding anatomy is better than memorizing the steps of a procedure	10 min
Hook	How the learners perceive the relevance of content to work	Faculty-led discussion on the consequences of improperly identifying or repairing a perineal laceration	10 min
Engagement	How learners apply the material, integrating it with prior knowledge and creating new knowledge	Flipped-classroom style discussion of anatomy through clinical prosection stations	70 min
Transfer	How learners reinforce the retention of new learning by applying it to a different scenario	Student-led summary to classmates of clinical scenario incorporating anatomical knowledge to improve surgical technique	30 min

engagement in a different context, such as a slightly different clinical case, or in the example above by having the students lead discussions to review the take-home points from reach of the stations.

As you are developing the session design, you also need to consider the laboratory space, resources, and the total number of participants. 185-person dissection laboratory sessions are run very different than 30-person prosection laboratory sessions. You need vastly different resources for both. In a larger laboratory exercise, you need more cadavers, dissection tools, PPE, and faculty to assist. For smaller prosection exercises, you need a few prosections, several probes, PPE, and fewer faculty. For any laboratory session, you should be aware of any informational technology (IT) needs that you may need. You may need to include the ability to play videos demonstrating examples such as surgical repairs. If you do need to use video capabilities, be sure to do a test run on that equipment to ensure the sound and video work with your space. With continued changes and curricular innovations, you may find yourself needing to update your laboratory needs over time. Over the past few years, we have updated our laboratory to include brighter lighting, better ventilation, designated spaces for specific programs, and newer audiovisual equipment.

These instructional design tenets hold true for virtual laboratories too. Technology should not drive your laboratory design; your laboratory design should dictate the technology. For example, if you've decided to run a virtual laboratory with breakout rooms, what video-conferencing system would work to meet your needs? If you've decided to use a web-based slide repository for a histology laboratory, are there concerns with bandwidth needed to access the images? How the laboratory space functions is a reflection of your overall session design and you should plan accordingly, regardless of format.

Setting Expectations

In addition to the overall design above, it is critical to set expectations in the design process. By using clear communication, you can help reduce anxiety for both learners and faculty. Learners and faculty should each know the goal of the session, the content being covered, how the session will run, what the schedule looks like, and any assessments that you plan to include. When dealing with multiple laboratory instructors, I suggest creating a faculty guide to follow during the session. For more experienced teaching faculty, this will help to narrow their extensive expertise to the most critical aspects of the session. For less experienced teaching faculty, this will help them review relevant content prior to the session. I also recommend doing a walk-through of the laboratory session space and resources with all faculty prior to the session. For lab sessions that we have done several times, a quick 30-minute faculty discussion before the session starts is adequate. For newer labs, I typically schedule a longer discussion and walk-through a few days before the session is supposed to occur. This walkthrough allows us to discover limitations in technology or laboratory space and to facilitate faculty feedback to create needed changes in the

session. Keep in mind that this is also critical in the virtual environment. If you have designed your online laboratory session to have breakout rooms and faculty cannot access the rooms, you have a major problem. The earlier you identify these issues, the easier it is to fix it to make the session run as smooth as possible.

Inclusive Teaching in the Laboratory Setting

While you are developing the session and setting expectations you should also consider how to make your laboratory session more inclusive. Inclusive teaching is not a single event, but rather a mindset. You should regularly ask yourself, "what can I do as an instructor to make sure all learners are engaged equally?" Inclusive teaching extends to both the environment (climate) and the activities (pedagogy).

From an environmental perspective, make sure physical space is ADA accessible and students can easily access everything in the laboratory. As the leader of the laboratory session, you are responsible for setting the tone and norms for the session. This includes establishing a positive rapport with fellow faculty and learners. Things you may want to consider are how you want faculty addressed (e.g., formal titles) and how learners preferred to be addressed (e.g., use of pronouns). You want to cultivate positive interactions and respectfulness among all participants.

From a pedagogical perspective, consider how the students are engaging with the material and how you are engaging them. Prior to any session, confirm that educational materials are inclusive and accessible. Examples include text descriptions for images, selecting font color and sizes that learners can easily read, and captioning for videos. For our anatomy teaching materials, we aim for a diversity of body sizes, race, and skin tones in any images, prosections, or cadavers. Regarding teaching techniques, use a variety of teaching techniques to engage all learners. Open-ended prompts and discussion engage some learners, but others may feel uncomfortable answering verbally; therefore, you may want to consider anonymous polling options as well.

Another aspect to consider if you are using small groups in the laboratory is how to assign groups. Do all your groups have diversity of experiences, background, expertise, or are some groups more homogenous? Ideally, you would want each group to have individuals with a range of experiences and backgrounds. For that reason, it is helpful to consider this factor before you get to your laboratory session.

Conducting the Lab

With all the effort to develop and plan, you might be surprised how fast the laboratory session goes! As the leader of the laboratory, your responsibility is to make sure the session runs smoothly. This includes ensuring that all participants keep to the

outlined schedule, cover the learning objectives, and promote a positive learning environment.

At the beginning of the session, provide learners with your roadmap for how the session will run. Provide a breakdown for each task that needs to be accomplished before the end of the session. Do not forget to mention any assessments that need to be completed during or after the session. If you followed the PLHET process, then your students should be aware of this; however, it never hurts to reemphasize this important content. If you are asking your learners to do something technical or skill-related in the session, you should demonstrate proper techniques for them. Some learners may opt to try it themselves first, but others may want some assistance. Offer the demonstration to everyone as a standard. If there is anything that needs to be completed before they leave the session, such as clean-up procedures, emphasize it at the beginning.

When teaching with other faculty, I suggest performing spot checks whenever possible to ensure they have what they need. Questions will continue to arise even after your planning. Faculty may need clarification on the session flow, the content, or resources (e.g., tools). For a two-hour session, I check in with my faculty every 20–30 min just to make sure that everything is still flowing smoothly. Finally, be sure to have fun! Laboratory teaching is interactive and a wonderful way to engage your students.

After the Lab

Now that your laboratory session has concluded, you should evaluate how it went. If your session is part of an official course, you will likely get formal student evaluations at a later point in time; however, the most useful feedback is the immediate feedback that you can solicit from participants once the session concludes. You do not need to make your evaluation overly formal. Rather, I recommend asking all participants the same three questions:

- What worked well?
- What didn't work well?
- What could be improved?

This type of feedback allows you to modify and correct issues immediately, as opposed to waiting several weeks for official evaluations. Additionally, learners and faculty may have very different suggestions for improvement. Both sets of data are valuable, and you have the discretion to act on suggestions as needed. This feedback may also cause you to assess your resources and space requirements if you have future sessions planned. From the OB/Gyn anatomy laboratory example, we heard from students that while the session was valuable and informative, the timing of the session would have been better earlier rather than midway through the clerkship. Faculty suggested increasing the amount of time dedicated to the final review and

discussion. Both of those suggestions were incorporated into the laboratory sessions the following academic year.

Pitfalls

With all the hard effort you put into planning and running your laboratory session, how can anything go wrong? Unfortunately, things can and do go wrong, even after the best planning. In my experience, these pitfalls fall into three major categories: timing, content, and structure. Any of the above pitfalls can result in your participants not learning what is intended. With proper planning many of these can be avoided.

Timing pitfalls involve inadequate time to accomplish the tasks you planned or not following the proposed schedule. Some of this is resolved through trial and error. Even the most proficient laboratory instructors are sometimes poor estimators of how long tasks will take. Based on the learners' experiences during the sessions, you may discover that you had too little time allocated to complete at task. Your participants are taking longer to move through the content that you had planned, which means they will not meet all the learning objectives. Alternatively, you may discover that you had much time allocated for a task and participants are moving faster than you anticipated. Therefore, you have wasted time that you could have used better for other purposes or to meet another learning objective.

Content pitfalls involve not following the learning objectives for the session. Invariably this happens when you have experts, well-intentioned as they may be, cover content that is not tied to the learning objectives. Perhaps the content is too detailed or inappropriate for the learner's level. While these topics may be conceptually related, they should not overshadow the overarching content and goals of the session.

Structure pitfalls involve a lack of clear structure and flow to the session. This may rear its head when you assume learners should know what to do without any guidance presented. You may not have provided clear instructions for how the session will run. Alternatively, your structure may be inadequate because you did not appropriately plan the necessary resources.

Summary

Laboratories within medical education span a wide range of settings and experiences. The most important aspect of incorporating laboratories within a curriculum is the instructional design process. Although time-consuming, a detailed design will help you plan an organized session and prepare for potential pitfalls to ensure the session runs smoothly. With the appropriate planning and organization, you can create well-received educational experiences for your learners.

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