Teaching Guide for GSIs

Facilitating Laboratory Sections

Almost all graduate students in the sciences will teach a laboratory at some point in their graduate careers. Labs should be a process of discovery for students as they uncover the mechanisms behind important scientific principles. The GSI's role is to lead students through the learning experience by giving them the conceptual basis for the lab, and to guide them through the investigation so they can make discoveries on their own.

It is common for students to miss the point of a lab. GSIs can substantially improve the usefulness of labs by providing the framework that students miss. What is the question we are answering? How will the data we collect answer this question? How can we collect this data?

Labs present a unique challenge as they combine many different aspects of teaching, including:

- lecturing
- organizing group work
- leading hands-on learning
- asking meaningful questions
- creating assignments
- evaluating student work

Your goal as a teacher is to make the most effective use of the lab period in order to give students a beneficial, hands-on experience of doing science. There are two aspects to teaching labs that are sometimes difficult to juggle but are interrelated and complementary:

- **Pedagogy:** Determining the best teaching methods for the desired outcome; making sure students think through the models they can use to explain what their data is showing and ultimately answer the main question.
- **Logistics:** Ensuring the experiments go smoothly and that your students understand the tasks they need to accomplish; helping your students accomplish those tasks in an efficient and timely manner.

Teaching Guide for GSIs

Holding these two aspects together can be challenging at times. However, combining a smooth-running, efficient lab section with sound pedagogical techniques will provide your students with a successful learning experience.

This section of the Teaching Guide presents techniques designed to help you meet both teaching goals.

In This Section

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Teaching Guide for GSIs

Pre-Lab Assignments

For students in lab courses, nothing feels more pointless than just going through the motions of a lab procedure without understanding why it is significant. Emphasize to students that experimental science is the basis for the models they learn about in lecture. Lab, unlike lecture, represents professional science in practice. Lab also represents a playground where curiosity is sparked and scientific theories are put to the test. If students recognize this, they will gain a better understanding of what science truly is and may be more motivated in their lab work.

Preparing students for lab involves the following:

- Helping students understand the models, theories, and principles addressed in the lab procedure — giving them a conceptual framework for the lab
- Ensuring that students know how the lab fits into the course content
- Outlining the lab procedure and data analysis
- Orienting students to the relevant equipment and safety procedures

A well designed pre-lab assignment can serve all these functions. Pre-lab assignments are tasks or homework that students complete before arriving in class for the lab period. Pre-lab assignments motivate students to prepare for the lab and help them connect conceptual understanding with an experiment.

There are several advantages for students in using a pre-lab assignment:

- Students come better prepared for the lab exercise.
- Experiments and exercises go more smoothly because students are familiar with the processes.
- Their understanding of the material is heightened.

There are advantages for the instructor as well:

- The assignment can streamline the process of writing a pre-lab introduction.
- The assignment can make it easier to teach the theory behind the lab, since students will have a firmer understanding of the principles behind it.

For many of the lab classes you will teach, the professor may already have pre-lab assignments written for you to give your students. However, in cases where there are no pre-lab assignments written into the course already, you may choose to create and implement your own.

Designing a Pre-Lab Assignment

Concepts and Types of Questions

First, think about the models and questions you feel are important to address in a pre-lab assignment. What do you want your students to have understood or thought about before they arrive in lab?

In order to help students frame the lab experiment, consider the main question your students should become able to answer:

- What question is this lab experiment answering?
- How will your data answer this question?
- How will you collect this data?
- How will you minimize ambiguity and control variables?

Here are some of the topics you might ask your students to think about in a pre-lab exercise:

- concepts, theory, and models
- procedure and methods (for an example see the Teaching Effectiveness Award essay by Jessica Smith [Chemistry], A Pre-Lab Assignment for a More Efficient and Effective Laboratory)
- troubleshooting and other experimental issues
- prediction of trends in data or other qualitative questions about data
- quantitative questions such as calculations with simulated data
- interpretation of simulated results

Linking to the Pre-Lab Introduction

It is important to consider how you will introduce the lab on the day of the lab section. It is most common to give a short pre-lab introduction.

- Connecting the questions and concepts addressed in your pre-lab assignment with those that you plan to address in your pre-lab introduction helps make certain that these two aspects of lab preparation complement each other.
- Use discussion of the pre-lab assignment as a starting point for the pre-lab introduction and as a tool for introducing the lab. In fact, you should go over at least some part of the pre-lab assignment at the beginning of the lab period. This ensures that students have understood the material and concepts therein before the lab exercise begins.

Format

Here are several ways that you may format your pre-lab assignment, each with advantages or disadvantages depending on the material, your class, and the outcomes you wish to achieve from the assignment:

- **Worksheet done before lab** (handed in at the beginning of lab): This format works well if you can create well-defined questions to help your students consider some theory or concepts related to the lab. Sometimes giving students sample calculations, data, or experiments on a worksheet is also helpful, if the lab material lends itself to this approach.
- **Assignment worth a few points** (handed in at the beginning of lab): This is useful when preparing for the lab requires students to research information on their own. You can also make this a small group assignment that a lab group or lab partners can do together to prepare for lab or to think about important concepts relating to the lab.
- **Quiz at the start of lab**: This is most useful if you want to ensure your students are preparing for lab on their own by reading the lab or background materials in advance. Again, it works well if the quiz can function as a starting point for discussion or an introduction to the lab.
- **Preparation of lab notebook** (checked at the start of lab): This can work well if having a comprehensive lab notebook is crucial to the students' understanding of the lab material (anatomy courses, involving dissections and labeling structures, are one example). Checking the students' lab notebooks can help confirm that students are making the best use of their

lab time and taking away the most valuable information from the lab. It also is an incentive for students to organize their lab material well, thus maximizing the benefits of the lab period.

- **Quiz on the web to be completed before class** (currently implemented in Chemistry 1A at UC Berkeley): Pre-lab web quizzes can be an excellent way to use technology to help your students prepare for lab. Having students take the quiz on the web before class will alert you to problems that students are having in understanding lab material. You can then take this into consideration when introducing the lab on the day of section.

Teaching Guide for GSIs

The Pre-Lab Introduction

Consider the following elements in constructing an effective pre-lab introduction.

Concepts and Models: What questions is this lab experiment answering?

- Begin the pre-lab introduction by going over related concepts from lecture. Assigning a pre-lab quiz can often address these concepts and be a great jumping-off point for the introduction.
- Discuss with students how concepts discussed in lecture relate to the lab exercise at hand. Use class discussion or small group work to help your students make links between theories or principles and lab practice.
- Help students make connections between the concepts addressed in the lecture portion of the class and their applications in the lab exercise. As the students begin the experiments or procedures, guide them through the principles and concepts being illustrated through the lab. Students should never leave the lab without understanding the point(s) of the lab.
- Discuss the scientific method (at least once during the semester) to help guide students through the lab experiment. This is especially important if students are designing the experiments themselves.

Data Analysis and Interpretation: How will your data answer this question?

- Provide examples of relevant data analysis and review them with the students.
- Allow students to work on sample data sets in groups or with lab partners. The pre-lab assignment can be helpful here (e.g., see a sample pre-lab assignment); give students sample data to analyze and interpret before the lab, and incorporate it into your pre-lab introduction.

- Discuss how the concepts above are quantitatively related.
- Ask students to consider the units involved for any graphs they make. Should the points form to make a line or other function they know?

Experimental Procedure: How will you collect this data?

Outline what the students should do during lab:

- Briefly go over the lab procedure with students before the lab begins. This helps students focus on the tasks and goals associated with the lab exercise.
- Mention what they need to observe, draw, record, or note. Put overviews or lists of tasks on the board to help students navigate their lab exercises. Be mindful that the lab experience should be a discovery process and should not feel like following a cookbook recipe.
- List what the students must hand in after the lab period.

Equipment and Safety Considerations

- It is your responsibility to make sure that students are prepared to conduct the lab in a safe manner.
- Introduce and/or demonstrate any unfamiliar equipment or materials, noting any possible safety concerns in using them.
- Give a short lecture or demonstration on lab safety and, as appropriate, chemical and waste disposal. You should receive this information from the course coordinator.

General Tips

- Choose an effective format for your lab sessions, and use it if applicable each week. Students will know what to expect every week in lab and can turn their attention to the concepts and procedures involved in each lab exercise. Using a consistent format also makes it easier for you to organize and plan the pre-lab part of the lab section.
- Think about time considerations: One of the most important and difficult aspects of the pre-lab introduction is its length. How much time will you spend introducing the material before students begin the lab? The amount of time spent on a pre-lab introduction will vary depending on the material

being presented, so try to judge this accordingly and prioritize getting students started with the experiment.

- Be aware that students tend to get frustrated and anxious to begin the lab if the pre-lab introduction is too long. Striving for an effective presentation while being brief is a sound (and challenging) goal for a pre-lab introduction.
- Use discussion and interaction as part of the lab introduction: Lecture is not the only format for introducing lab material. Often, working in small groups or having a class discussion is more effective in challenging your students to think about the lab. Students often learn as well or better from each other than they do from the instructor alone. Ask students to discuss at their tables and have one student share with the class. Have them take turns being the spokesperson.

Teaching Guide for GSIs

During and After the Lab

During the Lab

- Interact with the students for the entire duration of the lab. You should visit every group, pair, or student at least once if not more during the lab period.
- As you move around the room, ask pointed questions that require students to take their thinking one step further. If students have questions of you, try to refrain from just providing the answer. Instead, ask leading and focusing questions to guide students to discover on their own.
- Check on the students often. Ask questions that make the students connect the experiment and the concepts. Similarly, invite lots of questions!
- Know the lab methods thoroughly so you can help students with logistical and procedural questions.
- Consider pausing the lab once or twice (if possible) to go over frequently asked questions with the whole class, look at a demonstration, or discuss concepts and procedures. Very often, many students will have the same questions during lab. It is effective if you address these issues to the class at once. You may also want to skim the lab beforehand to consider natural stopping points while you are prepping.
- Make connections between the experiment (or procedure) and concepts. Remind students, and ask them to tell you, how the lab relates to lecture material and larger concepts.
- Prepare a range of questions to prompt reflection and discussion. Instead of asking “Any questions?” try asking “What are your questions?” or “What do you understand from this?” Be specific about a concept or topic. Simple questions like “What does this machine do?” or “What assumptions are being made for this experiment?” can help jumpstart the conversation. See also Asking Effective Questions.

After the Lab

- If possible, stop a few minutes before lab ends to summarize the major points of the exercise. If this is not possible, since groups often finish before lab ends, consider adding an end-of-class quiz.
- When you return the graded labs to your students, discuss common misunderstandings. Encourage your students to read your comments and learn from their mistakes. One technique to encourage this continued learning is to have a follow-up lab assignment in which students correct their labs and turn them in again.

Teaching Guide for GSIs

Asking Effective Questions

When you visit students as they work, take a minute to look at their lab and ask well structured questions that will elicit further thought and reflection. Why are good questions important?

- Questioning is essential for two-way communication between a teacher and student, or between students themselves. Questioning…
    - helps students build their understanding,
    - promotes high-level thinking,
    - draws out what students are thinking.
- Good questions promote student-centered teaching. Asking students thought-provoking questions makes them more aware of their learning process. They are given an opportunity to provide feedback about what they don't understand, what they do, and what they need in order to enhance their understanding.
- When asked a question by a student, rather than answering the question directly, consider countering with a question (or questions) of your own. Every time a student asks a question, there are at least two teaching opportunities.
    - The first is obvious: The student has some gap in his or her understanding (the point of the question), and you can help them sort this out.
    - The second is more subtle, but arguably more essential: You can help students learn how to figure out how to answer their own questions by guiding them with questions of your own.

Questions are also the essence of good science: asking well-defined, useful questions is an incredibly important skill for scientists. Demonstrate this skill to students, and point it out to them.

Broad versus Focused Questions

Broad questions require …

- open-ended answers ("How are these two concepts connected?")
- analysis ("How would you interpret these results?")
- prediction ("What will happen if you increase the amount of this substance?" "What do you think the outcome of the next part of the lab will be?")
- forming opinions ("Do you think we tested this hypothesis or theory in the best way?" "What is another way we could have done it?')

Ask broad questions when you want to initiate discussion. However, focused questions are better when you are looking for specific answers.

Focused questions require …

- recalling facts ("What is the function of this structure?")
- defining terms ("What is an [acid, mollusk, quasar, lever, vertex]?")
- categorizing ("What characteristics do all these elements share?")
- confirming ("Do you remember seeing this before?")

A common problem in lab is trying to start a general discussion by asking focused questions. Ask focused questions to verify students' knowledge of specific facts or concepts and ask broad questions to get them to make connections between these facts and concepts. If you want to enhance discussion, incorporate both focused and broad questions into your labs.

For examples of questions that invite students to think more creatively about problems and apply course concepts, see:

Brent, Rebecca and Richard M. Felder (2014). "Thinking Creatively and Critically." *Chemical Engineering Education* 48.2: 113–14. Republished with permission by Tomorrow's Professor.

Teaching Guide for GSIs

Managing Lab Partners and Groups

Managing lab partners and groups requires …

- knowing what to do when the group gets stuck and asks, "What do we do next?"
- organizing effective groups that accomplish their goals
- managing questions from different groups to avoid having to repeat yourself

Possible strategies for addressing these issues include asking questions that encourage deeper reasoning in students, such as these:

- What did you find when you did … [earlier part of the lab]?
- What does this mean … [a term, a figure]?
- How does this relate to … [earlier information]?
- How do we measure *h* ?
- What is your goal for … [next part]?

To help students work better in groups, you might determine which students are the strongest, then promote teamwork by asking them to explain their ideas to their groups. Furthermore, when a group member asks you a question, don't answer immediately. Instead, ask the other members of the group how they would approach the question. Often someone in the group will have an idea they haven't shared. This technique fosters group interdependence. See Asking Effective Questions for more tips on formulating good questions.

If groups are not working well, you might assign groups randomly each week so that students get to interact with all their classmates. If some students work quickly and finish before others, ask them to help in other groups, or to begin their data analysis. If students are not working on what they should be or seem distracted, ask specific questions about the process to get them back on track.

If you notice that many groups are getting bogged down in the same problem, it can be helpful to call the class together as a whole to discuss the difficulty. You can also identify a group that is doing well and ask them to explain their ideas to other groups. These kinds of interactions help students refine their ideas.

Equity Issues in Group Work

Students sometimes react negatively toward group work. This is often because some members feel they will have to do an uneven share of the work and that grades will not reflect individual effort. Of course, personality conflicts can also arise.

Repeated personality conflicts or other difficulties can be averted by randomizing the groups each lab period. It also helps to assign specific tasks to each group member. Asking teammates to evaluate each other's work can clarify who has been responsible for the group's progress, and assigning grades individually as well as for the group will help alleviate fears of unfairness.

It can also help to explain to your students why group work is valuable to them. See Group Work: Design Guidelines for a discussion of this topic and other topics related to Group Work.