A Quick Guide to Active Learning in Lectures[1]

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Motivation

We know from our own experiences that students learn more when they are forced to work through material. Yet when we talk to a powerpoint presentation for an hour, we render the students passive, as if they are watching a video, without the ability to rewind, replay, pause, and ponder. If we ask questions that are answered with blank faces or at best a few tentatively raised hands, then we are failing to engage every student, actively, in the lesson. If we can create an environment where students want to engage the material, and we challenge them to demonstrate their mastery of the material, then we can have some confidence that we have accomplished our teaching objectives. This document outlines an iterative development process that helps you design and deliver this kind of active learning lecture.

Active learning is not a passing teaching fad. A study by Freeman et al. (2014)[2], published in the Proceedings of The National Academy of Sciences, documents consistent improvements in student performance in active learning classrooms in 225 different experiments. Furthermore, active learning is not about using any particular technology or methodology. Active learning is about concretely identifying what you want your students to learn and experimentally verifying that they actually learned it.

> Sidebar: *Help! I've run out of time to redesign my lectures. I already ask students questions when I teach. Isn't that enough?* Designing a high quality lecture takes time. While we encourage you to invest the time to re-evaluate your lecture, you can quickly improve it *by altering how you ask your questions.* Do your questions require more than a simple yes/no or a fill-in-the blank? Do your questions check for comprehension and/or further the discussion? If so, then read the section "The Mechanics of Exercises" on page 3-4, where you'll learn how to make *all* your students engage actively with your questions, using techniques like "Think-Pair-Share." If your typical lecture sounds like the history lesson from *Ferris Bueller's Day Off*, please read on.

Step 1: Identify the 2 or 3 take-away points from the class. Phrase the take-away points as statements of things you want the students to be able to do at the end of the lecture. Use action verbs and avoid weak statements like "The students will understand…" From there, work backwards identifying simpler concepts and actions that students will need to master before they can accomplish your goals. This ranked list defines the bounds of your lecture.

This procedure has two benefits. First, you are shifting your focus away from what you will *teach* towards the material the students will *learn*. It is important to recognize that the two processes -- knowledge professed and knowledge acquired -- are not the same thing. Second, while we know what we have taught in a lecture, we do not know what the students have learned. By identifying a task that students should be able to perform, you have already started defining exercises that you can then use to assess what students have learned. Luckily for you and the student, the act of solving exercises also forces students to engage and learn the material.

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[2] Scott Freeman et al., *Active learning increases student performance in science, engineering, and mathematics.* PNAS 2014 111 (23) 8410-8415; doi:10.1073/pnas.1319030111

Sidebar: This concept of student actions sounds abstract. Are some actions better than others? How do you handle tasks that build on each other? For example:

- Students should be able to *calculate* the field of view of a camera given the optical properties of the telescope and the size of the CCD chip.
- Students should be able to *explain* how the focal ratio of a telescope influences the design of a survey.

The Bloom taxonomy gives some order to this by ranking learning objectives into six increasingly complex categories: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. You can see a short summary of definitions and commonly used verbs for each category in this pdf.

Do you have too much material? The answer to this is *invariably* "Yes**."** Do not squeeze an entire semester into one lecture. Your students do not benefit (and you waste your time) when you rush through material at speeds only an expert can follow. Remember that every high level objective students learn also requires them to master a foundation of simpler objectives. That takes time. Either you will need to reduce the number of high level objectives in your lecture, or you must assume that students already have mastered the basics. Use your judgement and consult with the DE SChool organizers to see what makes sense within the broader DE SChool curriculum.

Step 2: Identify and build your exercises: Find or create exercises that allow students to demonstrate the objectives you listed in step 1. You do not need to create exercises for every objective, as the high-level objectives implicitly test the lower level objectives. However, while it is natural to focus on your main objectives, take a moment to think about all the objectives. Do the more advanced objectives depend critically on one particular low-level objective? Is there one objective that students always struggle with? If yes, then you should consider building an exercise to focus on that problem point.

Exercises will likely take one of two forms. The first form will look like worked examples you may have seen or presented in a discussion section, or an example you would have worked through in a traditional lecture. There are a few things to keep in mind as you convert an example (or homework problem) to an exercise:

- *Exercises take time*. In an hour lecture, you probably have time for one, or maybe two of these.
- *Avoid busywork*. While it's nice to calculate fun extras, it'll steal time away from your main objectives.
- *Avoid mathematical grunge work*. You aren't testing students on mathematical manipulation.

Exercises don't need to be large, long, or include an explicit calculation. Sometimes a *qualitative* question focusing on either the concept or the process of problem solving may be more effective. For example: *Why* is it like this? *How* would you solve this problem? What principles apply? What factors do we need to consider? What assumptions do we have to make? If we changed X, how would Y change? These types of questions have definite advantages over some traditional exercises. They take less time, making them better suited for the middle of a lecture. And if structured correctly, they cannot be solved by plugging-and-chugging with the nearest equation.

Sidebar: Misconceptions. Students are not blank slates, but instead are the products of a lifetime of education and miseducation. From your prior teaching experiences, you can probably identify concepts that students always struggle with. Perhaps they think some principle is always true while it actually applies only in specific situations (e.g., 1-sigma errors are given by the standard deviation of your measurements). Or they think some principle applies in a situation when it actually doesn't (the seasons change because the Earth moves closer and farther from the Sun). One way to fix misconceptions is to use a "*predict-test-discuss*" exercise.

- Trigger (optional): Remind students of, or have students recall, their misconception. (How did you calculate errors in freshmen lab? Error propagation formulas, right?)
- Predict: Have the students use their pre-existing conceptions to analyze a problem where those methods will fail. (So if I have A=1, sigma_A=1, B=1, and sigma_B=1, what's the value and error for Z=A/B?)
- Test: Have the students perform the experiment and check their predictions. (Students do a Monte Carlo simulation of Z=A/B and histogram the results.)
- Discuss: Have the students try to explain what went wrong and how the new concept works. (Students recognize that Z is not distributed as a Gaussian, so the sigma_z they calculate is not a 68% confidence interval.)

Step 3: Build out the presentation. You will need to embed the exercises into a coherent lesson through traditional lecturing. Use standard techniques to introduce the topic and provide enough background information so that the students can complete the exercises. Here are a few tips to help you structure your lecture. These are suggestions, not rules.

- Since DE SChool lessons are one-off lectures, you will need to introduce your topic to your students. Remind them of facts and skills they already know on the topic. This helps activate their memory and link your new material to existing concepts.
- A qualitative, conceptual question early on that has students brainstorm can make students feel invested in the lecture. (What factors might be important? How might we solve this? What constraints are in play?)
- Meaty exercises assess whether the students have learned the main point of the lecture, and therefore naturally go towards the end. You can cover the material traditionally and then introduce the exercise as a test, or you could use the exercise to make your main point for you (an "ah-ha" moment). If you opt for the latter, budget additional time for the students to struggle.
- Plan to do an exercise, light or meaty, at least every 15-20 minutes. Student attention will likely drift if you talk for longer periods. Consider dividing your lecture into acts or mini-lectures, with each act focusing on one of your main take-away points.
- If you have a series of meaty exercises, it may make sense to split the lesson time. Use the first third of your lecture to present material traditionally. Use the remaining time to work through the exercises in groups.
- Reserve 3-5 minutes at the end of the lecture to summarize your main points.

The Mechanics of Exercises: How do you transition from lecture to exercise and back? It depends on how involved your exercises are and where you place them in the lecture.

If your exercise is "light," with a short, qualitative, conceptual answer, then you can use *"think-pair-share."* This procedure avoids the dreaded "dead-silent room with a Professor-on-the-prowl" scenario feared by many an undergrad.

1. Pose the question verbally and visually. Give students 30-60 seconds to think of the answer by themselves. (Yes, there will be a minute of thoughtful silence.)
2. Next, have them turn to their neighbor and discuss their answers and thought process for a couple of minutes.
3. Finally, call on groups and ask them to state and explain their answer.

This procedure has multiple benefits. First, students are forced to engage with the problem. Second, by articulating their reasoning they consolidate their understanding. Third, it fills the room with energy and discussion. That buzz allows you to "cold call" on groups without spiking student anxiety. Use this to engage the quiet students and those hiding in the back. *Think-pair-share* can be particularly effective near the beginning of a lecture by breaking the silence, engaging students in the material, and reducing the barrier to asking questions.

If your exercise is “meaty”, then have students break into groups of 3-4 around whiteboards and tell them to work out their answer on the boards.[3] There should be 1 marker per board, forcing students to interact. For these exercises, plan to spend at least 10 minutes to work and 5 minutes to summarize as a class (i.e., ask random groups: "What is your solution, and how did you get there?").

What do *you* do while they are working out the problem? You and any teaching assistants move around the room and engage the groups.

- *Listen to their conversation*. Are they stuck? Do they not understand the problem?
- *Check their thought process.* “Why did you choose that principle to start with? How did you arrive at this conclusion? How does your assumption here play a role? Walk me through this.”
- *Offer nudges:* “Have you thought about this? What else do we know about the problem? What did we do when we were working on that other example?”
- *Offer challenges:* For those who get the answer quickly, “What if we change this? How do we apply our answer to this other problem?” Have something in your back pocket.
- Facilitate interaction: Direct your questions at specific group members, especially those who are quiet or disengaged. If the person with the pen is doing all the explaining, ask another group member for their view. If you use the pen to write something, hand it back to a new group member.
- Watch for unhealthy interaction: Be on the lookout for unhealthy group dynamics such as domination by one member, or the exclusion of certain members through interruption and misappropriation of their ideas. When women in the group are being excluded, often subconsciously, it is known as “Speaking while Female.” The problem can occur with minorities, junior members, or any other time power dynamics are present. *Direct your questions* at the excluded members to draw them back in. Explicitly *acknowledge their contributions* to the discussion.

Step 4: Pre-test the exercises. Test your questions ahead of time. Can students complete the exercises based on the material you present? How long does it take to work through an exercise? The audience for the DE SChool is quite diverse. It's not going to be easy for any teacher, even with experience, to know how well their questions are going to work. Find willing colleagues and graduate students to be your test subjects. However, be sensitive to the fact that experts will often underestimate how much time it will take for learners to discuss a question or address a problem.

Further Reading:

Intrigue Your Students for Better Learning:
https://teachingcommons.stanford.edu/teaching-talk/intrigue-your-students-better-learning
Three Most Common Mistakes in Active Learning:
https://teachingcommons.stanford.edu/teaching-talk/three-most-common-mistakes-active-learning
Promoting Active Learning:
https://teachingcommons.stanford.edu/resources/learning-resources/promoting-active-learning
Resources offered through the Carl Wieman Science Education Initiative: http://www.cwsei.ubc.ca

[3] We will provide markers and “lap boards” or large pieces of paper for students to work on.