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These readings are a collection of short (1-2 page) documents with guidance on the details of implementing active learning in university courses. Most of these are created by the CWSEI and CU-SEI Science Education Initiatives and/or written by Carl Wieman where not explicitly credited. In addition to these materials, the workshop participants will read short chapters from the book, *The ABCs of How We Learn.* Chapters from *How Learning Works* are useful but optional, due to time limitations.

Contents

Additional Resources from the CWSEI and CU-SEI:

- Science Education Initiative Videos: www.cwsei.ubc.ca/resources/SEI_video.html (1-15 minute videos)
  - *Evidence-based science education in action, Clickers in the Science Classroom, …*
- Instructor Guidance: www.cwsei.ubc.ca/resources/instructor_guidance.htm
- Clicker Resources: www.cwsei.ubc.ca/resources/clickers.htm
- Learning Goals Resources: www.cwsei.ubc.ca/resources/learn_goals.htm
- Tools (COPUS observation protocol, Teaching Practices Inventory, BERI Student Engagement observation protocol, Learning Attitudes about Science surveys, …): www.cwsei.ubc.ca/resources/tools.htm
- Course Transformation Resources: www.cwsei.ubc.ca/resources/course_transformation.htm

Workshop introduction- overview of learning principles and course design

Educational Goal of a Course.

The educational goal we are pursuing is to maximize the extent to which the learners develop expertise in the relevant subject, where expertise is defined by the thinking done by skilled practitioners in the discipline, scientists, engineers, physicians, etc. This is not to say that every learner should become a scientist or engineer, or that they could become one by taking any one class, but rather that the value of the educational experiences should be measured by their effectiveness at changing the thinking of the learner to be more like that of an expert when solving relevant problems and, most importantly, making decisions in areas relevant to the discipline. In many courses, an additional goal is to have students come to recognize the value and intellectual interest of the discipline. This is another aspect of "expert thinking" about the discipline, and hence part of the same general educational goal.

Background on Learning

Research on learning provides a useful conceptual framework for thinking about effective teaching and learning. That leads to a set of general principles as to what is important for effective instruction. This framework and these principles are illustrated in this figure and can be briefly summarized as:

• Learners must strenuously and explicitly practice the cognitive components of expertise. This includes the unique disciplinary knowledge, the discipline-specific structures by which knowledge is organized and applied, and the ways in which experts monitor their thinking when learning and problem solving.
• Students must receive effective feedback to guide their thinking while carrying out such practice.
• Students must be motivated to do the hard work required for learning.
• Instruction must recognize and build on students' ideas and existing knowledge.
• Instructional activities need to be consistent with the basic mechanisms and limitations of how the brain processes and remembers information.

Primary course components and relevant constraints on course design:

A good instructor looks at all the components a course (classes, homework, exams, etc.) and figures out how to most effectively embed these essential instructional principles into all of the components in a coherent way. In doing so, they consider the constraints and opportunities afforded by the context in which the course is situated, such as teaching space, class size, TA support, etc.

• **Learning goals.** Defined in operational terms of what students will be able to do that demonstrates they have achieved all elements of the desired mastery, both cognitive and affective. These goals should guide the design of all other course components.
• **In-class activities.** Some selection of clicker questions and peer instruction, group activities, worksheets, student presentations, lectures, and other activities to help students actively develop their understanding.
• **Homework.** Pre-class reading or other preparation assignments, problem sets, projects, papers, and other mechanisms for student to further engage with the topics at their own pace and on own schedule.
• **Assessment and feedback, both formal and informal.** In-class, grading of homework, problem solving sessions, exams, surveys, peer review and discussion, instructor-independent measures of expertise such as concept inventories, and other ways for instructors and students to gauge achievement of the learning goals.
• **Constraints and Opportunities.** These typically include the available instructional space, incoming state of knowledge of students, TA support, grading support, instructor time, technology that can be used to support instruction, etc.

In a well-designed course, the instructor will optimize the use of each component to maximize learning.
The learning goals will be well articulated and define for instructors and students the desired learning.

Pre-class preparation will allow the students to gain basic facts and information without taking up valuable class time, and prepare the students to engage more substantively in class.
Class time is the best opportunity for students to deeply engage with the material, tackling challenging problems designed by the instructor to practice expert thinking, supported by the feedback and collaborative learning with fellow students and the informed instructor.
Homework builds on and extends the ideas examined in class, as well as providing additional more individualized practice.
Exams, primarily through studying for them, help the student organize and apply the ideas covered, thereby better solidifying them, and from the study and results, gain additional feedback that can help them improve learning.

There is never enough information available to get a new or transformed course perfect on the first try, and so you should assume that at least one iteration will be required for fine and/or coarse tuning.
Typically, the first iteration of a course incorporating these principles provides enormously more information about student thinking, background knowledge, and difficulties than was previously known. This provides a guide for substantial further improvement. While some instructors create new highly effective active learning courses as a complete unit, many others are more comfortable taking a more incremental approach, adding an increasing number of active learning elements over 2 or 3 iterations of the course.

A detailed case study of a major transformation of a course (Introduction to Quantum Mechanics) is given at http://cwsei.ubc.ca/resources/files/Course_transformation_case_study.pdf.

The Nature of Expert Thinking and How Novices Differ

A basic educational goal is to have students learn to make relevant decisions more like an expert in the subject they are learning. Here we summarize features of expert thinking. Experts in a subject not only have a lot of knowledge, but they have a complex mental framework by which all this knowledge is organized. This organizational structure is common to the discipline and is structured around use. This allows the expert, when faced with a new problem, to decide if the problem is likely to be soluble and to quickly and efficiently decide what knowledge is relevant and useful and which is not. In science and engineering fields, expert knowledge tends to be grouped in terms of fundamental concepts and predictive mental models, where each is identified by the key underlying structural features and their relationships that a given problem context must have for that concept/model to apply, independent of the various surface features of the situation. When faced with a problem, the expert looks at the underlying structure, and on that basis selects the models and associated solution methods to apply. If the problem matches exactly to a single model, and all the information needed for a solution is given, then it is an exercise, not a "problem". The expert can automatically invoke a well-known solution procedure with no further decisions, and hence little additional thought, required.

For a more authentic problem, the expert will make a series of decisions in solving the problem. We see these decisions as largely the same across disciplines, but how the decisions are made is quite specific to the knowledge and reasoning of the discipline. The expert will start by selecting what model(s)s could apply, and on that basis decide what approximations or simplifications are appropriate, how to decompose the problem into separable pieces, what information is needed to test the models, etc. They will then prioritize and efficiently seek out the most useful additional information. The additional information and subsequent conclusions are evaluated in terms of the competing models. Typically, the various models come with associated solution procedures/explanations/treatments applicable to that model, and so as the number of possible models is narrowed down, these solution procedures are applied. Finally, when an answer/conclusion is reached, there are a set of discipline-specific criteria the expert uses to test for "failure modes", including if the answer is reasonable.

During this process, the expert will be monitoring their understanding and progress. They will choose a new alternative if the original approach appears unproductive. They will also invoke multiple representations of the problem and the information gathered, typically using discipline-specific representations that have been found particularly useful for visualizing and identifying important features. Experts also have acquired rapid and accurate execution of frequently used procedures. Although it has not been exhaustively tested, current evidence and common sense strongly suggests that the most effective way to learn expert decision making is to practice making those decisions in authentic problem scenarios, with guiding feedback as to how to improve.

Research has identified specific differences between experts and novices. Experts have:

- Rapid and easy retrieval of relevant information from memory; novices tend to remember piecemeal, making search and retrieval difficult
- Fast reasoning through a chain of possibilities; novices jump to conclusions without checking what makes sense.
- Recognition of data, ideas, or conclusions that match or conflict with prior knowledge; novices often do not recognize they are living with a contradiction.
- Efficient integration of new information related ideas into existing mental structure; novices have no structure and so just memorize new ideas.
- Experts perceive underlying structure in problems that guides them in solving; novices are distracted by irrelevant surface features and miss important structure
- Spend time to organize cases and evidence to find structure; while novices tend to "dive" into a task without organizing the information.
- Experts monitor their progress and thinking and recognize when to revise; novices do not.
- Experts check their answers using specific criteria; novices fail to check answers

First Day of Class – Recommendations for Instructors

CWSEI, 2014

Set the Environment

The first day of class can have a large influence on students' perception of the entire course. By the end of the first class, you want students to have a good sense of why the course is interesting and worthwhile, what kind of classroom environment you want, how the course will be conducted, why the particular teaching methods are being used, and what the students need to do (generally) to learn material and succeed in the course. It is also important to give the students the sense that you respect them and would like all of them to succeed.

Establish Motivation

Provide an entry-level preview of the course material and explain why the course material is important & interesting. Avoid jargon as much possible. Where applicable, make connections to:

Real world/everyday life

What students know

What students will need to be successful in future studies or career

What students are interested in, current events, …

Personalize the learning experience

Welcome students to your class – make it clear that you are looking forward to working with them.

Introduce yourself, including describing your background and interests in connection to the subject, e.g.:

Why you find it interesting and exciting for them to learn

How it applies to other things you do (research, …)

[Students—especially those majoring in the subject—say it is inspiring to hear about the instructor's background and research, and how it is relevant to the course.]

Introduce teaching team

If applicable: TA's and anyone else involved that students will be interacting with (could show pictures or have them come to class)

Make an effort to find out who the students are and their expectations, motivations, and interests, e.g.:

Ask them a series of questions about major, goals, background, … (perhaps use clickers or a survey)

If appropriate, ask them to introduce themselves to other students they will be working with. [note: use with caution; some students say it makes them uncomfortable if used as a general "icebreaker", but it is appropriate to introduce themselves to group members with whom they will be working]

Establish Expectations (best if also handed out and/or online, not just spoken)

Describe overarching (course-level) learning goals—big picture view

Emphasize that you want them to learn and your role is to support their learning

Explain how course will be conducted, what will happen in class, expectations for out of class work, overview of schedule, and marking scheme

Explain why you're teaching the way you are teaching, how the different components support their learning (especially important if you are teaching differently than most other courses are taught);† e.g.:

Teaching methods based on what is known about how people learn

Students need to play an active part and be intensively engaged in the learning process, …

Describe (generally) how to succeed in your course

Learning and improvement take practice and effort; as well as good feedback.

A good activity is to tell students: "1. Think of something you are really good at. Write it down (you don't have to share it with anyone). 2. Now, in one or two words, describe how you got to be good at that thing. 3. On the count of 3, shout out how you got to be good." The overwhelming word shouted will be "PRACTICE". Then talk to them about what kind of practice is the most effective for mastering the material in this course.

Give general description of how assessments are used for both feedback and marks, leaving details to be read on course ebsite

Give advice on how to study

Express that you feel they can succeed if they put in the effort

Details (syllabus, detailed schedule, detailed learning goals, academic conduct, deadlines, rules …)
Don't go into details during first class; give links to more details on course
Could give an assignment involving reading these.

Other Tips

Good practices	**Avoid**
Check out classroom before first class (avoid technical problems)	
Start class on time (sends message that you expect them to be on time)	
Telling students you think they can all succeed if they put in the effort (fine to say the course is challenging, as long as also express that it is interesting/worthwhile and do-able)	Telling students threatening things such as: you expect some to fail; or lots of students don't like the course and/or have found it very difficult
Address academic conduct in context throughout course (e.g. talk about plagiarism when you are giving a writing assignment)	Emphasizing rules and penalties first day (sends message of distrust, and they're not listening anyway)
Provide students with some experiences that give a sense of what future classes will be like	Talking the entire class time
End class on time with slide containing pertinent info (your name, office hours, contact info website, homework, …)	Ending class early

In future classes: reinforce these messages periodically in the appropriate context.

[†] For examples, see *Framing the Interactive Engagement Classroom:* www.colorado.edu/sei/fac-resources/framing.html

What <u>Not</u> To Do; Practices that should be avoided when implementing active learning

CWSEI, 2013

We and others have written about how to implement active learning in the university classroom, but we have noticed some practices by well-meaning instructors that we feel should be avoided. The numbered items are generally applicable to all types of active learning; there are a few clicker-specific items at the end of the table.

	Don'ts	**Comments**
1	Don't use active learning without giving students insight into why you are teaching this way	It's important that students feel that the active learning techniques you are using are to their benefit. Some instructors will explain to their students why they are teaching this way (e.g., that research shows that people learn much more when they are actively engaged...), and others will engage students in discussion about their experience in a particular activity. If you don't address this, students may conclude that you are using less effective techniques or that you are experimenting on them; this can cause resentment and low engagement. It is also good to briefly remind students of the benefits periodically during the term.
2	Don't immediately tell the students the answer and/or explanation	It is usually best to let the students discuss, and then have them share their reasoning with the class.
3	Don't leave activities unresolved	It is important for the students to hear your expert perspective and reasoning. The activity has prepared them to learn from your explanation. Even if you think all the important aspects have come out in the class discussion and/or a large fraction of the students have the correct answer, it is important for you to do a clear and explicit follow-up.
4	Don't forget to make students accountable	Some approaches to building in accountability are: Have the students turn something in (such as a worksheet with all the group members' names on it), use some clicker questions at key points and/or to follow-up on the activity, have random (or all) groups present their results, etc. Ensure that clickers are tied to student IDs.
5	Don't have an activity that is not clearly targeting specific learning goals	Activities take time, and therefore should be targeted to important learning goals.
6	Don't overlook motivation	People are much more willing to expend effort if they are intrinsically motivated to do so. It is good to set an activity in a motivating context (e.g. a context that is interesting and relevant to the students).
7a	Don't stay in one location of the room during group discussions	By circulating around the room, you can get a better sense of student thinking about the topic (particularly their difficulties and/or misconceptions), and also encourage them to engage in the activity.
7b	Don't spend too much time with one student or group during an activity	Instructors can easily lose track of time when talking with students. This has 2 detrimental effects: you don't get the benefits of circulating around the room (7a), and many students may become disengaged.
8a	Don't give too many instructions at once and/or make an activity overly complicated	While it is good to make an activity cognitively challenging, introducing too many complications at once adds cognitive load and will confuse and distract students from concentrating on the main goals.
8b	Don't make the activity too easy	Trivial clicker questions or activities that have students blindly following steps or repeating memorized facts are a waste of time. Make activities sufficiently challenging so that most students need to discuss and use reasoning to complete them. Consider adding "bonus" questions or problems to keep the high achieving students engaged.
9	Don't expect things to go perfectly the first time you run an activity	If you are running an activity that is new to you, or with a significantly different group of students, it often will not go as planned. Be flexible and modify the activity as needed for the next time. If possible, it is very helpful to test activities in advance with a small group of students and/or discuss it with teaching assistants and other instructors.
10	Don't bite off more than you can chew	Don't try to do more new things in the course than you have time and resources to prepare. You can end up feeling overwhelmed and discouraged. Also, students are usually quite tolerant of an activity that does not go perfectly (#9), but far less tolerant when instructor is obviously disorganized and poorly prepared.

11	Don't forget to clearly indicate the start of an activity	Students will often wait for a signal before starting an activity. Instructors can be expecting the students to start discussing in groups, without realizing the students are waiting for a "Go" signal.
12	Don't lock into a rigid timeline	It's important to be flexible. It is hard to predict the time needed for an activity. Cutting off an activity too soon will leave students frustrated, and going too long will bore students and waste time. Don't use a timer for cutting off clicker responses, instead rely on your judgment.
13	Don't wait for every student or group to finish	Apply the "75% rule" for clicker votes. If 75% of the students have clicked in, announce that you will be closing to vote soon (e.g. in 10 seconds). For any group activity, you can get a sense of students' progress as you circulate. In longer activities, it is good to have check points where you bring the class into sync.
14	Don't attach high stakes to activities	Accountability is necessary, but assigning a large amount of marks for correctness causes students to seek the "right" answer without worrying about why it is right. Instructors typically give participation points for students who did the activity. If you give marks for correctness, keep this at a low level.
15	Don't embarrass individuals	Be careful in how you react to student statements, particularly if they say something wrong. When calling on individuals, it often is more comfortable for them if you ask them for their *group's* reasoning.
16	Don't get stuck using only one strategy	In order to achieve different types of goals, use a variety of types of activities; if you use clickers, use a variety of question types. Design activities to elicit student reasoning.
17	Don't make comments in advance about the difficulty of activity	Saying things like "I think everyone knows this" or "This should be an easy one" – you are just making them feel stupid if they don't think it's easy. Also, if you think it is very easy, why use class time on it?
18	Don't rely too much on comments by individual students, or solely on student self-reports about their learning	When there are a few outspoken students, it is very easy to jump to the conclusion that their views are representative of the entire class, but that's often not the case. Use surveys of the entire class or more extensive sampling. Also, student self-reports of what and how they are learning are often inaccurate. Although you should not ignore self-reports, before acting on them you should confirm with other evidence.
19	Don't be afraid of a silent moment	Students need time to think after being asked a challenging question.
Clicker-specific Don'ts		
	Don't leave out the peer discussion	Using clickers is not good in itself, it is *how* you use them that matters. Peer discussion has been shown to increase student learning, particularly for reasonably challenging conceptual questions.
	Don't show the first vote histogram if you plan to have the students vote twice	In Peer Instruction, students first vote individually and then discuss the question in small groups and vote again. Showing the histogram after the first vote biases the students toward the answer that got the most votes. You can always give a verbal characterization, such as "the vote is split between several options".
	Don't stop the vote collection without warning	Students will rush to put in an answer if they think you might cut off the vote without warning.
	Don't go into 'police-mode' for catching students with multiple clickers or not participating enough	Talk with individual students if you see that they are clearly off-task or have multiple clickers (doing the voting for students who are absent), but don't make it a big focus. It needlessly distracts the rest of the class.
	Don't limit yourself to questions with only one right answer	Some of the best peer discussion and whole-class discussions are around questions with more than one defensible answer. For example, you could ask "which is the best answer" or "which is the most efficient method". In the follow-up discussion, you could ask students what would have to change about the situation to make a particular answer the "best".

Further resources: www.cwsei.ubc.ca/resources
(includes materials developed by CWSI

Better Ways to Review Material in Class

by Carl Wieman, 2014

A substantial amount of class time is spent reviewing material from previous courses or the previous class meeting. It is very common for instructors to give such review lectures that can occupy one or more classes at the beginning of a term, and/or 5-10 minutes at the start of each class. When we had trained observers at UBC watching the attention of students during classes, it revealed that this form of review was less than useless. Rather than helping students improve their memory and understanding of the material, it primarily diverted their attention to thinking about things other than the class they were in, and this made it harder to get them reengaged when new material was being covered. In retrospect, it is easy to understand why this method of review fails. There is a very well established result from cognitive psychology that familiarity with a topic makes people erroneously believe they understand it. When a person is being lectured on something they believe they already know, they will become quickly bored and start thinking about other things (or checking email, etc.). This means that students who have previously heard about the topic being reviewed will probably not pay attention, and those students who are not familiar with it will probably quickly get lost in the rapid review.

The better way I found to do review is to replace ALL review lecturing with problems that the students solve in class that cover the material I want to review. This is particularly easy to do if they have clickers. Doing a problem gets them actively thinking about the relevant material and testing their understanding. If they get the problem wrong, and often even if they don't, they are then primed to ask questions and listen to responses and explanations to learn why. Also, if there are things that everyone in the class already knows, I can see that immediately from their problem solutions or clicker responses, and can quickly move on and avoid wasting class time talking about that topic. That leaves more time to spend on the topics where many struggle with the relevant review problem.

A final benefit is that I end up with a good idea of what topics individual students, and the class as a whole, have and have not mastered. As I move on to the subsequent material, I have a vastly better sense of their state of mastery than I previously got from review lectures, and can tailor instruction more effectively.

Another review method: two-stage review

An alternative review format to use at the start of a course is a two-stage review.[1] This has similar and possibly greater benefits. Give the students a quiz in class that has the review problems on it, have them do it individually and turn it in, and then have them do a group quiz in groups of 3-4 and turn in 1 answer sheet per group. The resulting discussion will provide nearly all the students with the primed and targeted review that they need. The instructor will then only have to worry about dealing with those students whose individual tests indicated they have seriously deficient backgrounds, and dealing with those topics where there are widespread deficiencies. During the group test portion, the instructor should listen in on the various group conversations. That is likely to reveal any widespread difficulties that can then be immediately addressed after the completion of the group test. There would also be a variety of more subtle benefits to this exercise having to do with classroom dynamics, and, as mentioned above, the instructor will know much more about their students' prior knowledge as they move on to subsequent material.

There is a fear that starting the first day with a difficult test will set the wrong tone for the course, so it is best to introduce the two-stage review with a statement like: "This is a carefully designed set of practice problems for your review and discussion, to help you prepare for the upcoming material. This will have no influence on your course grade, except in that they may help you to be better-prepared to do well in the course."

A two-stage review was implemented in a UBC science course in the spring of 2014. The 3rd year course built on topics covered in the 2nd year pre-requisite course, but the instructor knew that the students had a variety of backgrounds in that material. Overall, the experience was very positive for the students and instructor, and the instructor learned of some misconceptions that many of the student had.

[1] The two-stage review is patterned after the successful two-stage exams now used in a variety of science courses at UBC. See: *Examinations That Support Collaborative Learning: The Students' Perspective*, G. Rieger & C. Heiner, Journal of College Science Teaching, Vol. 43, No. 4, pp. 41-47 (2014) and references therein (www.cwsei.ubc.ca/SEI_research/)

Teaching Expert Thinking

(Wendy Adams , Carl Wieman, and Dan Schwartz,)

Experts and novices differ:

The study of differences between experts and novices has revealed important distinctions in how they organize and apply their existing knowledge and how they learn new ideas.

- Experts have a mental framework for organizing their knowledge while novices do not have such a structure. Experts exhibit:
- Effortless retrieval of relevant collected facts from memory.
- Novices tend to remember piecemeal.
- Fast reasoning through a chain of possibilities.
- Novices jump to conclusions without exploring what makes sense.
- Recognition of data, ideas, or conclusions that conflict with prior knowledge.
- Novices often do not recognize they are living with a contradiction.
- Efficient integration of related ideas.
- Novices tend to memorize new ideas rather than integrate them.
- Experts also have developed abilities to perceive structure in evidence or situations. They:
- Notice relevant structure that cues them to next steps.
- Novices miss "obvious" cues that should trigger a new line of thought.
- Recognize whether disparate instances have the same underlying structure.
- Novices tend to organize examples based on surface features.
- Spend time to organize cases and evidence to find structure.
- Novices tend to "dive" into a task without organizing the information.
- Identify empirical discrepancies that can drive the high effort of idea revision.
- Novices do not recognize when it is time to revise their ideas.

How do we put novices on a trajectory to expertise?

Just telling students the expert knowledge seems like an efficient way to teach, but it is efficient because it is a shortcut. The price of the shortcut is that students do not develop integrated knowledge structures. This leaves them with the novice characteristics listed above. Telling students is much more effective if they have already engaged in investigating the structure of a phenomenon or idea. Instructors need to avoid the blind spot of assuming that what is obvious structure for them exists for the student. Investigating the structure does not mean solving a series of discrete or step-by-step problems, because students will treat each step as a separate exercise. Instead, one proven way to get students to explore structure is to have them complete "invention" activities. Students receive a set of carefully selected cases, and their task is to invent a compact description that generalizes across the cases. Students do not need to discover the correct answer. Rather, the invention task helps students notice important structure in the cases and to form an organizational framework that prepares them to understand conventional descriptions. After this task, students can be told the expert knowledge. The added benefits of the invention-then-telling approach do not always show up on routine exercises, of the sort given on most exams (though it doesn't hurt). However, strong differences are evident when students are given more expert-like tasks that include learning new related ideas and applying their knowledge to new situations (Schwartz, et al. 1998; 1999; 2005).

A good invention task has specific characteristics:

Clear goal: The task should present a clear, challenging goal of trying to develop a compact and consistent description or representation of the "important features" across the cases.

Typically, the description entails integrating several features in one representation (e.g., a ratio):

Find an index for pieces of wood that will allow you to predict if they will float or sink,

Create a graph that you think displays the important patterns from the experiment.

Design a cell membrane that allows certain substances to pass through but not others. Test of goal: Is the goal consistent with the sort of thing an expert does when trying to describe novel findings?

Contrasting cases: The task should include multiple cases simultaneously, so students notice structure and structural variations that transcend superficial differences.

Cases should systematically vary on key parameters so students try to see how these variations relate at a deeper, structural level.
Two to four contrasting cases provide a reasonable level of difficulty.
A single case works too, if students will spontaneously generate contrasting cases.
Test of cases: Are the cases structured so that a reasonable (but wrong) description based on just one or two of the cases would fail to work for the rest?

Context: The task should involve things relatively familiar and meaningful to the students.
Students should recognize, maybe with help, when a description does not work for a case.
Test of context: Does the task and cases make sense to the students?

Level of difficulty: Students should have partial success, even if they do not come up with the solution that took experts centuries to discover and covers all cases.
When teaching complex ideas, use multiple activities that are each limited in scope.
Each contrasting cases activity should introduce one or two new structural parameters.
Test of difficulty: Can the students always get started but seldom find perfect/complete answer?

Avoid jargon: these trigger the common "What was that formula we learned?" response, rather than, the "This is new task" response. For example, in the wood task, avoid the term density.
Test of terminology: Will students not try to use some process they have learned or can look up?

Design cycle: Try with a few students first and modify as needed before using with a class. Test of design: Do they slowly begin to notice and try to represent the key structures that an expert can see easily in the cases?

Collaboration: invention activities work best when done by pairs of students.
Test of collaboration: Do students make comments to each other like, "But, look here, would that work here, for this one?!", rather than dividing up the task and working independently?

A 5-page version of this document with references and examples of invention tasks is available at http://www.cwsei.ubc.ca/resources/instructor_guidance.htm

REFERENCES

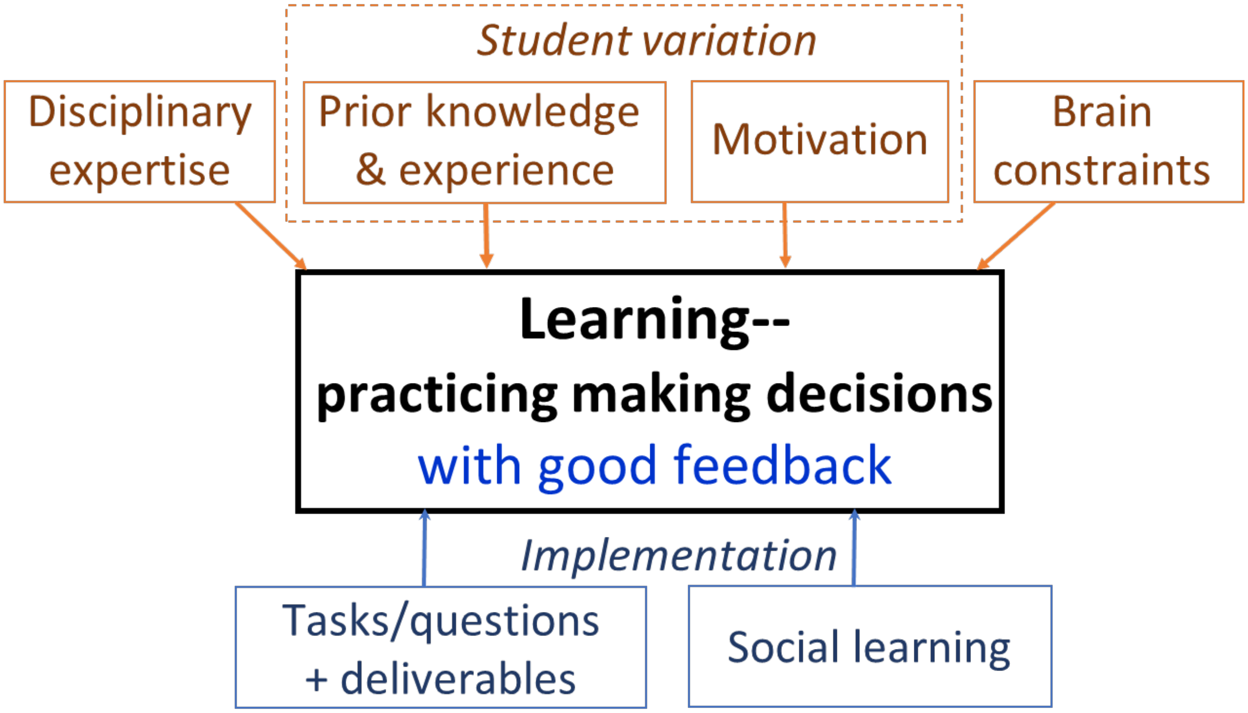
Bransford, Brown, and Cocking, How People Learn; Brain, Mind, Experience, and School, NAS Press, 2000. Chapters 2 and 3 provide a good general introduction to what is known about expert novice differences in thinking and learning.

Schwartz, D. L., Bransford, J. D. and Sears, D. (2005). Efficiency and Innovation. Transfer of Learning from a Modern Multidisciplinary Perspective edited by Jose Mestre. Information Age Publishing; North Carolina (1-52).
This paper considers a new focus on the type of assessment used to evaluate transfer. Two types of assessment are described that help explain the apparently contradictory views of transfer literature. Sequestered Problem Solving (SPS) is the typical type of assessment we usually give on exams. PFL offers new information to the students on the exam and then tests if they learned the new information. There is also a theoretical description of innovation versus efficiency.

Schwartz, D. L., Lindgren, R. and Lewis, S. (2008). Constructivism in an Age of Non- Constructivist Assessments. Constructivist theory applied to instruction: Success of failure? Tobias, S. and Duffy, T. (Eds.). Taylor Francis.
Provides a nice description of how students construct their own knowledge. It describes why invention activities are an effective way to create a mental framework for a specific concept before student learns the facts and procedures about the concept. It explains why providing the facts and procedures first "short-circuits" the learning process.

Wineburg, S. (1998). Reading Abraham Lincoln: An Expert-Expert Study in the Interpretation of Historical Texts. Cog. Sci. , 22 (319-346). Shows the expert-novice difference in tackling new material. This paper shows how an expert handles a new problem in a related field (not their field of expertise) compared to how novices (high school students) handles the same problem. The historians expressed doubts about their interpretations and appending strings of qualifications to their conclusions. The students quickly formed interpretations and typically never looked back.

Overview of deliberate practice and elements that enable activities to be effective



The rectangle at the center represents "deliberate practice", the learner practicing the very specific thinking processes that are to be learned, typically problem solving decisions. During that process they are getting timely, specific, and actionable feedback on how to improve and reflecting on their progress. Feedback is usually coming from combination of fellow students and informed instructor.

While deliberate practice is essential for learning, there are many other factors that are important to enable the deliberate practice to be effective:

- First and foremost, the tasks they are practicing must involve the components of thinking and decision making used by an expert in the discipline (when working on a corresponding task). These should be sufficiently challenging so at least some parts will not be readily mastered by the students even working unassisted in groups. However, they should be structured so all students can become engaged with the problem and make some practice, and grasp the key difficulties so they are primed to learn from later guidance from instructor
- It must recognize and connect with learner's previous knowledge and experience
- the nature of the task and rewards must motivate the learner to put in the serious effort required

Both of these two will vary across individual learners and groups of learners, requiring information to be gathered and likely iteration and modification, often in real time during class, as the instructor develops better understanding of learners and their specific learning challenges.

- The brain can only pay attention to a very limited set (5-7) of new items on short time scales, such as the length of a single class. More brain capacity is available for learning if the number of new items, "cognitive load", is limited, for example by not introducing lots of new jargon or ideas into a given practice activity.
- Additional individual practice of specific elements (homework, study, …) is required for the learner to achieve mastery.

Assessments That Support Student Learning

CWSEI, updated 2014

Key points and factors from the review paper "Conditions Under Which Assessment Supports Student Learning," by G. Gibbs and C. Simpson[1]

<u>Key points</u> (extensive references to data supporting all these points are listed in the original article)

From the students' point of view:

What is tested in a course dominates what students think is important and what they do.

Effective feedback is the most powerful single element for achieving learning. Feedback that is not attached to marks can be highly effective.

Students who focus on picking up cues as to what will be on exams and study accordingly do much better than those who do not. Students often realize this form of studying is not the same as studying to master (i.e. understand and apply) the course material.

Students prefer courses with a significant marked assignment component, feeling that such courses provide them with more practice and feedback, and the assessment is fairer.

Marked assignments versus exams:

Much assessment fails to engage students with appropriate types of learning.

Exam scores correlate very weakly with post graduate performance. Scores on marked assignments are better predictors than exams of long term learning retention.

When assignments are a significant fraction of the course mark, the failure rates are 1/3 what they are when course mark is based solely on exam scores. Students also study and learn in more naïve ways when mark is based solely on exams. Although not in Ref. 1, there are techniques to minimize cheating on such marked assignments.[2]

<u>Factors that make assessments contribute to learning</u> (and are frequently neglected)

Assigned and assessed tasks that:

are focused on the most important aspects of the course (tied to learning goals),

require extended time to complete,

are given frequently,

engage students in appropriate forms of study/effort.

Students need to have a clear concept of the assigned task and of learning in the discipline. The criteria for setting the mark on the assignment needs to be explicit and understood by the student.

The single most important element of assessment supporting learning is the frequency and type of the feedback provided with the assessment. Feedback that supports learning:

is frequent and sufficiently timely to the task so that it still matters to the student

focuses on student performance and learning, rather than student characteristics

is specific and detailed, addresses small chunks of material, and provides guidance for future efforts

matches the purpose of the assignment and encourages the student to improve

is supported by mechanisms that require the student to attend to and act upon the feedback

<u>Implementing good assessment and feedback without spending excessive time marking</u>

It is particularly challenging to have frequent assignments and timely feedback in large-enrollment classes. Below are a few examples of ways to do this.

Online, computer graded homework. There are numerous systems for this. (Instructor needs to generate or find source of good multiple-choice questions, many systems provide these.)[3]

- Problem-solving sessions associated with quizzes or homework. This could be informal (groups of students voluntarily get together to work on problems with or without TA or instructor present) or formal (tutorial, recitation, workshop with TA and/or instructor using Socratic approach).
- Peer Instruction:[4] during class pose questions, student discussions about which answer is correct, vote on answer, instructor does short lecture on which answer is correct & why. Works in large lecture halls (This moves the feedback part into the classroom and shares it between students and instructor. Some coverage of material is moved from lecture to assigned reading.)
- Regular in-class group exercises done in stages that include partial deliverables (sketches, lists, worksheet answers, etc) which are discussed in class. Simply working in groups provides "instant" peer feedback (as above), and the whole class benefits from feedback that results from the instructor-led discussions at intermediate stages of the exercise.
- Just-In-Time Teaching:[5] Web-based assignments due a short time before class, followed by discussion/lecture focusing on areas of student difficulty (often involves adjustment of teaching based on responses, for large classes, instructors usually go through a subset of the responses). Can also be implemented as quiz at start of class with electronically collected responses.
- Have some long-answer or essay-type questions on assignments, but only grade some of these (important to be clear to students that they will get some credit on a problem for turning something in, and a subset of those problems will be graded for marks – students won't know in advance which questions will be graded)
- Have multistage assignments with feedback in the middle that students need to use to complete assignment (way to get students to act on feedback)
- Peer assessment (important for instructor to provide good marking rubric). Imperfect feedback from a fellow student provided almost immediately can have much more impact than more perfect feedback from an expert many weeks later. Students learn a lot by *doing* peer assessments – particularly when done as a group activity.[6]
- Self assessment or reflection assignments (e.g. have students grade own work using a rubric created by instructor, or have students go over a problem from previous assignment that they got wrong and explain what they did, and why it was not the correct approach.)
- 2-Stage exams:[7] students do the exam individually first, turn their answers in, and then repeat the exam in groups. Students get timely feedback from each other and learn from the exam via reasoning with peers. They usually do significantly better on the group part vs. the individual part.

<u>The bottom line?</u>

Teaching students to monitor their own performance should be the ultimate goal of feedback.[1] Continuous support for improving these skills will help students transfer learning to new situations and become effective lifelong learners.

[1] G. Gibbs and C. Simpson, "Conditions Under Which Assessment Supports Student Learning," Learning and Teaching in Higher Education, V. 1, pp. 3-31, (2004), http://www.open.ac.uk/fast/pdfs/Gibbs and Simpson 2004-05.pdf

[2] Effective techniques are designing assignments to be of obvious benefit to the learning of the student, have substantial overlap with the exams, and have some portions of the assignment that involve "explaining in your own words".

[3] S. Bonham, "Reliability, compliance, and security in web-based course assessments," Physical Review Special Topics - Physics Education Research V. 4, paper 010106 (2008).

[4] C. Crouch and E. Mazur, "Peer Instruction: Ten years of experience and results," American J. Physics, V. 69, pp. 970-977 (2001).

[5] See: http://jittdl.physics.iupui.edu/jitt/

[6] K. Topping - Review of Educational Research, V. 68, No. 3, 249-276 (1998), http://rer.sagepub.com/cgi/content/abstract/68/3/249

[7] B. Gilley & B. Clarkston, "Collaborative Testing: Evidence of Learning in a Controlled In-Class Study of Undergraduate Students," J. College Science Teaching, V. 43(3), pp. 83-91 (2014); G. Rieger & C. Heiner, "Examinations That Support Collaborative Learning: The Students' Perspective," J. College Science Teaching, V. 43(4), pp. 41-47 (2014).

Two-Stage Exams

CWSEI, 2014

In a two-stage exam, students first complete and turn in the exam individually and then, working in small groups, answer the exam questions again. During the group part students receive immediate, targeted feedback on their solutions from their fellow students and see alternative approaches to the problems. This makes the exam itself a valuable learning experience[1] while also sending a consistent message to the students as to the value of collaborative learning. In the numerous implementations at UBC, students are always highly engaged in spirited discussion during the group part of the exam. This exam format was first introduced in the UBC Faculty of Science in 2009 and is now being used in at least 20 science courses.

We have found that students' response to the use of two-stage exams is overwhelmingly positive. In response to a survey, 87% of the students recommended continued use of two-stage midterm exams and only a few percent recommended against their use.[2] Some student quotes indicate what they found useful about the exams:

> *"I was able to instantly learn from my mistakes."*
>
> *"Interesting. All had different ways [of] approaching the question. Very helpful to understand everyone's response and why they thought their answer was correct."*

Implementation

Two-stage exams can be easy to implement and have worked well in many UBC science courses.

Stage 1: Individual, between 2/3 and 3/4 of the examination time; a standard formal examination that students complete working alone.
Stage 2: After students turn in their individual exams, small groups solve similar or identical problems during the remainder of the examination time.

Generally the switch between the individual and group stage can be done in less than 5 minutes, even in large classes, if there is at least one instructor or teaching assistant for 50 students. The CWSEI has produced a short video showing logistics of a two-stage exam in a large class.[3]

The group portion begins after all individual exams are collected. Students work in groups of three or four on (mostly) the same problems as in the individual portion. They must come to a consensus on the answers and hand in one copy with the names and student ID numbers of all group members. Since the students have already worked on each problem during stage 1, solving the same problems again in stage 2 usually takes much less time – including the time for discussions and agreeing on a solution.

Strategies that have worked well:

Good practices	comments
Explain to the students why you are conducting exams this way	Tell students on the first day of classes that examinations will be conducted in this format and, more importantly, why this is done in this way.
Make exam about 2/3 as long as you would for a normal exam	Timing: have the individual part take up about 2/3 of the total time (e.g. 50-55 min out of an 80 min slot). It is more challenging to do a two-stage exam in a 50 min slot, but it is doable.
Give the majority of the exam score for the individual part	Typically weight 85-90% for the individual portion, and 15% to 10%, respectively, for the group portion.
Assure students that their overall exam score will not go down due to the group part	Implementing a policy that a student's grade cannot be lower than the individual score addresses concerns about fairness. In practice, it affects only a few high-performing students, as groups perform equal or better than individual students in almost all cases.

Give clear instructions	Clear instructions need to be given during the individual-to-group transition. For example, students should remain seated while their individual exams are collected. Remind and check that all names and student numbers are listed on the group exam.
Have a well-defined plan for managing the switch between individual and group parts	The switch can be done in less than 5 min; best to have at least one instructor or TA per 50 students. A short video showing logistics in a large class is at: http://blogs.ubc.ca/wpvc/two-stage-exams/.
Group size of 3 or 4 students	If groups are too large, there will not be enough time for each student to have their say, and it may be harder for groups to come to consensus. On the other hand, groups of 2 students will not have as much diversity of strategies.
Give out only one exam per group	It is very important that each group gets only one exam; they must come to consensus on their answers. If each student has their own, they give up on discussion too easily and don't correct their errors.
Various approaches for group part can be used	Examples of approaches that have been successfully implemented: 1. Repeat entire exam 2. Repeat subset of questions (e.g. the most challenging ones; conceptual questions work well) 3. Turn open-ended questions into multiple choice or ranking tasks 4. Add a more challenging question that wasn't on the individual part
A variety of question types can be used	Two-stage exams work well with any question type except for longer essay type questions and lengthy calculations. Most other types of questions are short enough or structured such that everyone can contribute.
Discourage students from working alone during group part	TAs and instructors can help with forming groups. Encourage all group members to be involved in discussing every problem.

It doesn't take much effort to run a two-stage exam; creating the group portion of the exam is easy because it is very similar or identical to the individual exam. The additional grading time of the group exams is short because there are fewer of them and most solutions are correct. This exam format is very popular with students; they appreciate the value of the immediate feedback and the learning that results from it.

[1] B. Gilley & B. Clarkston, Collaborative Testing: Evidence of Learning in a Controlled In-Class Study of Undergraduate Students, J. College Science Teaching, 43(3), pp. 83-91 (2014), www.cwsei.ubc.ca/SEI_research/files/Gilley-Clarkston_2-Stage_Exam_Learning_JCST2014.pdf.

[2] C. Wieman, G. Rieger, & C. Heiner, Physics Exams that Promote Collaborative Learning, The Physics Teacher, 52, pp. 51-53 (2014), www.cwsei.ubc.ca/SEI_research/files/Physics/Wieman-Rieger-Heiner_Two-Stage-Exam_PT2014.pdf; G. Rieger & C. Heiner, Examinations That Support Collaborative Learning: The Students' Perspective, J. College Science Teaching, 43(4), pp. 41-47 (2014), www.cwsei.ubc.ca/SEI_research/files/Rieger-Heiner_2-stage-Exams_JCST2014.pdf.

[3] Video (7.5 min): A two stage, 50 minute midterm exam for 300 students; excerpts with commentary, http://blogs.ubc.ca/wpvc/two-stage-exams/

Motivating Learning

Student motivation is probably the single most important element of learning. Learning is inherently hard work; it is pushing the brain to its limits, and thus can only happen with motivation. Highly motivated students will learn readily, and make any class fun to teach, while unmotivated students will not learn and will make teaching painful. Fortunately, research shows that there is a lot an instructor can do to motivate their students to learn.

It is important to recognize that motivating learning is a central element of good teaching. Often, it is assumed that university students should be motivated to learn in every class, but that is not a reasonable expectation. Course requirements, assignments, and exams exist because students do not yet have the experience and wisdom to recognize which courses to take and what activities they need to complete in those courses to achieve appropriate educational goals. For the same reason, a student cannot be expected to come into every course motivated to learn the material. If a student does not know the material in a course, how can they know it is important and fulfilling to learn? The instructor, an expert in the subject, is uniquely qualified to show students why the material is important, intellectually interesting, and valuable for them to learn. Conveying this message is an important goal of any effective instructor.

What can an instructor do to motivate their students to learn? This is a subject that has been widely studied, and two excellent references are given below. While individuals vary, there are three elements that are consistently relevant to the motivation to learn: personal relevance, some control of the learning process, and a sense that one can master—and is mastering—the material.

Personal relevance & interest:

First, the material must be seen as personally relevant, interesting, and/or useful to the learner. The emphasis and challenge here is on “to the learner.” That means recognizing the students’ backgrounds and experiences and aspirations, and finding ways to connect the material to those. What you see as interesting may not be interesting for many of your students. In practice, making the material relevant usually means finding ways to present it in terms of authentic real world situations and problems that the students can relate to. Showing how the material will be used in careers that they aspire to is also motivational. Rather than first introducing a lot of formalism and jargon, and then at the end showing how it can be applied to solve some meaningful problem, do it the other way around. Present the problem first, and then introduce the formalism as the way to solve the problem. Make sure that your assignments do not leave students wondering, “Why would anyone (besides my teacher) *care* about the answer to this problem?”

The attitude you convey about the subject is also important. Tell the students why you find the subject interesting. While it is good to show that you are enthusiastic and excited about your subject, it is even better to find ways to convince your students that the subject is interesting. What a person finds interesting is shaped by their knowledge and past experiences. Don’t assume that because you see the material as interesting, the students should as well (and if they don’t, there is something wrong with them).

Choice and control:

A second almost universal motivating element is for the learner to feel they have some degree of control over the learning process. Relatively modest amounts of control or choice can make a large difference in motivation. Obviously, there are many elements of a course where you, as the expert, should be determining the choices. However, look for other areas where the students can decide. For example, allowing some choice over assignment topics or formats, and having projects where the student can choose a topic of particular interest to them.

Sense that one can master the material:

The third general motivating factor is providing the learner with a sense that they can master the subject, and that they understand the process to follow to achieve that mastery. These are best addressed by having suitable levels of challenge in the course and providing clear feedback as to how well students are meeting those challenges. Assignments that the students see as challenging, but they can then also see they successfully completed (and as a result now have capabilities and knowledge they previously did not have), are highly motivating. It is also important that the feedback and grades are aligned with the course goals. It is demotivating for a student to feel they worked hard and mastered the material in a course, only to do badly on an exam because it was highly dependent on knowing some solution trick that was quite peripheral to the course as a whole.

The feedback that best motivates learning is that which stresses the importance of effort and the specific processes and strategies for learning. Feedback and grading that focuses on what the student has mastered, and how they can improve, is more motivating to most students than feedback that focuses primarily on their standing relative to their peers.

Failure to adequately address student motivation has important consequences for students from groups under-represented in the field of study. If the instructor ignores motivation, the students who are most likely to see the subject as worth learning are those whose backgrounds, and corresponding attitudes, are most like that of the instructor. Those students whose backgrounds are different, which by definition includes most members of under-represented groups, will be less likely to understand the appeal of the subject and consequently more inclined to put their efforts into pursuing some other discipline.

Some suggested instructional strategies to improve student motivation:

Motivational factor	**Instructional Strategies**
Personal relevance & interest	• Use authentic real world contexts when possible • Choose problems that the students can relate to • Show how material is useful in other courses and/or future careers • Before launching into definitions, procedures, mathematical formalism, etc., introduce a meaningful problem that motivates the need to learn these details and tools • Check that all your assignments pass the "why would anyone *care* about the answer to this problem?" test • Show your own interest and enthusiasm for the subject • If you are uncertain as to what the students will find interesting or relevant, ask some students (a good group to ask are students who recently took the course)
Choice and control	Build some flexibility into your course, within reason • If there are some optional topics in the course, have students vote on which ones to include • Let students choose the topic for a project or assignment • If there is more than one reasonable way to manage assignments, have students vote on which they prefer
Sense that one can master the material	• Communicate clear learning goals to the students • Express to the students that they can master the material if they put in effort • Create assignments and activities that are challenging, but doable with effort (a diagnostic or other assessments in the course can help determine the appropriate level of challenge) – Build in early success (e.g. ramp up the difficulty in an activity, so that all students can relatively easily complete the first part) – Build "bonus" challenges into activities to keep the faster students engaged • Regularly provide feedback that gives students a clear sense of how well they are mastering the material • Make sure the course elements and assessments are aligned with the learning goals • Explicitly point out to students how much they have learned • Give students specific advice on how they can improve their learning

References:

Ambrose, S., M. Bridges, M. DiPietro, M. Lovett, and M. Norman. 2010. *How Learning Works: Seven Research-Based Principles for Smart Teaching* – chapter 3. San Francisco: John Wiley & Sons.

Pintrich, P. 2003. "A Motivational Science Perspective on the Role of Student Motivation in Learning and Teaching Contexts." *Journal of Educational Psychology* 95 (4): 667–686.

Basic instructor habits to keep students engaged

by Carl Wieman, 2010

It is best to start doing all of these at beginning of the term.

1. **Pay special attention to the back of the room, particularly in a lecture theatre.** Walk up aisle as frequently as practical, look at back of room frequently, call on students at back in preference to students in front, repeat student questions so the class can hear, ask students to speak loudly when asking or responding to a question, regularly ask students in back if they can see what is on screen or board and hear what is being said, and don't let chatter in back of the room get out of hand. ALWAYS be conscious of your natural tendency to engage in what effectively becomes a private discussion between you and an individual student in the first or second row.

   See end of document for more detailed advice on paying special attention to the back of the room.

2. **When you are talking, regularly stop and ask for questions. Make sure you wait an adequate length of time for response.** What seems like very long time to you is actually short amount of time for a person to collect their thoughts and phrase a question. Instructors typically wait less than 2 seconds, often less than one, before concluding there are no questions and moving on. A few such very short waits convince students that when you say that you are asking for questions it is just a ritual, and you do not actually want any. Since your time sense in this situation is so skewed, initially you might even use a watch to time yourself to ensure you have waited an adequate amount of time, like 20-30 seconds.

3. **If you have a clear impression from facial expressions that students are lost, just say you sense that, and say you need them to ask questions so you can help them, and then wait**. At first they won't believe you, but if you wait long enough (a minute seems like an eternity in that situation) and you look directly at them, someone will ALWAYS ask a question and that starts a discussion. Do that once or twice early in term, and they will learn that you do expect them to raise questions and will then do so quickly.

4. **When a student asks a question, sometimes offer the question to the whole class before answering it yourself.** This reinforces the message that whole class, rather than just you and questioner, should be involved with, and learning from, student questions and answers.

5. **Avoid the tendency to sit back and wait while students discuss a clicker question or in-class activity**. Instead, circulate around the room and listen to them, so you can use what you hear in the follow-up discussion.

6. **After completing a clicker question or in class activity, share student thinking**. If you solicit some answers/explanation or questions from students, rather than you just explaining it, it sends the message that this is about communication and feedback, and it will stimulate ongoing questions from students. If they have written down answers, project some of those (if you have a document projector) or sketch them on the board to share with the class. Sharing answers or calling on a student is not very traumatic for them if they have already worked as group. Call on them to present their group's thinking or answer. Students are normally full of questions after any such activity in which they are obviously engaged, so if you are not getting any questions, you need to figure out what to change.

7. **Define transitions clearly**, such as switching between times for activities involving general student discussion and times when there needs to be general quiet and raising hands before speaking. If you don't, the boundaries get fuzzy, and there can be enough noise in the room that those in back cannot hear and feel left out. Markers that signal a boundary, such as sounding a bell, are quite effective.

8. **Be careful not to send out messages that suppress student engagement**. Obvious examples are suggesting a question is annoying or stupid, asking for questions and only waiting a second, or overlooking raised hands. Some others are:

   a. Jumping in to correct student use of terminology or a small error when main point is correct or relevant. Either ignore the part that is wrong, or correct as an afterthought after discussing the main point.

   b. Suggesting at the outset that a clicker question or activity should be very easy for them. This tends to decrease student motivation to discuss it amongst themselves or to ask you questions.

c. Not discouraging highly vocal students who are asking questions primarily to show off rather than to seek an answer. It can send message that asking a question in class is only about showing off.

9. **Avoid facing away from any part of the classroom.** As soon as you are talking with your back to the students, you are conveying that this is a monologue, not a conversation/explanation to them.

10. **Avoid distractions that split their attention.** For example, having a complex image displayed while actually talking about something else. Students will quickly become lost and disengaged.

More detailed advice on paying special attention to the back of the room, particularly in a lecture theatre:

a. Walk up aisle as frequently as practical.

b. Very explicitly look at back of room frequently. Call on students at back in preference to students in front, and sometimes explicitly call for answer to question only from students in back. Look at the back and wait patiently for answer when you do so.

c. It is almost impossible not to sometimes overlook raised hands in the back half or sides of even a mid-sized classroom and never realize it. This only has to happen 2 or 3 times and you have sent clear message that those students in back are not really part of the class, and they will all stop asking questions from then on. Every now and then apologize for the possibility and encourage students to call out and let you know if this happens.

d. When a student at front says something, if room size allows, ask them to repeat loudly enough and turn so the rest of the class can hear, and regularly remind students when asking questions to do so. In larger rooms (including anywhere you use microphone), you always need to repeat the student question or comment. Force yourself to do that consistently. Even if it is a room that you will have to repeat question for the back, regularly encourage students to talk as loudly as possible so other students can hear them. The best context for this is when there is good question-- make a comment like “That is excellent question, everybody in room should hear and think about that, so can you say as loudly as possible so others can hear?” This sends an explicit message that whole class is involved and should be learning from student questions, and that it is not just a conversation between you and one student. ALWAYS be conscious of your natural tendency to engage in what effectively becomes a private discussion between you and an individual student in the first or second row.

e. Regularly ask students in back if they can see what is on screen or board and hear what is being said. Instructors very frequently fail to recognize what cannot be seen or heard from the back. (Whenever you have walked up aisle, look down to see what viewing is like from student perspective.) Just the act of your checking with them makes them feel more involved and part of the class.

f. A common error in a large classroom is to ignore bunch of chatter going on in back of room and then only teach to the front half. DON’T. The earlier in the term you recognize and act on this, the less of a problem it will be. The best preventative measure is regularly walking up the aisle and so you are talking directly to the people in back as much as possible. Also, when you hear chatter in back growing, go up and ask non-talking students in back if they can hear what you were saying and student questions asked from the front. When they say they can’t, tell the students to stop talking so other students can hear. (This is a much better tactic than justifying their being quiet on explicit or implicit grounds they are being rude to you.) If that still fails to quiet the chatter, just stop talking and calmly wait while looking at the noisy students in the back.

g. A good way to control off-task talking is pick someone who seems to be among the worst early in term and, find out their name. When they start talking, call on them by name, asking them if they have a question. If they are actually talking about class material and do have question, great. Answer it, then add some comment like, “When you have a question, just raise your hand and ask--we are in same room after all.” If they were talking about something else entirely and confess to no question, then gently admonish them to be quiet so students around them can hear the class material. Point out that students often complain about others in back talking in class, making it hard to hear, and they need to be more considerate of their fellow students.

h. When groups are engaged in clicker question discussion or small group activity, try to first walk to the back of class and interact with the students there. Avoid the very common mistake of frequently getting grabbed by students at the front and spending a lot of time with one group and so you seldom get up to the back.

Student group work in educational settings

CWSEI and CU-SEI, 2008

Although group work is sometimes hailed as an educational panacea, the realities are considerably more complex. Many studies of group work have been done, and they show a wide variety of results. These range from dramatic improvements in student learning and satisfaction to negative impacts on both. The potential benefits of social interaction on learning are readily apparent. Who has not understood a topic better through explaining it to a colleague and/or having that person raise questions about an explanation? Also, in many situations, peers can provide an effective low cost substitute to individualized instruction by the teacher. However, achieving these and other benefits, such as learning teamwork skills, do not come automatically, and there are clear potential downsides to group work, including the time for organizing groups and dealing with intra-group problems, potential student resentment, more complex grading policies, and difficulties in scheduling and room layout. To achieve the maximum benefit from group work, an instructor must carefully consider the desired educational goals and the benefits, tradeoffs, and pitfalls of introducing different types of collaborative work, and then choose the most suitable type.

Here we briefly review different levels of group work and list the potential benefits and negatives, and what requirements research has shown are needed to ensure a high probability of success.

Levels of collaborative activity – Benefits, Requirements for success, and Negatives

1. Multiple, brief small group discussions in class

(in response to challenging instructor questions or in-class assignments)

A. Benefits: Learn through explanations to others, learn metacognitive skills through analyzing other's reasoning, learn jargon through use in discourse, learn to carry out scientific discourse. Peers provide low level help and feedback, such as catching arithmetic mistakes and avoiding "getting stuck". The stress of speaking in class is reduced, particularly if student is asked what their *group* thought.

B. Requirements: Incorporating this in class is relatively easy – just provide some reason for students to discuss the material with each other. Implementation needs to include some minor reward system or class expectation to promote the group discussion, because otherwise it will not happen spontaneously for many students. Group size should be small (2-4). Two low-effort options for group formation that enhance interaction over just "talk to your neighbour" are: 1) instructor randomly assigns, or 2) students self-organize and register their group online. Such formal groups particularly enhance interaction if students are occasionally required to provide group consensus answers. While it is preferable to have a range of backgrounds and levels in each group, the benefits in this setting are usually not considered large enough to be worth the effort. The benefits are primarily from avoiding groups composed solely of low motivation and low ability students. With mixed groups, the better prepared students can provide explanations to the weaker students, with benefit to both.

C. Negatives: Minor. Time needed to form student groups. Potential disruption due to off-topic discussions in class (usually minor).

D. Other: Opinions vary, but we recommend keeping group composition stable, except where problems.

2. Informal, out-of-class study groups

A. Benefits: Like 1A, plus students can study more effectively by getting low to moderate level feedback from each other. This avoids wasting time from "getting stuck" or overlooking trivial mistakes. Students can succeed at more challenging and complex assignments. Students may find course work more satisfying and enjoyable, and learn teamwork skills.

B. Requirements: Minor. Regularly encourage and discuss the benefits of study groups. Ensure that marking/grading scheme does not appear to penalize collaboration, as discussed below. Provide some form of both group and individual incentives. For example, collaborating can improve grades on assignments, but there are also exams that are closely aligned with assignments. Assignments must be challenging to draw students into meeting for study groups. Make it logistically easy and not socially challenging to form into groups. For large classes, this likely will involve scheduling a room and time for students to meet and/or website for connecting up. Having instructor or TA at these study sessions can draw more students, but it is important that the instructor/TA does *not* provide the answers.

C. Negatives. Negligible. Time needed for elements of B.

3. **Formal in-class group activities** (such as tutorials, concept mapping, labs, …)

A. Benefits: Same as #2, but involves all students. Plus students can develop more teamwork skills.

B. Requirements: Best to have a challenging activity where students work with ideas that are typically difficult to learn and the activity requires them to think about and debate these ideas with each other. Need course structure and space conducive to group work (4/table works well). TAs with role of facilitating group discussion and Socratic teaching works well. Grading options include: only for participation, grading individual work, or grading collective work. Be explicit about why and how collaborative learning is beneficial. If grading collective work, need time and attention devoted to why and how to work in teams effectively, roles and responsibilities of team members, and evaluation of contributions as part of team. Often rotating roles are assigned, manager, recorder, sceptic, etc.

C. Negatives. Time and personnel needed to organize facilities and groups.

4. **Formal in or out-of-class collaborative assignments- collective group work and shared marking**

A. Benefits: Same as #3, plus reduces time for marking assignments.

B. Requirements. Similar to #3, and a significant goal of the course should be to have students learn to work in teams. Assignments must encourage teamwork, such as being sufficiently difficult or complex that is easier to set up team and work together than to complete as an individual. Assignments that require judgement decisions are found to be most effective at encouraging diverse participation. Groups should be formed by the instructor in a manner that assures equal diversity and skills across groups and is perceived to be scrupulously fair. There must be timely feedback on the functioning of group and a process for dealing with intra-group squabbles.

C. Negatives. 1) There will be some level of student resentment and intra-group disagreements over credit and level of effort. 2) Time required to create groups and deal with logistics. In many courses, groups will not spend the 40 hours of interaction that has been cited as needed to have a highly effective team. 3) Instructors who are not experienced in implementing this can find it difficult to obtain good results.

D. Other. Group size 4-5 is considered optimal, with all visibly under-represented minority students in a group with at least one other minority student.

5. **Learning with fully developed teams**

A. Benefits. Same as #4, plus students learn to work as part of team to solve problems and manage projects that would usually be impossible for an individual to complete.

B. Requirements. Major part of course goals needs to be learning teamwork. All of #4B, plus requires more attention to group size, composition, task assignment, general group interaction, and reward system. Majority of course should be team based project(s). More time and attention devoted to why and how to work in teams effectively, roles and responsibilities of team members, and evaluation of contributions as part of team. Teams should have at least 5 and preferably 6 or 7 members, and the composition should be as diverse as possible.

C. Negatives. Similar to #4, plus significant time required to create good team-based learning projects.

Group work and marking/grading scheme

If student marks depend on relative student ranking ("grading on curve", "normed", etc.) there is a clear disincentive for a student to collaborate with other students. The inherent contradiction between telling students that they must collaborate, while at the same time penalizing them for helping other students through the marking scheme, will always result in student discomfort and resentment.

References & Resources

C. Crouch and E. Mazur, Peer Instruction: Ten years of experience and results, American Journal of Physics, V. 69, pp 970-977 (2001). *A good review of Peer Instruction (falls under Level 1 in this document), including a description of the method and data on effectiveness for improving student learning.*

P. Heller and M. Hollabaugh, Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups, American Journal of Physics, V. 60, pp. 637-644 (1992). *A good reference on structuring and managing cooperative groups.*

M. Prince and R Felder, The Many Faces of Inductive Teaching and Learning, Journal of College Science Teaching, V. 36(5), pp. 14-20 (2007). *A nice overview of various forms of inductive teaching that discusses both group and non-group approaches, benefits, and ease (or difficulty) of implementation.*

Team-based Learning: A Transformative Use of Small Groups, ed. by Larry K. Michaelsen et al. (2002). *A good reference on Team-Based Learning and also a good reference on group dynamics (chap. 4 by Birmingham & McCord is on research on group dynamics); also see:* UBC Faculty of Applied Science website on Team-Based Learning cis.apsc.ubc.ca/services/team-based-learning/

Group Activities; Establishing value and setting class norms for behavior

Carl Wieman 4/18

An important step in making collaborative learning in the classroom go well is to establish the purpose and value of the group work, and to set norms of behavior for interactions between the group members. The latter is particularly important when there are students from different demographic groups that may have rather different social norms. I have been using the following activities to establish values and norms, and they seem to work well. This is done on the first day of class. It serves two different beneficial purposes. First, they are a good first-group-activity, as the answers are nontrivial, and it is something where everyone feels equally qualified to contribute. Second and most importantly, it has the class establish norms for behavior in group work. I think this is better than me giving them a bunch of rules to follow, because they think more about the issue and internalize it, and they are setting the standards themselves, rather than it being my rules.

I have them assemble into groups of 3 or 4, and I tell them how they will be working together to solve many problems over the term, starting with this task:

I. Value. "1) Take a few minutes to individually write down on a sheet of paper a list of the benefits that can come from working collaboratively with other students."

(I walk around monitoring what people are writing down. If any student is not writing down anything, I tell them to, and stand over them waiting until they start writing. When most seem to be finished, I direct the class to proceed to step 2.)

"2) Now share your lists with the other members of the group, and come up with a general list. ."

3) I then call on groups in sequence to give me an item from their list that has not already been offered. (There are a few standard things that virtually everyone has, so this goes quite quickly.)

4) I put up my own list (below) which is on a PowerPoint slide. It usually matches fairly well with theirs.

"*Why work together (in class and out)?*

1. Learn more-- avoid getting stuck. New ways to think about topic, things overlooked.

2. Learn from explaining and discussing. [I mention the extensive research on learning through teaching.]

3. Getting more specific help ("forgot 2 in exponent")

4. Practice monitoring your thinking. Checking reasoning and answers.

5. Can solve harder, and therefore more interesting problems and often is a more fun way to work.

But to learn, even with group work you still need to do significant thinking on your own.

Express ideas in own words and thoughts and equations. Test your understanding."

II. Norms of behavior. I tell them that for groups to work effectively, it is important to agree on standards for how to behave in the group work, and I am sure they have all seen good and bad examples. To establish a class consensus on desired behavior, they will now do this activity.

"1) Take a few minutes to individually write down on a sheet of paper a list of behaviors that make group work most productive and enjoyable." (I monitor to ensure everyone is doing, as above.)

"2) Now share your lists with the other members of the group, and come up with a general list that your group agrees upon. Make copies of this to keep."

3) I then call on groups in sequence to give me an item from their list that has not already been offered. (There are a few standard things that virtually everyone has, so this goes quite quickly.)

4) I put up my own list (below) which is on a PowerPoint slide. It usually matches what they have already said, although sometimes they have missed one that I have, so I briefly give the missing item and say why I think it is important to add to their list (usually invoking a research study). There are also occasionally some that they will add, which are often elaborations on what it means to "be nice".

- *Be nice-- don't make any derogatory comments about other students and their ideas.*
- *Make sure that everyone participates and gets to offer their thoughts.*
- *Make sure everyone gets listened to. (I mention research showing that groups that perform badly almost always fail to listen to each other.)*
- *Don't interrupt when another student is talking.*
- *Come to class prepared.*

For the next few classes, I am particularly careful to watch for students violating the list of good behaviors, and when they do, I gently remind them of the class list, and how they are not following norms of behavior we agreed upon. (Most commonly, this is one member of a group answering a question and being interrupted by another, particularly females being interrupted by males.) That gentle reminder is generally sufficient to change behavior.

Creating and implementing in-class activities; principles and practical tips

CWSEI, updated February 2018

1) Choose a goal or topic to focus the activity

Look closely at your material and ask yourself some of the following questions:

a. What is the most important content or learning goal and how might the activity support that?
b. Are there existing materials (such as a lecture, assignment, or exam question) to base the activity on?
c. Is there an important framework, model, or concept to reinforce?
d. How will it be giving them practice thinking, particularly making decisions, like an expert in the subject?
e. What is most difficult? What gives students trouble? Are there exam questions students do poorly on?
f. Is there a controversy in the material? Is there material that would make a good discussion?
g. What could students work out on their own with reasonable effort?

2) Decide how students will engage with the material

The next step is to look at the material you've selected and decide how the students will interact with it. This is key for developing activities. Try to design it so all of the students engage deeply with the content, not just a few.

a. Consider your context. How many students are in your class? How many may require some accommodation? Will you have help administering the activity? How will this work in your particular classroom setting? If the students will work in groups, how large will those be and how will they be formed?
b. What type of activity will be used? If you have difficulty deciding, discuss it with a colleague. Here are a few options that work well with a variety of topics:
   i. Think/Pair/Share [typically 5-15 min] – This type of short activity is designed to let everyone engage with the material first individually and then in pairs. First the instructor poses a question, then students spend one minute thinking or writing silently about the idea on their own (you may have to enforce silence, some students will likely try to talk). Then students form groups of 2, each partner takes a minute or so describing their thoughts. Finally, the instructor facilitates a discussion with the whole class. This activity will usually increase students' responses to questions posed in class. Peer Instruction with clickers is a variation on this.
   ii. Worksheets [typically 15-50 min] – Write a set of questions that lead students through the content in a structured way and photocopy enough for everyone (but see #5d below). Encourage them to work in groups of 3-4. The problem difficulty should be very challenging for most students working individually, but reasonably doable in groups. Make the first part relatively easy, so that all groups know how to start, with later parts more challenging. Intervene regularly to keep groups synchronized, as shown on page 3.
   iii. Case Study [typically 15-50 min] – In a case study, students engage with the content in a real-world context. Many people present cases or examples to students in lectures, however it is more effective to give the students material and handouts (e.g. graphs, maps, data, …) that describe the conditions of the case and have them work in groups to make decisions about it. Choose a case that is compelling and requires the students to both analyze the situation and come to a decision or series of decisions and then justify their choices (examples: how to proceed with a project, what to recommend to clients, where to drill, what future changes to expect, how to reduce energy loss, which technique or instrument to use to achieve a goal, etc.).

3) How will the students be motivated to put in effort?

a. Is it challenging, but doable in groups? Will students see that they are becoming more "expert" at something?
b. Can you connect the activity to a good real-world example or something they may do in their future careers?
c. Does it convey why you and others see this topic as interesting and important?
d. Does it involve them making decisions and justifying actions, not simply following set procedures?
e. Does the activity relate to tasks students will be asked to complete on homework and exams, so every student recognizes the benefit of individually participating and mastering the material?

4) What product will students generate?

a. Consider more sophisticated tasks. For example, have students make and justify a **decision** (and perhaps identify the **criteria** used to make a decision), produce a **prediction**, produce a **ranking**, or make a **judgment** (e.g. best/worst/most efficient).
b. Consider having students produce a novel representation, such as a specialized graph or sketch.

c. It is usually best to avoid products that depend simply on applying a procedure (such as solving a familiar quantitative problem) or involve extensive writing. These tend to cause more "solo" than "group" work, and are better given as homework. Class time is better spent developing scientific reasoning, and getting feedback.

5) Logistics and facilitation

a. Decide how large your groups will be. In a large lecture hall with fixed seats, keep it to 2-3 unless you have them talk with rows in front/behind them. Four-in-a-row doesn't work because the people on the ends get left out.
b. Make it very clear what students are expected to do. Ask: "does everybody know what to do?"
c. Decide how many copies of the activity you will hand out. If you have difficulty getting many of your students to work in groups, you can hand out only one sheet per group and make it clear that you expect only one submission per group. On the other hand, it is beneficial for all students to have a copy of their work; some instructors have the students use "carbonless" copy paper, or turn in photos of work via Gradescope or similar.
d. During the activity, CIRCULATE and listen to what students are talking about. Look for examples from groups that you could show to the rest of the class for discussion. Provide timely specific feedback as useful.
e. Be flexible. Timing and difficulty level will never be perfect, so monitor how students are doing and modify activity in real time. Delete parts that are taking more time than they are worth, add questions to provide help.
f. Share good questions: if someone asks a very good question, tell them to ask it during whole-class discussion.
g. Collect something from the students (completed worksheet, clicker answers…) so they are accountable for doing the work. You don't need to grade them, but check off for participation and use these to inform you on their progress.
h. Wrap up the activity. Have a few groups explain their answers. Look for different answers that can spark discussion and thought. Finish by giving your summary, referencing their work and skipping parts they all did correctly. Avoid giving a full solution; that may encourage students to skip the work and wait for your solution.

6) Assessing the activity

After you've run your activity, reflect on how it went and how it might be improved.

a. Did anything surprise you?
b. Did the students understand what was required? Were they frustrated?
c. Did they engage the way you thought they would? Do you need to adjust the difficulty level?
d. Did they learn what you were trying to teach them (and how can you tell)?
e. Did they enjoy it?
f. Do you need to modify any of your learning goals based on how this went?

7) Other considerations

There are a few other considerations that help in developing activities:

a. Create checkpoints during the activity (e.g. a clicker question, or a brief full-class discussion) within longer activities so you can help groups stay roughly in synch.
b. For the fast groups, add a "bonus" question at the end that you expect only a few groups will get to.
c. Save class time by having them prepare for the activity. Assign reading and have them answer some relevant questions prior to class so they will have the basic information needed to start the activity.
d. Remember feedback! How are you going to measure and communicate how they've done during class and later? Is there a follow-up task (homework, exams, …) that will ensure they think about and use the feedback?

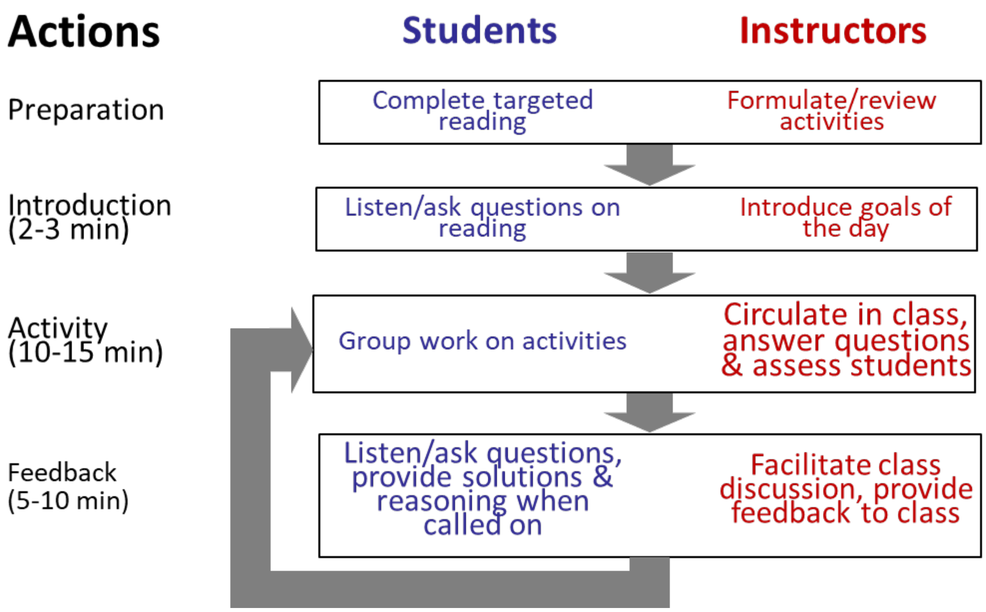
8) Integrating activities into your course structure

a. Aim to make activities a normal, regular part of in-class time.
b. If you're transitioning from dominantly lecture delivery, a good goal is to incorporate at least one 5-minute activity into each 50-minute lecture period, or a longer activity each week. There is probably something in each of your lectures that could be turned into a good activity.

It is very helpful to bounce your ideas off other faculty, and/or teaching assistants. For more resources, see: www.cwsei.ubc.ca/resources/instructor_guidance.htm. Particularly relevant 2-pagers: *Group Work in Educational Settings* and *What Not To Do; practices that should be avoided when implementing active learning*.

Activity timeline

You should not wait until all groups finish before having the feedback stage. That is poor use of class time and many of the groups will get bored waiting. All that is required is that all groups have fully engaged in problem, and so they can learn from your feedback. Typically go to feedback after ~3/4 have completed problem, or you see a common issue many groups are stuck on.



Using Clickers in the Classroom

Adapted excerpts from: Clicker Resource Guide; prepared by CWSEI and CU-SEI
www.cwsei.ubc.ca/resources/files/Clicker_guide_CWSEI_CU-SEI.pdf

Clickers are student response systems that provide is a way to rapidly collect an answer to a question from every student; an answer for which they are individually accountable. This allows rapid reliable feedback to both you and the students. Questions are usually in a multiple choice format.

TYPES OF CLICKER QUESTIONS

Clicker questions can serve many purposes – below are some common uses:

1) Quiz on the reading assigned in preparation for the class
2) Test recall of lecture point
3) Do a calculation or choose next step in a complex calculation
4) Survey students to determine background or opinions
5) **Elicit/reveal pre-existing thinking**
6) **Test conceptual understanding**
7) **Apply ideas in new context/explore implications**
8) **Predict results of lecture demo, experiment, or simulation, video, etc.**
9) **Draw on knowledge from everyday life**
10) **Relate different representations (graphical, mathematical, …)**

While each mode can be useful in the right circumstances, those in **bold** above are the uses that we have seen the largest direct impact on learning and the uses that students report they find of most value. These also reflect the deepest mastery of a subject and hence have been shown to be the most challenging for students. We recommend that most questions fall into these bolded categories.

Recommended Approach to Using Clickers

For questions of the bolded type, and are appropriately challenging so a significant fraction of students will be incorrect on first vote, it is best to usually follow these steps:

Step A: Question & Individual Vote

Instructor poses the question, often with some remark about its purpose. Students have time to think about the question individually and answer individually with clicker. A good rule of thumb is to cut-off voting with announcement of 10 more seconds after 80% have voted, rather than using any set time.

Step B: Peer Discussion

Before seeing the individual vote distribution, students discuss the question in pairs or small groups (Peer Instruction).[1] Instructor moves throughout the classroom, listening in on the discussions.

Step C: Second Vote

Students submit answer using clicker after group has decided, using timing as above.

Step D: Whole-class Discussion

Instructor and students have follow-up discussion, emphasizing the "why" of correct options and "why not" for incorrect options. The instructor should also make sure that any residual issues or student questions from the discussion are explicitly addressed before moving on.

[1] C. Crouch, J. Watkins, A. Fagen, and E. Mazur, "Peer Instruction: Engaging Students One-on-One, All at Once," Research-Based Reform of University Physics, 1 (1) (2007). www.compadre.org/Repository/document/ServeFile.cfm?ID=4990&DocID=241

Important points about using clickers:

- Clickers are not a magic bullet – they are not necessarily useful as an end in themselves. Clickers become useful when you have a clear idea as to what you want to achieve with them, and the questions are designed to improve student engagement with important ideas, student-student interaction, and instructor-student communication.
- What clickers do provide is a way to rapidly collect an answer to a question from every student; an answer for which they are individually accountable. This allows rapid reliable feedback to both you and the students. They also assure all students are engaged with the material.
- Used well, clickers, in combination with your listening in on the group discussions, will tell you when students are disengaged and/or confused, why this has happened, and how you can fix the situation.
- The best questions focus on concepts you feel are particularly important and involve challenging ideas with multiple plausible answers that reveal student confusion and incorrect reasoning and generate spirited student discussion.
- A common mistake is to use clicker questions that are too easy. Students value challenging questions more and learn more from them. Students often learn the most from a question that they get wrong. Often, all students in a group will get an answer wrong before discussion, but correct after discussion.
- Students should be given some time to think about the clicker question on their own, hence the value of individual vote, before discussing with their peers.
- Good clicker questions and discussion result in deeper, more numerous questions from a much wider range of students than is normal in a traditional lecture class.
- Listening to the student discussions will allow you to much better understand and address student thinking.
- Even though you may sacrifice a small amount of coverage of content in class, students will be more engaged and learn much more of what you do cover.[2]
- When a significant fraction choose an incorrect answer, it is important to go over why that answer is incorrect and not just give the correct answer.
- When clickers are used well, students overwhelmingly support their use and say they help their learning.

For more resources on clickers, visit:
www.cwsei.ubc.ca/resources/clickers.htm

[2] L. Deslauriers, E. Schelew, C. Wieman, Improved Learning in a Large Enrollment Physics Class, Science, Vol. 332, no. 6031 pp. 862-864 (2011). [available at www.cwsei.ubc.ca/SEI_research/]

Thought Questions: A New Approach to Using Clickers

Teresa Foley & Pei-San Tsai, University of Colorado Integrative Physiology Department & CU-SEI, 2010

Developing a good clicker question with reasonable answer choices and distracters is not an easy task. It is difficult to develop clicker questions that provide an appropriate intellectual challenge. A new approach to clicker questions, called “thought questions,” can facilitate this process. Faculty only need to develop the question while the students will do the rest! Thought questions are higher-level, open-ended questions that a faculty member poses to the students. After a brief discussion of the question, one group of students is asked to answer the question and provide a rationale for the class. Subsequently, the entire class uses their clickers to vote on whether or not they agree with the answer and rationale. If the majority of students do not agree, another group attempts to answer the questions and the process continues until the class agrees.
Pei-San Tsai first implemented this method of clickers in the Endocrinology course this past spring, and the student feedback was overwhelmingly positive! Thought questions were subsequently been tested in Immunology and Introduction to Human Physiology during the summer, and the students again approved the approach.

Steps for developing and implementing thought questions

1.) Start by choosing a learning goal to assess.

2.) Develop an open-ended thought question for the goal. An application-type question where the students have to predict the outcome works best for creating thought questions. (See example thought questions below.)

3.) After presenting the thought question in lecture, organize the students up into groups of 3-4 and allow 5- 7 minutes for discussion.

4.) Choose one group to present an answer and rationale to the class. The instructor may need to repeat the group’s rationale so that all students understand the explanation.

5.) The class uses clickers to vote on the answer and rationale. (Clicker question: Do you agree with the answer and rationale? A. Agree, B. Disagree, C. Don’t know)

6.) If the majority of the class disagrees, ask another group to explain their rationale to the class. 7.) Repeat the clicker voting until the majority of the group agrees.

Sample thought questions

Endocrinology (IPHY 4440):

If you put a plate between the median eminence and the adenohypophysis to cut off the portal system, what do you think would happen to the secretion of tropic hormones?
When you inject epinephrine directly into the hypothalamus of an animal, the secretion of several tropic hormones is changed. How is this possible since epinephrine is not a releasing hormone?
What would you predict would happen to the ovulatory frequency if one ovary were removed?

Immunology (IPHY 4600):

Given that all blood cell types derive from the pluripotent hemopoietic stem cell, why are there so many different types of cells in the immune system?
What would be the consequence of a bioterrorist attack that released smallpox virus into a city?
From an immunological viewpoint, why would it be inadvisable for a mother who has recently given birth to move with her newborn to a foreign country where there are endemic diseases not prevalent in her homeland?

Tips for successfully implementing thought questions in the classroom

1.) Start early and start simple. It is important to set the tone early in the semester. On the first day of lecture, ask 1-2 easy-to-moderately challenging thought questions. This will send a clear message to the students that they need to be active participants in the classroom. The more challenging thought questions should be saved for later when the students have more confidence.

2.) Be consistent and ask 2-3 thought questions per lecture. As for traditional clicker questions or any other in- class activities, consistency is important. Although you will cover less material during the semester with this approach, students will be more engaged and will learn more.

3.) Personalize the questions by using real-life scenarios, clinical examples, or case studies. This will reinforce the importance of the material you are presenting.

4.) Listen carefully for common misconceptions. As the students are generating the answer choices for the thought questions, this is a perfect opportunity for you to address student thinking and misconceptions. You can even create future thought questions to address these misconceptions.

5.) Given the open-ended structure of thought questions, exams must include a short-answer component.
There must be a match between in-class expectations and the format of the exams.

Orchestration of active learning activities: instructor role overview

The role of the instructor in deliberate practice is to design authentic practice tasks, and then to provide timely, specific, nonthreatening feedback to the learner as they practice the desired skills. Good feedback does not just offer the correct solution when the learner makes an error, but specifically addresses the errors in their thinking. Helping learners see how their thinking was wrong and what to do to improve it makes a very large contribution to learning. During class, the instructor is acting much like a good athletic coach, monitoring the learners and giving them specific feedback on what they did right and how to improve. In class, the instructor will also provide broader feedback to the entire class on larger parts of the activity, making sure everyone understands the correct solution to that part and allowing students to ask questions that may not have been covered.

During class the good instructor will be intently focused-- monitoring student thinking, assessing students progress and learning, answering questions, identifying difficulties or errors, thinking of the most effective feedback to provide to address those errors, and deciding which activities and student questions to spend more or less time on based on the real time perceived needs of the students. While challenging, it is also quite exhilarating, as the instructor is much more deeply engaged with the students and much more directly transferring their hard- earned expertise, and the students are much more deeply engaged in the material than when the instructors are lecturing. Of the hundreds of instructors who have learned to teach this way in the programs Wieman has run, essentially none have reverted back to lecturing.

The process of having students work with others in a structured way provides several benefits. First, students are guaranteed the multiple benefits of "collaborative learning" including getting immediate feedback on their ideas from others, and avoiding extended time "being stuck", and triggering the valuable cognitive processing that is involved in thinking how to teach someone else. For an instructor, being able to listen in on the group discussions and see what the groups have written down provides invaluable monitoring of what the students are thinking, to guide the instructors feedback. This is in addition to the off-loading of much of the valuable feedback. To realize these benefits, it is necessary to keep the groups small, ideally three, four maximum, and have some individual deliverables, to ensure all students are fully engaged and the instructor can readily catch and help students who are lagging.

Instructor Activities during class. (adapted from Jones, Madison, Wieman, Phys. Rev. —Phys Ed. Res. 11, 020108 (2015))
During the students' group activity work in class, the instructor circulates through the room assessing progress by listening in on discussions, which they do a lot of, and answering questions by individual groups as needed. Many of these are just to confirm their correct answers. (Students very quickly get used to instructors listening in on their conversations and largely ignore it.) The instructor also assesses the work that groups have written down and asks groups questions to gauge their understanding and progress. If there is little cooperative dialog between group members, or the instructor wants to assess the learning of a group member that does not speak much, the instructor poses a question to one group member and then asks other member(s) to comment, or to provide an alternative answer (thereby initiating dialog). We have found the ratio of students to instructors and TAs can be as high as 35∶1 before running into difficulty answering most of the student questions and performing an adequate class-wide assessment of progress during a 10–15 min activity. We note that not every group is visited by the instructor during a given activity for this assessment. To operate at this high ratio, we have found the following guidelines helpful:

- The instructors need to continuously move around with a goal of spending only a few minutes at most with each student group or question; [A common failure is to get into an extended discussion with one group, neglecting the others. This is particularly bad if the discussion is one that would benefit all. In such cases, shift to whole-class discussion/feedback.]
- If there is a common misunderstanding or question shared by several groups, the instructor temporarily interrupts work on the activities to address the class as a whole on this issue. This interruption usually lasts only a few minutes at most, just clarifying a point;
- If the instructor notices that one group has successfully solved a problem while a nearby group is still struggling with same issue, then the instructor asks the first group to serve as the "expert" to provide guidance to the second group. This strategy also leverages peer-wise instructional benefits [17] as well as renews the engagement of more advanced students who might have already finished more of the activities.

At longer intervals (usually 10-15 minutes), normally dictated by natural breaks in the activity, the in-class activities are suspended and the instructor provides feedback by discussing solutions for the preceding activities. The students are well primed for this feedback by their previous work. This procedure also serves to keep the students covering similar material, by resynchronizing all the students before moving on to the next task. We have found the duration for a given exercise can be quite variable, and so the time to stop for whole class feedback is best based on class progress. A typical cutoff is when 2/3 of class is finished with the basic concepts and have spent some time considering, but not working through the more in-depth questions.

When delivering feedback, the instructor works through a prepared solution of the activities, while simultaneously engaging the students for input, comments, and questions on the solutions as they are presented. Little time is spent on parts that the instructor knows nearly everyone completed without much difficulty, while the most time is on parts students struggled with, focusing on what they did that was incorrect (usually something overlooked) and how they could improve. If we note a particularly clear or alternate solution written by a student, we use it in place of (or as a supplement to) the instructors' solutions. After class, the solutions to the activities are posted online for students to use as a reference.

Using active learning class time most efficiently. Maximizing coverage of material in class.

1. Not all (or even any) need to get correct or entire solution. Just struggle with key ideas and structure to prepare to learn/appreciate solution.
2. Can have students finish up as part of homework, particularly more lengthy calculations. If have practiced solving novel problems in class, are able to cover new material on HW.
3. Can save lots of class time by not having students watch you derive things. (if worth learning, than worth having students go through as structured HW problem)
4. Don't waste time and brain cells on interesting little digressions or minor details. Everything has cost in terms of using up working memory.
May need digressions to keep awake in standard lecture, but not in active learning class, and harms learning ideas.

a. Create checkpoints during the activity (e.g. a clicker question, or a brief full-class discussion) within longer activities so you can help groups stay roughly in synch.
b. If you know you will have fast groups add a "bonus" or extra consideration to the end of the activity, one you expect only a few groups will get to.
c. Save class time by having them prepare for the activity. Assign targeted reading and have them answer some relevant questions prior to class.

Don't spend too much time with one student or group during an activity.
Instructors can easily lose track of time when talking with students. This has 2 detrimental effects: you don't get the benefits of circulating around the room (7a), and many students may become disengaged.

Don't wait for every student or group to finish. Apply the "75% rule" for clicker votes. If 75% of the students have clicked in, announce that you will be closing to vote soon (e.g. in 10 seconds). For any group activity, you can get a sense of students' progress as you circulate. In longer activities, it is good to have check points where you bring the class into sync.

As this derivation is much more mathematically sophisticated (and thus would require a disproportionately large amount of class time), rather than step through the derivation, the final expression is provided and students are asked to explain the physical meaning of the terms in the expression and to relate them to a statement of the Huygens-Fresnel principle.
Multiple activities each lasting between 5 and 15 minutes (usually closer to the latter) are optimal; the students stay more fully engaged and "resynchronizing" the class after 15 minutes with new activities prevents the students from dispersing too broadly in their progress on completed activities. Starting activities with simple introductory questions followed by more complex questions provides a natural way to maintain high class engagement in cases where there is a wide range of prior knowledge or experience. This structure prevents less prepared students from struggling without any success while still allowing more advanced students to find intellectual challenges in the material.

Notation is a special case, which can waste a lot of time if not made clear. In this case a brief mini-lecture was given at the start of class, providing a clean example to illustrate the notation; this is particularly important if multiple texts are used with different notation conventions.

The activity-feedback sequence is repeated throughout class, ending always with feedback.
We almost never complete all the prepared activities, as the intent is to push students to their limits. The unused activities are usually applied to the next class unless a new topic is scheduled. If the last feedback session is articially shortened due to time constraints (occurring in approximately 25% of classes) we specically ask students to finish looking over solutions outside of class. However, if unfinished activities were particularly important for the following material we assign the activity as homework due at the beginning of the following class.

Improving Learning by Reducing Unnecessary Mental Load

The portion of the memory that remembers (or equivalently "pays attention to") and processes new information on short time scales (the "short term working memory") has a very limited capacity. Many studies have shown that anything that adds demands on working memory ("cognitive load") that is not essential for the desired learning will reduce that learning (Mayer and Moreno 2003, Mayer et al., 2008). Thus every "new" thing (not in their long term memory) presented to the learner has a cost, even artistic background graphics and peripheral interesting facts or stories ("seductive details"). Correspondingly, anything that can link different pieces of information so they are seen as related aspects of a single thing, e.g. 8, 1, 0, 2 vs year 2018 backwards, reduce the demands on working memory and free up cognitive resources.

Below is a list of strategies for reducing unnecessary cognitive load to enhance learning during class:

Organization of how material presented.
The standard approach of first presenting the formalism, definitions, equa's, and then moving on to apply to solve problems introduces large cognitive load, because learners have no organizational structure or context by which to connect all these pieces of information.
If instead learner is first presented with a meaningful problem to be solved, and challenged to try to solve it (structured in such a way they will notice key features of context & concepts even when unsuccessful, see Teaching Expert Thinking) they will establish a basic organizational structure for the topic, and then as formalism and solution procedures are introduced they will fit into this structure as tools to solve the problem. The resulting connections will reduce the cognitive load.

Any material that is presented through lecture or telling involves a large cognitive load, but there are a variety of ways this can be minimized. Items are listed below, with the most important in bold.
Lecture organization:

- **<u>Begin with list of learning objectives for the lecture</u>**
- **<u>Provide an explicit organizational structure or outline, and revisit it during the lecture</u> (the organization is always much less obvious to a student than it is to the instructor)**
- **Use a chronology or slide progression that makes logical sense**
- To extent reasonable, convey one message per slide, summarized in the title
- Slides should make sense on their own as much as possible
- **Explicitly link new material to prior topics**
- **Make clear delineations and transitions between topics** (refer back to organizational structure)
- Organize topics into chunks with lecture breaks (such as problems or activities designed to use or solidify information just presented) between chunks
- **Avoid peripheral information and seductive details. Find ways to make material interesting that is directly linked to the desired learning objectives.**
- **Reduce jargon to absolute minimum**
- **Introduce and define any necessary new terms explicitly, and do not assume they will be remembered when seen later—give reminders**
- Arrange for learning of simpler components, such as new terms and characteristics, to happen prior to lecture (e.g. pre-reading assignment)
- Accompany complex ideas with additional diagrams and/or analogies

Slides and visuals:

- **Slides should be visually clean and concise with simple fonts and backgrounds**
- **Use high contrast between slides and backgrounds**
- **Use bullet points with short phrases rather than complete sentences**
- **Avoid large blocks of text**
- **Avoid figures and pictures that are purely for visual appearances; everything should be directly relevant to ideas to be conveyed**
- **Avoid figures with extensive text and details that are not essential**
- **Include titles and labels for all figures**
- **When using a figure, highlight important takeaway messages**

- **Emphasize important points visually by bold text, large font, and/or colors.**
- **Be willing to modify graphics from other sources - the creators' design is not necessarily educationally optimal**
- **Use animations to step through the slide as you talk about each point on the slide, rather than displaying large amounts of text all at once, which can split student's attention**
- **Avoid distracting animations that are irrelevant to objectives (text spiraling in, etc.)**
- **If there is a point in the presentation when the instructor wants to be talking or presenting something without a slide, include a blank slide in the presentation so student attention is not split between verbal input and unrelated visual input**

Pacing:

- **Leave slides up long enough for students to absorb and/or record the information. Remember, this takes much longer when one is seeing them for the first time. This implies the number of slides should be limited, usually no more than one per 2 minutes.**
- **At appropriate times, pause to invite questions and note on slide. Wait for at least 5 seconds (will seem like an eternity) to allow students to formulate question before deciding there are none and moving on.**
- Solicit feedback on pacing, visibility, and ease of hearing in real time
- Provide a skeleton framework for note taking

The Two Conflicting Purposes of Lecture Slides

Instructors often use the same PowerPoint slides for two different purposes:

1. Presentation of the material
2. Lecture notes as a reference source for students' further study at home.

Designing slides to address these two purposes simultaneously comes at a price. If higher priority is given to lecture presentation, the slides may be too abbreviated to serve as good reference. If they are a good reference source, they likely will be too dense for optimum use in class. To avoid this conflict, instructors can make slides primarily for class and then include more text and details in the notes section of the slides or on additional slides that are not shown in class. Another solution is to create two sets of materials – one for class and one with more detail for later reference and, possibly, guidance to instructor during class but not shown to students.

References:

R. Mayer and R. Moreno, "Nine Ways to Reduce Cognitive Load in Multimedia Learning," Educational Psychologist, 38(1), 43–52 (2003).

R. Mayer, E. Griffith, I. Jurkowitz, and D. Rothman, "Increased Interestingness of Extraneous Details in a Multimedia Science Presentation Leads to Decreased Learning," Journal of Experimental Psychology: Applied, 14(4), 329–339 (2008).

Preclass-Reading Assignments

Why they may be the most important homework for your students

By Cynthia Heiner and Georg Rieger, CWSEI 2012

We usually think of homework as a task, such as a problem set, in which students apply what they have learned in class. But homework can prepare students to learn in future classes. Here we discuss the benefits of pre-reading assignments, report on what students think about pre-reading, and give tips on how best to implement pre-reading assignments to make them effective.

What are pre-reading assignments and what are their benefits?

Traditionally, students are first introduced to a topic in lecture; however, students can read the textbook before coming to class and complete a short quiz on the reading. This is a pre-reading assignment. The first benefit of such assignments is that students will get more out of class if they already know the basic definitions and vocabulary, as well as having already had the chance to work through simple examples and think about concepts at their own pace. This helps control for the variability in background knowledge of the students, and students regularly mention in surveys that pre-reading helps them follow what is covered in class. Also, Louis Deslauriers has monitored the student questions in lectures and noted that student questions are on a cognitively higher level in weeks with pre-reading assignments compared to those in weeks without. Second, by looking at the average responses to pre-reading quiz questions or by directly asking your students what was difficult in the pre-reading assignment, you can gain insight as to which topics your students find difficult. Third, you don’t have to spend (much) time on definitions or low-level examples, so you have more class time to focus on the more challenging material.

What students think about pre-reading assignments

Assigning reading is not new. However, in science classes students often do not read the assigned text on a regular basis. So what is different with our pre-reading approach? The assigned readings directly target material used, but not repeated, in upcoming classes and are coupled with targeted quiz questions. This leads students to recognize the textbook as being helpful to their learning.

Typically 85% of students report that they read the assigned text every week or nearly every week when the pre-reading assignments are implemented as described here. This has been true across numerous courses spanning several science disciplines. Slightly higher numbers report completing the online quiz (for which self-reports match closely to the computer record). When asked what motivated them to do the pre- readings, the most frequent single answer was the contribution to their grade, but more than half the students said it was because they found the pre-readings ‘helpful for understanding the material’, and ‘to know what to expect in lectures’.
Examples of student comments:
Student A: “*I know that if I complete the pre-reading I will better understand what is going on in the lecture as well as I can figure out where I need to pay the most attention and potentially ask questions.*”
Student B: “*I think this forced me to think and was very beneficial to start off the week as I would come into class knowing what to expect and what was expected of me.*”
Student C: “*To be honest, I did so because it was for marks. After a while, I didn't mind reading it; and the questions on the pre-reading quizzes help me understand some of the concepts.*”
How to implement pre-reading assignments
The pre-reading approach is a variant on “Just-In-Time-Teaching” (JITT[†]), in which every class is preceded by a pre-reading assignment and a quiz with open-ended questions about the difficulties encountered. The instructor reacts to these postings by adjusting the lecture to discuss the difficulties “just in time” for the next class. The full JITT approach requires a strict timetable for the students and the instructor, which is

[†] C. H. Crouch, E. Mazur, Am. J. Phys. 69, p. 970 (2001)

challenging to implement in many courses, particularly ones with large enrollments, and/or multiple sections. Here we offer a 'softer' approach to JITT that provides many of the same benefits. The students get a weekly pre-reading assignment to complete over the weekend, preparing them for the next week of classes. There is a quiz on the reading due before class. There are three key components for the successful implementation of pre-reading assignments: (1) the reading is very specific, (2) the quiz questions explicitly refer to the textbook, and (3) the instructor does not begin class by repeating much of the material in the assigned reading.

Best practices

The assignment should focus on what you plan to discuss in class. This creates a clear connection between the reading and the expectations of the students for class.

- Omit everything that is not necessary. The shorter the assignment is, the more likely the students will actually read it and focus on the key material. Some instructors believe in longer, less focused, readings from which the students are expected to extract the relevant material. This is an unrealistic expectation for a first exposure to the material.
- The reading should be guided with explicit prompts for the students of what to look for while reading.
- Give a reading quiz for marks. By assigning marks, you are telling your students that this assignment is important, even if the actual numerical value is small. We have seen that weightings of between 2% and 5% of the course grade achieve similar ~85% reading completion rates, while assignments without associated marks have much lower completion rates.
- The questions on the quiz should force the students to read the sections you want them to read and concentrate on the figures that are rich with information. By referring to specific figure numbers, (or equations, etc.) in the textbook, students must at least open the textbook to be able to answer the question.

- Refer in class to things from the pre-reading– but ***do not*** re-teach them. The point of pre-reading is that the students are expected to come to class prepared with some knowledge. If you re-teach it all, the students will quickly realize that pre-reading is a waste of time and stop doing it. Explain the purpose of pre-reading in your first class and stick with the approach.

While there are various quiz options, we have found that a multiple-choice online quiz is better than a paper or clicker-based in-class quiz. In addition to saving precious class time, having the students do the assignment at home with their textbooks open lets them review – before class – their mistakes (and at their own pace). A reading quiz is not a pop quiz -- the idea is to prepare students and not to surprise them. Pre-reading assignments should take less than an hour, with the quiz portion, typically around 5 questions, taking no more than 10-15 minutes of that time. Use mostly questions that all students could answer with the book, but add in a few that require a little more "reading between the lines". Don't forget: your goal is to draw their attention to something in particular and to motivate, not to trick or overly burden them during their first exposure to the material.

It is important that the students understand why and how the pre-reading will be beneficial to them. Explicitly explain your rational and expectations. On the one hand, you expect the students to read the text and try hard to answer the quiz correctly. On the other hand, you do not expect them to "teach themselves" the material nor understand it all completely from the textbook alone. This first exposure gets them started and helps reveal the trouble spots to both the students and the instructor. It is worth repeating the benefits of pre-reading to your students a couple of times during the term.

Creating good homework problems (and grading them)

by Carl Wieman

Homework is a vital part of learning in university courses, arguably it is where most of the learning takes place. Doing homework is typically where the student will put in the most hours of intense thought about the subject, and such intense thought has been shown to be essential for developing mastery.[1] However, the sheer amount of effort expended is not sufficient to ensure mastery. Students have completed thousands of practice physics problems and still do poorly on problems involving the use of simple physics concepts.[2]

Applying the ideas of reference 1, the essential features for making homework support learning are:

- there is challenging and prolonged practice of the components of expert thinking the student is to learn
- the student is motivated to invest the necessary time and effort
- the student gets feedback on their practice that gives them guidance as to how they can improve

We and others have shown large learning gains by analyzing the thinking a scientist or engineer uses, and then having students practice and get feedback on this type of thinking in class.[3] The same approach can be applied to the design of homework problems. We start by listing the components of expert thinking that one wants the students to develop, and consider the mine shortcomings of typical "back of the textbook chapter" problems.

Generic components of expertise in all fields of science and engineering. Be able to:

a) Identify what concepts and/or models are useful for solving the problem (not just a numerical solution, but problem can also be prediction, explanation, pathway, justification for conclusion, criteria or method for testing, etc.) and have criteria to use to decide which concepts and models are relevant and which are not;
b) separate surface features from the underlying structural elements that determine what concepts apply;
c) identify what information is needed to solve the problem and what is irrelevant;
d) look up and, as appropriate, estimate values and/or deduce information that is needed but not given;
e) make appropriate simplifying assumptions;
f) break down a complex problem into appropriate pieces;
g) plan a solution;
h) use multiple specialized representations of information and move fluently between them to gain new insights, and identify criteria for deciding which representation is most useful in a given situation;
i) carry out routine frequently-needed solution procedures quickly and correctly, and have criteria for choosing when a specific procedure should be used;
j) articulate and suitably apply a set of criteria for evaluating if a solution or intermediate result makes sense.

If one considers a typical back-of-the-chapter homework problem, it is clear that few of these components are practiced. First, all the information that is needed to solve the problem is given, and no extraneous information is given. Any simplifying assumptions are explicitly stated ("neglect friction and air resistance"). So items c), d), and e) are removed. Second, the chapter 5 problems only use chapter 5 concepts and equations, and the problems themselves are even organized to match the order of topics in the chapter. So the student never has to use a), and seldom uses b). A typical problem will only call for a final answer, so f) and g) may be done by the student, but how they do them will remain hidden and the student will not get feedback on how they might improve. A solution will only call for the use of one representation and so provide no practice at h). Finally, j) is not used, as the problems do not call for arguments as to why the answer makes sense.

So the typical problem will result in the student primarily practicing and getting feedback on i), carrying out routine procedures or regurgitating facts that are given in textbook. In addition, most standard problems in chemistry and physics will strip away the context, to avoid complicating the routine practice. Students are asked to balance meaningless sets of chemical equations or calculate the forces on frictionless blocks sliding down inclined planes. Such idealized artificial problems provide no motivation for students put in effort or see any value in mastering the subject, in addition to removing the practice of most components of expert thinking.

A criterion for any homework problem should be that it can pass the "Why should anyone care about the solution to the problem?" test. [Anyone that is, other than the instructor.] The best problems are ones that the students can see provide solutions that are obviously relevant and useful to their immediate surroundings or intended future careers, but admittedly that can be a high bar. However, it is not so difficult to find some meaningful task a person in some occupation would need to carry out that utilizes the knowledge and skills involved in the problem. If you find yourself unable to find any such context, you should ask yourself why you are bothering to teach this material. I have dropped more than one topic after this realization.

The other design criteria for good homework problems are that the problems and the required solutions explicitly involve all the items, a) to j) above, as mapped onto the context of the specific content and concepts and solution procedures that you want students to master. There may well be other aspects of expert thinking you also want to include, both more discipline-specific aspects and less (e.g. "be able to write an articulate well-reasoned explanation"), depending on your learning goals. No single problem needs to include all items.

As you incorporate the design features a)-j) in your homework problems, make them an explicit part the solution that students are required to produce (or stand-alone problems for specific features). For example, a part calling for a list of the concepts that apply and what features of the problem determine that choice, a part asking for what quantities/information are needed and estimates for values of any quantities not given, what procedures or techniques will be employed (Fourier transformation, use of multiple equations with multiple unknowns, …), approximations to be used, justification for why the answer makes sense and the criteria used to support that justification. This means a solution will involve far more than something like a simple number or fact. It provides them with far more explicit practice and feedback on how to develop and improve expert skills than does producing a single number which they find out is correct or not.

Grading homework

Such detailed solutions can be challenging to grade if one has many students and little support. There are various options for reducing the grading burden.

1) Computer grading. Many parts of such a problem can be computer graded if one structures them appropriately. For example, asking what concepts apply can be made into a multiple choice question, where the options are the 20 or so concepts covered in the entire course and students have to choose all that apply. These same choices are given for every problem like this. One can have a similar list of perhaps 10 or so criteria to use in checking if an answer or intermediate result makes sense. These sorts of more demanding multiple choice computer graded problems can be made even richer by having ranking or ordering tasks of the items.

2) Grade selectively. For problems poorly suited to computer graded format, grade some fraction (1/2-2/3) with full credit if turn in any serious attempt at solution, with more detailed grading and feedback on the remainder.

3) Use peer grading, in which students grade each other's solutions. There are computer programs to facilitate the process. Two documents with resources and guidance on student peer review are posted on the CWSEI website at http://cwsei.ubc.ca/resources/instructor_guidance.htm#assess.

Make the last question of every homework set be "How much time did you study for this class this week?" Monitor those responses and adjust workload accordingly to match institutional expectations.

Having students attend to feedback on homework

Using feedback to improve is vital for learning. We have found three simple ways to encourage this.

1. For any question on which a student loses points, give them the option of getting some fraction (1/4-1/2) back by turning in an explanation of *what was incorrect about their thinking that resulted in the error*.
2. Have each homework set contain a "reflection" problem such as, "Review your previous homework and the solution set, and then list all the problems you did incorrectly, what you did that was incorrect on each of those problems, and what you need to do differently on future problems of this type. If you did all the problems correctly, identify how you could improve a solution or which problem was most difficult and explain why."
3. Have the exam problems be *very* similar to homework problems and advertise to the class that this will be the case. It is easier to do this if you have good explicit learning goals for the course where it is clear that both homework and exam problems are testing the achievement of the learning goals.

References: **1.** A. Ericsson, R. Krampe, C. Tesch-Romer, Psychological Review 100, 363-406 (1993); **2.** T. Byun and G. Lee, Am. J. Phys., Vol. 82, 906 (2014); **3.** Deslauriers, Schelew, and Wieman. 2011. Science 332:862-864

Creating and Using Effective Learning Goals

CU-SEI and CWSEI

An important first step in course transformation has been to define explicit learning goals for each course which then shape the instruction and assessment. Here we briefly describe the process and benefits of writing learning goals. Learning goals explicitly communicate the key ideas and the level at which students should understand them in terms of what the students should be able to *do*. Learning goals take the form: "**At the end of this course, students will be able to...**" followed by a specific action verb and a task. For each course, faculty typically define five to ten course-level goals that convey the major learning themes and concepts, as well as topic-level learning goals (also known as "learning outcomes" or "objectives") that are more specific and are aligned with the course-level learning goals. Below are examples of learning goals from an introductory genetics course and a 2nd year physics course. A variety of other examples are available at the SEI learning goals resources link given below.

Examples of learning goals from an introductory genetics course (Univ. of Colorado-CU)

Course-level learning goal:

Deduce information about genes, alleles, and gene functions from analysis of genetic crosses and patterns of inheritance.

Topic-level learning goals:

a) Draw a pedigree based on information in a story problem.
b) Distinguish between different modes of inheritance.
c) Calculate the probability that an individual in a pedigree has a particular genotype or phenotype.
d) Design genetic crosses to provide information about genes, alleles, and gene functions.
e) Use statistical analysis to determine how well data from a genetic cross or human pedigree analysis fits theoretical predictions.

Examples of learning goals from a 2nd year physics course (Univ. of British Columbia-UBC)

Course-level learning goal:

Be able to argue that the ideas of quantum physics are true and that it is useful for engineers to know about them.

Topic-level learning goals:

a) Given a simple physical system, be able to draw the relevant potential energy curve needed to model dynamical behaviour.
b) Be able to explain the essential role of the quantization of light as demonstrated by the photoelectric effect in the operation of a photomultiplier tube, a solid state photodetector such as used in motion sensors, and the human eye.
c) Be able to design an experiment for determining the composition of an unknown pure metal based on the photoelectric effect.
d) For an unknown material, be able to analyze whether it is a conductor, insulator, or semiconductor, and then predict what electron energy distribution it must have.
e) Qualitatively design a semiconductor diode that will only allow current to flow in one direction.

The following process of developing learning goals has worked well for course transformations in the SEIs: A working group composed of faculty members who have previously taught a course and those who teach subsequent courses is formed. These working groups typically include a facilitator whose role is to review and synthesize materials, and create learning goal drafts. Learning goals are drafted by referring to materials used by instructors who previously taught the course, with emphasis on homework assignments, exams, and other materials that demonstrate what instructors want students to be able to do. Faculty members who teach subsequent courses communicate what they expect students to know coming into their course. The members of the working group discuss and revise these learning goals until a consensus list is generated, which for any instructor teaching the course would typically cover 70-80% of the class time. One of the most critical aspects of writing learning goals is choosing a verb that describes exactly what students should be able to do. Many faculty are tempted to use the verb "understand," but this is not specific – two faculty members could both say "understand" but have completely different expectations as to what students should be able to do. We recommend creating learning goals that convey the relevance and usefulness of any particular content to students. Use everyday language and applications when possible, and minimize the use of technical jargon. Many courses at CU and UBC include goals that focus on skills, habits of mind, and affective outcomes such as: "Students should be able to justify & explain their thinking and/or approach to a problem or physical situation."

Based on our experiences, we formulated a check-list to help instructors create and critique learning goals.

Check-list for creating learning goals:

- ☐ Does the learning goal identify what students will be able to do after the topic is covered?
- ☐ Is it clear how you would test achievement of the learning goal?
- ☐ Do chosen verbs have a clear meaning?
- ☐ Is the verb aligned with the level of cognitive understanding expected of students? Could you expect a higher level of understanding?
- ☐ Is the terminology familiar/common? If not, is knowing the terminology a goal?
- ☐ Is it possible to write the goal so it is relevant and useful to students (e.g. connected to their everyday life, or does it represent a useful application of the ideas)?

We also aligned the verbs with the cognitive level expected of students. The table below shows levels of learning and examples of verbs that match each level, based on Bloom's taxonomy of the cognitive domain.

Levels of cognitive understanding and corresponding verbs

Level	Description	Representative Verbs
Factual Knowledge	Remember & recall factual information	Define, List, State, Label, Name
Comprehension	Demonstrate understanding of ideas, concepts	Describe, Explain, Summarize, Interpret, Illustrate
Application	Apply comprehension to unfamiliar situations	Apply, Demonstrate, Use, Compute, Solve, Predict, Construct, Modify
Analysis	Break down concepts into parts	Compare, Contrast, Categorize, Distinguish, Identify, Infer
Synthesis	Transform, combine ideas to create something new	Develop, Create, Propose, Formulate, Design, Invent
Evaluation	Think critically about and defend a position	Judge, Recommend, Justify, Defend, Criticize, Evaluate

Benefits: Writing learning goals requires effort and time, but carries multiple benefits. Faculty use learning goals as they plan class time, develop homework, and create exams. All aspects of the course become better aligned, and focus on what faculty most want the students to achieve. Faculty using learning goals report that writing good exam questions becomes easier. At CU and UBC, we have seen that the cognitive level of exams often increases as faculty align the questions with the higher cognitive level of the learning goals.

Sharing the learning goals with students improves faculty-student communication. Learning goals are often posted online and each lecture begins with the relevant learning goals for the day. Surveys reveal that students are overwhelmingly positive about having access to learning goals. The greatest reported benefit is that learning goals let students "know what I need to know," which helps students focus on important ideas and study more effectively.

For departments, writing learning goals has informed, shaped, and aligned the departmental curriculum. By considering the learning goals from multiple courses, departments have discovered that some concepts were taught in an identical manner in multiple courses and other critical concepts were omitted entirely. As a result faculty members who teach different courses have begun to work together so that their goals complement each other and encompass what every student should be able to do by graduation. For instance, some fundamental evolution concepts were added to the CU biology curriculum after this process revealed their absence.

Resources:

www.cwsei.ubc.ca/resources/learn_goals.htm – Examples of learning goals from many UBC & CU SEI science courses.

"At the end of my course, students should be able to …": The benefits of creating and using effective learning goals, Michelle Smith & Kathy Perkins, Microbiology Australia, pp. 35-37 (2010). http://microbiology.publish.csiro.au/?act=view_file&file_id=MA10035.pdf

What is the Value of Course-Specific Learning Goals?, Beth Simon and Jared Taylor, J. Coll. Sci. Teaching, **39**, pp. 52-57 (2009).

A Thoughtful Approach to Instruction: Course transformation for the rest of us, S. Chasteen, K. Perkins, P. Beale, S. Pollock, & C. Wieman, J. Coll. Sci. Teaching, **40**, pp. 24-30 (2011).

Promoting course alignment:
Developing a systematic approach to question development

By Françoise Bentley and Teresa Foley, 2010
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When students cannot easily determine the connection between assessments in a course, they often complain that such assignments or activities are "busy work" and "do not help in preparing for the upcoming exam." In order to avoid such discontinuity, it is important that every element of a course be aligned with a set of well-defined learning goals. Using the following systematic approach, faculty can develop a bank of questions that align with a single learning goal. These so-called "suites" of questions can then be used in different settings to measure student learning. For example, one or more questions could be used for formative assessments (e.g., a clicker question, quiz, or homework), while a variation of the question(s) could be used on a summative assessment (e.g., a final exam). This systematic approach to question development helps faculty focus on their primary educational goals, while it allows students see that the practice they are receiving from assessments is measuring and improving their learning. As an added bonus to using this approach, course exams can be written well in advance of the exam date!

Steps for developing "suites of questions"

1. Start by choosing a learning goal that you would like to assess.

2. Determine the settings where you would like to assess your students (i.e. during lecture, homework, exam, recitation/tutorial, or lab).

3. Develop an initial question for this goal. An application-type question where the students have to predict the outcome of a change in a scenario works best for creating a suite of questions.

   For example, you could create a clicker question that has the students predict the result of <u>increasing</u> a certain variable.

4. Identify what aspects of your question have differing variables/factors that can be changed over a series of questions.

   Using the example above, a related homework question would have students predict the result of <u>decreasing</u> that same variable.

5. Depending on the nature of the question, you can develop at least one exam, one clicker, and one homework question aligned to the same learning goal.

   For example, the corresponding exam question would have students read the scenario and predict if a variable <u>increases, decreases, or causes no change in a particular output quantity</u>.

Example “suite of questions” for a common learning goal

<u>Learning goal</u>: Predict whether a molecule will move across a cell membrane and by what mechanism; explain how concentration and/or electrical gradients influence its movement.

<u>Homework question:</u>

Below is a depiction of a portion of the cell membrane that is positively charged on the intracellular side and negatively charged on the extracellular side. Further in this cell, the concentration of ion X^+ in the intracellular space is high and in the extracellular space is low.

++++++++++++++++++ intracellular $[X+]_{high}$
<- membrane
- - - - - - - - - - - - - - - - - - extracellular $[X+]_{low}$

Use the figure above to determine what gradients play a role in the movement of ions.

Does an **electrical gradient** exist for X^+? If it exists, what is the direction?
No. b) Yes, inward. c) Yes, outward.

<u>Clicker question</u> using the same scenario as the homework question:

Does a **concentration gradient** exist for X^+? If it exists, what is the direction?
No. b) Yes, inward. c) Yes, outward.

In these examples, the homework and clicker questions are assessing the same concept (electrochemical gradients and ion flow), but in multiple ways. For an exam question, you could use a different ion and have the students predict the electrical and concentration gradients of a related scenario.

<u>Exam question:</u>

Consider a typical cell that is temporarily hyperpolarized to -100mV.

What would be the direction of the chemical and electrical forces acting on K^+ while the cell is hyperpolarized?

a) chemical in, electrical in
b) chemical in, electrical out
c) chemical in, no net electrical
d) chemical out, electrical in
e) chemical out, electrical out
f) chemical out, no net electrical
g) no net chemical, electrical in
h) no net chemical, electrical out
i) no net chemical, no net electrical

Observation Guide/checklist for an Active-learning Classroom

(simplified version on 3rd page) C. Wieman 6/5/16

(This is to apply to modest size class, 6 to 80 or so, where students can work in groups, with the instructor circulating around them, often with TA helping.)

I. Activity design (assuming worksheet)

a. Is goal of activity clear to students, so they engage quickly, or do they spent time trying to figure out what they are supposed to be doing or why?

b. Does goal of activity seem appropriate? Does it involve practicing some skill that experts commonly use? Does it involve creating or interpreting a novel representation? Is there a particular difficulty or controversy in the task, rather than simply carrying through a lengthy procedure or something involving lots of writing, which could be better done as individual homework?

c. Motivation-- is activity put in meaningful context (address real world issue or clear how will be useful in future activities)? Does task involve a decision or judgement with justification? Is task challenging, but doable working together, but with some easy initial parts that everyone can become engaged with? Does it relate to the type of problems on future exams and/or homework?

II. Activity Implementation

a. Is it introduced in terms of big picture and/or learning goal for day? Does the instructor periodically return to this to remind students how they are progressing through big picture?

b. Is there something students have to first do individually, ideally with some kind of product, before engaging in collaborative work?

c. If there is any confusion about task, does instructor quickly notice and clarify to whole class?

d. Is there a clear deliverable (completed worksheet etc.) that students are expected to produce? (Ideally both individually and collectively.)

e. Does the instructor circulate, monitoring how each group is doing, helping as needed but not spending too much time with one or small number of groups while neglecting the others? Are the instructor and TA appropriately dividing up oversight and feedback?

f. Are groups being monitored for level of engagement, group interaction, and progress towards solution?

g. Does instructor or TA tend to jump in with answers or long lectures to groups or larger class before students have had sufficient opportunity to struggle with task?

h. Are groups kept to appropriate size (2-4) so everyone can be engaged? Does the instructor intervene to encourage interaction in group where needed?

i. Are there checkpoints at appropriate intervals, where instructor breaks in and makes sure everyone has reached a specific point, to resynchronize activities and ensure spread between groups is not getting too large and no group is stuck for too long?

j. Is instructor monitoring progress and keeping duration of task appropriate, so few if any groups are finished for long enough to get off task, but all groups have been able to make substantial progress, before instructor brings class together for whole-class wrap up discussion?

k. Is there appropriate wrap up, which brings out the important ideas and covers things some or all groups did not figure out, but avoiding spending time redoing what all groups already successfully completed? (i.e. is wrap-up adjusted according to how students did on the activity?). Is engagement encouraged by having various groups explain different parts of answer? Does wrap up lecture go on so long and/or repeats what they have already done, so that students start to disengage (not looking at instructor, etc.)? Do students never engage in the first place, because they know instructor will just be going through a detailed answer, regardless of what they do?

l. Does instructor pause for questions and allow plenty of time (at least several seconds!) for students to formulate questions? Does instructor take good questions got during circulating amongst groups and bring them up during wrap up (either by telling the student is good question, wait and ask during wrap up if appropriate, or repeating the question asked)?

III. Student understanding and engagement

a. How many students are off task and for how long? Are all students productively engaged, both individually when supposed to be, and as part of group when supposed to be?

b. When groups are stopped and raising their hands with a question, does instructor or TA notice them quickly? Are there times when multiple groups are waiting with hands raised waiting for help?

c. Are there any students who are being excluded from group discussions? Are these issues of chair and table layout, group size, gender or ethnicity? Does instructor notice and intervene to encourage collaboration?

d. Are most groups getting activity nearly completed?

e. Are many students asking deep questions during activity wrap up phase?

f. Are there students not asking questions of the instructor, but whispering to neighbors during or right after instructor talking or at start of next activity? (May indicate they have question but are uncomfortable asking.)

Observation Guide for an Active-learning Classroom--simplified C. Wieman 6/5/16

(This is to apply to modest size class, 6 to 80 or so, where students can work in groups, with the instructor circulating around them, often with TA helping.)

I. Activity design (assuming worksheet)

a. Is goal of activity clear to students, so they engage quickly?

c. Do the students show interest in the task, as indicated by level of attention and discussion?

II. Activity Implementation

a. Is it introduced in terms of big picture and/or learning goal for day? Does the instructor periodically return to this?

d. Is there a clear deliverable (completed worksheet etc.) that students are expected to produce? (Ideally both individually and collectively.)

e. Does the instructor circulate, monitoring how each group is doing, helping as needed but not spending too much time with one or small number of groups while neglecting the others?

f. Are groups being monitored for level of engagement, group interaction, and progress towards solution, with intervention where evident problems?

i. Are there checkpoints at appropriate intervals (5-10 minutes), where instructor breaks in and makes sure everyone in class has reached a specific point?

j. Is activity being cut off at suitable time, usually with balance of some but not all groups being finished, but all making substantial progress?

k. Is there appropriate wrap up, which brings out the important ideas and covers things some or all groups did not figure out, but avoiding spending time redoing what all groups already successfully completed? (i.e. is wrap-up adjusted according to how students did on the activity?).

l. Does instructor pause for questions during wrap up and allow plenty of time (at least several seconds!) for students to formulate questions?

III. Student understanding and engagement

a. Are all students productively engaged when supposed to be? (Periodically check how many checking phones or otherwise obviously off task.)

b. Are there groups spending significant time waiting with hands raised?

c. Are there any students who are being excluded from group discussions?

d. How many students are asking substantial questions during the class?

Guide to reflection on effective course design and implementation.

(could possibly be used in tenure tenure/promotion package, or for accreditation.)

For your course, explain if and how you incorporated the following elements:

Course Design. (see below for explanations and learning research justifications of the items listed)

1. How do your learning objectives reflect how students will be learning to make decisions like those of an expert in the area (e.g. when solving problems, diagnosing, explaining, etc.)?
2. How did you determine and address the relevant prior knowledge and beliefs (both helpful and not) of the students?
3. How have you reduced superfluous demands on students' working memory?
4. How did your activities and assignments support the students developing an expert organization of the respective knowledge?
5. How did you motivate students to value the material and work hard to master it?
6. How were the necessary component skills and concepts identified, and how did you have students both practice the individual skills and put them together to solve larger problems?
7. How was guiding feedback folded into students' practicing of authentic problem solving/analysis?
8. How are you providing multiple opportunities spread throughout the course for students to revisit important topics or skills, to improve long term retention?
9. How did you create a desirable course climate where all students felt comfortable participating and being part of a learning community?
10. How are you preparing students to continue learning as part of their professional practice?

Implementation.

- Complete the teaching practices inventory (TPI) for the proposed course, looking at the results broken down by category. http://www.cwsei.ubc.ca/resources/TeachingPracticesInventory.htm
  In processing of completing it, you may get some good ideas of things to modify or add.
- List the main features of implementation of this design in terms of what you do and what you have the students do in and out of class (*beyond what is already characterized by the TPI*).
- List the main features of assessment you used and describe how those were aligned with the course design goals.

Explanation for course design elements listed above. For much more complete discussions, see the books "The ABCs of How We Learn", and "How Learning Works".

1. Good learning objectives go beyond the content to be covered. They are operationalized in terms of what students can do, and they take into consideration when and how students will use that content. They should help the students establish a hierarchy of importance, by identifying the few big ideas across the course, rather than treating every fact and skill at the same level of importance.
2. Prior knowledge has a tremendous influence on what students are able to learn from a course and what they find difficult or easy, as well as what motivates and demotivates them. Instructors often project their own knowledge onto students, without recognizing the misconceptions or holes that may exist in students' prior knowledge. These overlooked holes often result in students' becoming overwhelmed as new material is presented.
3. The brain can only pay attention to and process a very limited set of new ideas due to the limitations in the capacity of the short term working memory. Learning is improved by avoiding any inessential mental demands, such as caused by use of jargon, overly complex and detailed figures or lack of figures when explaining spatial relationships, and poorly organized material.
4. Experts in a subject have highly structured knowledge that enables them to effectively and efficiently access needed information. The structure helps them recognize how one idea relates to another, in which context one idea is more important than another, and what information is relevant and needed for a given problem and what is irrelevant.
5. Serious learning requires a large mental effort. The motivation to put in that effort plays an enormous role in the how much a student will learn. Making the material interesting and relevant in the short or long term to the students' goals, making them believe they can succeed, and providing assessments that seem authentic will all enhance motivation.
6. Decomposing and sequencing complex concepts and skills is a key step for a teacher as it calls upon their expertise in the subject, which students have yet to develop. Often times, teachers can give students the individual pieces, but overlook that putting them back together to solve complex tasks also calls for expertise that students must learn through practice.
7. To increase their expertise, students must practice the thinking and decision making of experts by doing challenging tasks that explicitly practice that thinking. But no instruction or student is perfect, and there will be a need for feedback. To optimize learning, students need timely and specific feedback which they can use to self-correct. To reach higher levels of mastery, students also need to learn to generate their own feedback without supervision (e.g., by checking their ideas).
8. To become highly fluent in the material and have long term retention, students need to revisit key facts and skills multiple times throughout the course.
9. While students are individuals, much of their learning occurs in social settings, such as a class, and is highly dependent on social interactions. Social forces can enhance or inhibit learning.

The mastery students get from a course or program will always be far less than what is required for a successful career. Students need to be prepared to learn on their own in a variety of contexts.

Readings below are just for reference, not included in required reading for training workshop.

Grading-- research and philosophy (by C. Wieman)

Grading is a matter of individual philosophy and preferences, but here I (Carl Wieman) offer some relevant research and my personal opinions. It is important to recognize that by the time they reach college, students have been conditioned to believe that grades define what is important, and so an activity is seen to be important for learning only if it is associated with a grade. For this reason, and the weakness of standard course exams to measure many important elements of mastery, as discussed below, I have attach grades to many different components of the course, essentially rewarding students for everything they might do that will contribute to their learning, such as preparing for class, participation in class, homework, exams, follow-up review of their mistakes, etc. The amount each counts to their grade depends somewhat on the effort required, but students are not very discriminating as to the point value versus the time required, only that there are points attached.

With regard to how heavily to weight exams in grading, first, it is important to realize that the classic examination, where students are sequestered in room with no access to resources, is a far less meaningful measurement of mastery than what most instructors assume. As discussed in the two page summary in this workshop guide of the Gibbs and Simpson review of assessments, the outcomes of such exams show little correlation with performance of later real world tasks. There are two primary reasons for this. First, as normally created by the typical instructor, the actual exam questions and how they are graded are quite idiosyncratic. Students frequently report they do better when they focus more on the instructor's idiosyncrasies in asking questions instead of on mastering the material. This is avoided when there are detailed learning goals of the type discussed in this guide that serve to define the course instruction and the exam questions, but that is not typically the case for most courses.

The second likely reason for the lack of correlation between authentic tasks and exam scores is that they involve such different thinking. In solving real tasks, the best workers are very efficient and effective at tapping into other sources of knowledge and expertise (written and in person) and applying this to solving the problem at hand. They also have to make extensive decisions about what are appropriate approximations and simplifications. Under the typical sequestered exam conditions and problems, neither these nor other important skills come into play. However, the sequestered exam does demand unique specialized skills, such as being able to balance off accuracy against meeting severe and arbitrary time constraints. This often calls for solutions procedures that are undesirable in solving real world problems. Finally, the high stress environment of the high-stakes sequestered exam results in performance being considerably affected by the students ability to handle the stress, something that is known to be influenced by social-psychological factors unrelated to mastery of the material.

The research indicates that learning is improved if there are frequent low stakes exams, and one or a few high stakes exams is detrimental, as one would expect from the ideas above. Another way grading can have a detrimental impact learning is grading "on a curve" where a student's grade is determined only by how they compare with other students. This discourages students from realizing the substantial benefits of collaborative learning. My personal philosophy has been to make exams as authentic as possible by allowing complete access to books, notes, and internet. I was intimidated at first at creating such an exam, it turned out to be easier than I thought. Anything a student can look up and learn within the very limited time of the exam is so unimportant I don't want remembering it to count very much, and any question that follows a substantial learning goal is impossible for a student to do unless they come into the exam with a substantial body of knowledge.

Making the most of demonstrations, videos, animations, or simulations in lectures and laboratories

Jane Maxwell and Jared Stang, CWSEI, 2015

This 2-pager is based on a workshop offered at the UBC Annual Science Education Open House on April 13, 2015, www.cwsei.ubc.ca/EOYevent.html. Many thanks to all those who participated for sharing their ideas and insights!

Make a prediction: Which of the following resources will lead to the most learning: an animation of a dynamic process (e.g. a heart pumping blood), or a set of static images and descriptions for the same process?1
No really – make a prediction before you read any further!
Ready? It turns out that there is no significant difference in the learning gains achieved using animations and static images, so long as the two resources include the same content.2,3,4 To understand this counter-intuitive result, consider the reasons why students may fail to learn from a demonstration, video, animation, or simulation (referred to from now on as demo/video).

Students may fail to learn from demos/videos if they:[5]

- See demos/videos as entertainment or as a break from lecture rather than as an opportunity to test or expand their understanding
- If seen as unimportant, students will tune out or switch into passive observer mode
- Lack prior knowledge required to interpret the demo/video
- Novices may struggle to distinguish signal vs. noise
- Failure to connect concrete elements of demo/video with symbolic representations used in class and on tests
- Possess *incorrect prior knowledge* that biases their interpretation
- Students may even misperceive or misremember what happened in the demo/video, in which case the demo/video may increase their confidence in that misconception
- Mistake familiarity with what is happening in the demo/video for true understanding
- Lack opportunities to test their descriptions and explanations

We can summarize the points above by saying that, ***in order to be effective for learning, a student must invest mental effort in using the demo/video to test or further their own understanding***.

In the earlier case of animations vs. static images, the animations may actually require students to invest less mental effort, since students "don't have to mentally envision how the parts are moving."[1]
Acknowledging that not all videos, simulations, animations, and demonstrations are optimized to help students engage in this way, what strategies are available to instructors to overcome the pitfalls and encourage students to invest their mental effort?

Strategies to help students learn from demos/videos:

- Before the demo/video, give clear prompts how students should engage
- Whenever possible, ask them to make a prediction; this significantly increases the number of students who correctly observe the demo[6]
- "As you watch this, I want you to focus on/look for…"
- Have students record a measurement from the demo/video, if appropriate
- Pause to refocus or provide new prompts as needed

Strategies to help students learn from demos/videos (continued):

- Clearly communicate how the demo/video is important/helpful to learning
- How does it connect to learning goals?
- How will engaging with the demo/video help students to succeed on assessments?
- Incorporate contrasting cases to help students to focus on key features
- In live demos or simulations, compare/contrast at least 2 different conditions so that students observe *trends* or *differences* rather than isolated phenomena
- For videos and animations that don't include contrasting cases, or if time is short, add a hypothetical contrasting case: "What would happen if we changed…"
- Ask students what they saw, rather than assuming that they all perceived the results in the same way you did

"What did you see/notice?"

"What were the key features …"

- Incorporate different representations along with videos/demonstrations
- Consider how students would be asked to represent the information on a test or assignment and incorporate those representations (shorthand notations, equations, vector diagrams, circuit diagrams, graphs, molecular structures, …)
- Even better, have the students create these representations before checking them against your own!
- Provide students with opportunities to develop and test their explanations
- Before the demo/video, "Why did you make that prediction?"
- Once students have observed the demo/video, "What happened and why?"
- Pause and allow time for students to think individually or write down their explanations
- Ask students to test their explanations with peers and look for points of disagreement or confusion
- Use clickers or worksheets to add structure, collect feedback, and ensure that instructions are clear and students are participating
- Consider showing the demo/video in parts, with pauses for students to predict, write an explanation, and/or talk to their neighbor about what they're seeing and thinking
- Leave time for questions and listen carefully

References and resources:

2. Derek Muller, "This will revolutionize education," https://www.youtube.com/watch?v=GEmuEWjHr5c
3. Boucheix, Schneider (2009) Static and animated presentations in learning dynamic mechanical systems. *Learning and Instruction*. 19(2), 112-127
4. Clark (1994) Media will never influence learning. *Educational Technology Research and Development*. 42(2), 21-29
5. Kim et al. (2007) The effect of animation on comprehension and interest. *Journal of Computer Assisted Learning*. 23(3), 260-270
6. Roth, McRobbie, Lucas, Boutonné (1997) Why may students fail to learn from demonstrations? A social practice perspective on learning in Physics. *Journal of Research in Science Teaching*. 34(5), 509-533
7. Miller et al. (2013) Role of physics lecture demonstrations in conceptual learning. *Physical Review Special Topics - Physics Education Research.* 9(2), 020113-1 - 020113-5
8. PhET interactive simulations, https://phet.colorado.edu/en/simulations/category/new
9. Sokoloff, Thornton (2004) *Interactive Lecture Demonstrations, Active Learning in Introductory Physics* (p. 374). Hoboken, NJ; John Wiley & Sons, Inc.