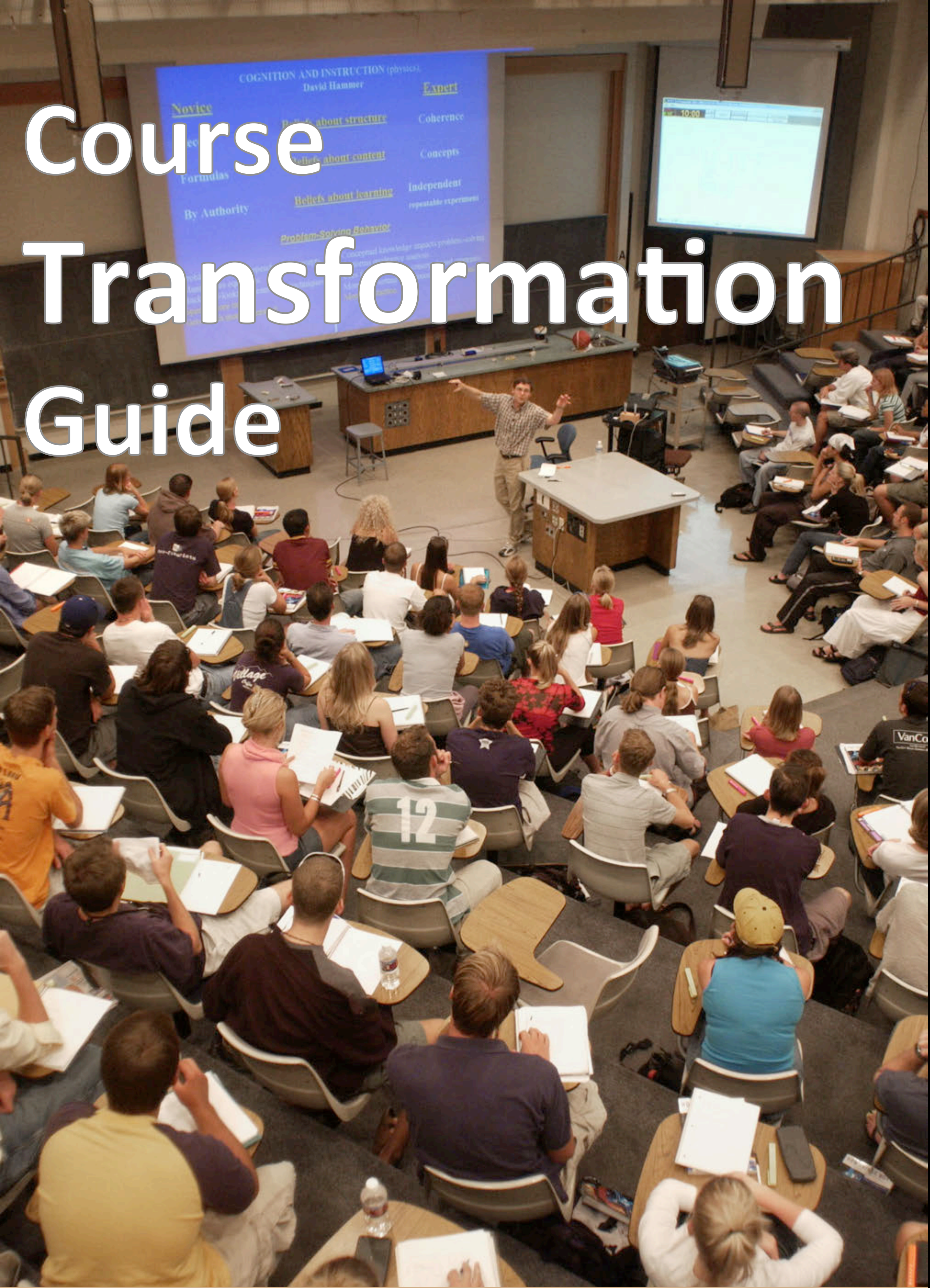
Course Transformation Guide



UBC and CU Science Education Initiatives

A guide for instructors interested in transforming a course, and their instruction, to use research-based principles and improve student learning.

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Course transformation framework—Overview

Carl Wieman

Introduction

I have been involved in the transformation of the instructional practices of many science courses. Initially I did this for my own courses, and later I was supporting the efforts of other faculty, as part of the Science Education Initiatives at the University of Colorado and the University of British Columbia to transform dozens of courses in many different departments. These transformations implemented research-based instructional practices to increase student engagement and learning.

This packet of materials is a guide for faculty for carrying out such a transformation. In some respects such a course transformation is much like doing a science experiment, there are numerous techniques and details that one needs to know, but one has to also understand the concepts and principles behind the design to be successful. This guide is an attempt to put all of this, from underlying concepts through details of successful implementation together in as succinct a fashion as possible.

Background

Results from research on learning provide 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, particularly as they apply to science and engineering education, are provided in the excerpt from my article "Applying New Research to Improve Science Education" that is below.

Very briefly, the essential elements for effective learning are:

- Students 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.

With this framework in hand, you now need to look at all the components of a course you will be teaching and map these essential instructional elements onto those components in a consistent fashion, in accord with the constraints and opportunities afforded by the context in which the course is situated. Unless there are a lot of resources and prior information available, it is usually more successful to not carry out a total transformation in the first iteration of the course, but rather to develop the design and then incrementally add things over two or three iterations of the course.

<u>Primary components and relevant constraints on course design</u>

- **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, problem sets, projects, papers, and other mechanisms for student to further engage with the topics at their own pace.
- **Assessment and feedback, both formal and informal.** In-class clicker question and discussion, via 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 (what is known and what are the needs for diagnostics), prerequisites or lack thereof, constraints related to preceding and/or following courses in an established sequence, TA support, grading support, instructor time, technology that can be used to support instruction, etc.

There is never enough information available to get a course transformation perfect on the first try under any circumstances, 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.

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.

CARL WIEMAN

Applying New Research to Improve Science Education

Insights from several fields on how people learn to become experts can help us to dramatically enhance the effectiveness of science, technology, engineering, and mathematics education.

Science, technology, engineering, and mathematics (STEM) education is critical to the U.S. future because of its relevance to the economy and the need for a citizenry able to make wise decisions on issues faced by modern society. Calls for improvement have become increasingly widespread and desperate, and there have been countless national, local, and private programs aimed at improving STEM education, but there continues to be little discernible change in either student achievement or student interest in STEM. Articles and letters in the spring and summer 2012 editions of Issues extensively discussed STEM education issues. Largely absent from these discussions, however, is attention to learning.

This is unfortunate because there is an extensive body of recent research on how learning is accomplished, with clear implications for what constitutes effective STEM teaching and how that differs from typical current teaching at the K-12 and college levels. Failure to understand this learning-focused perspective is also a root cause of the failures of many reform efforts. Furthermore, the incentive systems in higher education, in part driven by government programs, act to prevent the adoption of these research-based ideas in teaching and teacher training.

A new approach

The current approach to STEM education is built on the assumption that students come to school with different brains and that education is the process of immersing these brains in knowledge, facts, and procedures, which those brains then absorb to varying degrees. The extent of absorption is largely determined by the inherent talent and interest of the brain. Thus, those with STEM "talent" will succeed, usually easily, whereas the others have no hope. Research advances in cognitive psychology, brain physiology, and classroom practices are painting a very different picture of how learning works.

We are learning that complex expertise is a matter not of filling up an existing brain with knowledge, but of brain development. This development comes about as the result of intensive practice of the cognitive processes that define the specific expertise, and effective teaching can greatly reduce the impact of initial differences among the learners.

This research has established important underlying causes and principles and important specific results, but it is far from complete. More research is needed on how to accomplish the desired learning most effectively over the full range of STEM skills and potential learners in our classrooms, as well as how to best train teachers.

What is learning STEM?

The appropriate STEM educational goal should be to maximize the extent to which the learners develop expertise in the relevant subject, where expertise is defined by what scientists and engineers do. 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 problems and making decisions relevant to the discipline. As discussed in the National Research Council study *Taking Science to School*, modern research has shown that children have the capability to begin this process and learn complex reasoning at much earlier ages than previously thought, at least from the beginning of their formal schooling. Naturally, it is necessary and desirable for younger children to learn less specialized expertise encompassing a broader range of disciplines than would be the case for older learners.

Expertise has been extensively studied across a variety of disciplines. Experts in any given discipline have large amounts of knowledge and particular discipline-specific ways in which they organize and apply that knowledge. Experts also have the capability to monitor their own thinking when solving problems in their discipline, testing their understanding and the suitability of different solution approaches, and making corrections as appropriate. There are a number of more specific components of expertise that apply across the STEM disciplines. These include the use of:

- Discipline- and topic-specific mental models involving relevant cause and effect relationships that are used to make predictions about behavior and solve problems.
- Sophisticated criteria for deciding which of these models do or don't apply in a given situation, and processes for regularly testing the appropriateness of the model being used.
- Complex pattern-recognition systems for distinguishing between relevant and irrelevant information.
- Specialized representations.
- Criteria for selecting the likely optimum solution method to a given problem.
- Self-checking and sense making, including the use of discipline-specific criteria for checking the suitability of a solution method and a result.
- Procedures and knowledge, some discipline-specific and some not, that have become so automatic with practice that they can be used without requiring conscious mental processing. This frees up cognitive resources for other tasks.

Many of these components involve making decisions in the presence of limited information—a vital but often educationally neglected aspect of expertise. All of these components are embedded in the knowledge and practices of the discipline, but that knowledge is linked with the process and context, which are essential elements for knowledge to be useful. Similarly, measuring the learning of most elements of this expertise is inherently discipline-specific.

How is learning achieved?

Researchers are also making great progress in determining how expertise is acquired, with the basic conclusion being that those cognitive processes that are explicitly and strenuously practiced are those that are learned. The learning of complex expertise is thus quite analogous to muscle development. In response to the extended strenuous use of a muscle, it grows and strengthens. In a similar way, the brain changes and develops in response to its strenuous extended use. Advances in brain science have now made it possible to observe some of these changes.

Specific elements, collectively called "deliberate practice," have been identified as key to acquiring expertise across many different areas of human endeavor. This involves the learner solving a set of tasks or problems that are challenging but doable and that involve explicitly practicing the appropriate expert thinking and performance. The tasks must be sufficiently difficult to require intense effort by the learner if progress is to be made, and hence must be adjusted to the current state of expertise of the learner. Deliberate practice also includes internal reflection by the learner and feedback from the teacher/coach, during which the achievement of the learner is compared with a standard, and there is an analysis of how to make further progress. The level of expert-like performance has been shown to be closely linked to the duration of deliberate practice. Thousands of hours of deliberate practice are typically required to reach an elite level of performance.

This research has a number of important implications for STEM education. First, it means that learning is inherently difficult, so that motivation plays a large role. To succeed, the learner must be convinced of the value of the goal and believe that hard work, not innate talent, is critical. Second, activities that do not demand substantial focus and effort provide little educational value. Listening passively to a lecture, doing many easy, repetitive tasks, or practicing irrelevant skills produce little learning. Third, although there are distinct differences among learners, for the great majority the amount of time spent in deliberate practice transcends any other variables in determining learning outcomes.

Implications for teaching

From the learning perspective, effective teaching is that which maximizes the learner's engagement in cognitive processes that are necessary to develop expertise. As such, the characteristics of an effective teacher are very analogous to those of a good athletic coach: designing effective practice activities that break down and collectively embody all the essential component skills, motivating the learner to work hard on them, and providing effective feedback.

The effective STEM teacher must:

- Understand expert thinking and design suitable practice tasks.
- Target student thinking and learning needs. Such tasks must be appropriate to the level of the learner and be effective at building on learners' current thinking to move them to higher expertise. The teacher must be aware of and connect with the prior thinking of the learner as well as have an understanding of the cognitive difficulties posed by the material.
- Motivate the student to put in the extensive effort that is required for learning. This involves generating a sense of self-efficacy and ownership of the learning; making the subject interesting, relevant, and inspiring; developing a sense of identity in the learner as a STEM expert; and other factors that affect motivation. How to do this in practice is dependent on the subject matter and the characteristics of the learner—their prior experience, level of mastery, and individual and sociocultural values.
- Provide effective feedback that is timely and directly addresses the student's thinking. This requires the teacher to recognize the student's thought processes, be aware of the typical cognitive challenges with the material, and prepare particular questions, tasks, and examples to help the learner overcome those challenges. Research has shown several effective means of providing feedback, including short, focused lectures if the student has been carefully prepared to learn from that lecture.
- Understand how learning works, and use that to guide all of their activities. In addition to the research on learning expertise, this includes other well-established principles regarding how the human brain processes and remembers information that are relevant to education, such as the limitations of the brain's short-term memory and what processes enhance long-term retention.

Although many of these instructional activities are easier to do one on one, there are a variety of pedagogical techniques and simple technologies that extend the capabilities of the teacher to provide these elements of instruction to many students at once in a classroom, often by productively using student-student interactions. Examples of approaches that have demonstrated their effectiveness can be found in recommended reading articles by Michelle Smith and by Louis Deslauriers et al.

Effective STEM teaching is a specific learned expertise that includes, and goes well beyond, STEM subject expertise. Developing such teaching expertise should be the focus of STEM teacher training. Teachers must have a deep mastery of the content so they know what expert thinking is, but they also must have "pedagogical content knowledge." This is an understanding of how students learn the particular content and the challenges and opportunities for facilitation of learning at a topic-specific level.

This view of STEM teaching as optimizing the development of expertise provides clearer and more detailed guidance than what is currently available from the classroom research on effective teaching. Most of the classroom research on effective teaching looks at K-12 classrooms and attempts to link student progress on standardized tests with various teacher credentials, traits, or training. Although there has been progress, it is limited because of the challenges of carrying out educational research of this type. There are a large number of uncontrolled variables in the K-12 school environment that affect student learning, the standardized tests are often of questionable validity for measuring learning, teacher credentials and training are at best tenuous measures of their content mastery and pedagogical content mastery, and the general level of these masteries is low in the K-12 teacher population. The level of mastery is particularly low in elementary- and middle-school teachers. All of these factors conspire to make the signals small and easily masked by other variables.

At the college level, the number of uncontrolled variables is much smaller, and as reviewed in the NRC report *Discipline-Based Education Research*, it is much clearer that those teachers who practice pedagogy that supports deliberate practice by the students show substantially greater learning gains than are achieved with traditional lectures. For example, the learning of concepts for all students is improved, with typical increases of 50 to 100%, and the dropout and failure rates are roughly halved.

Shortcomings of the current system

Typical K-16 STEM teaching contrasts starkly with what I have just described as effective teaching. At the K-12 level, although there are notable exceptions, the typical teacher starts out with a very weak idea of what it means to think like a scientist or engineer. Very few K-12 teachers, including many who were STEM majors, acquire sufficient domain expertise in their preparation. Hence, the typical teacher begins with very little capability to properly design the requisite learning tasks. Furthermore, their lack of content mastery, combined with a lack of pedagogical content knowledge, prevents them from properly evaluating and guiding the students' thinking. Much of the time, students in class are listening passively or practicing procedures that neither have the desired cognitive elements nor require the level of strenuousness that are important for learning.

Teachers at both the K-12 and undergraduate levels also have limited knowledge of the learning process and what is known about how the mind functions, resulting in common educational practices that are clearly counter to what research shows is optimum, both for processing and learning information in the classroom environment and for achieving long-term retention. Another shortcoming of teaching at all levels is the strong tendency to teach "anti-creativity." Students are taught and tested on solving well-defined artificial problems posed by the teacher, where the goal is to use the specific procedure the teacher intended to produce the intended answer. This requires essentially the opposite cognitive process from STEM creativity, which is primarily recognizing the relevance of previously unappreciated relationships or information to solve a problem in a novel way.

At the undergraduate level, STEM teachers generally have a high degree of subject expertise. Unfortunately, this is not reflected in the cognitive activities of the students in the classroom, which again consist largely of listening, with very little cognitive processing needed or possible. Students do homework and exam problems that primarily involve practicing solution procedures, albeit complex and/or mathematically sophisticated ones. However, the assigned problems almost never explicitly require the sorts of cognitive tasks that are the critical components of expertise described above. Instructors also often suffer from "expert blindness," failing to recognize and make explicit many mental processes that they have practiced so much that they are automatic.

Another problem at the postsecondary level is the common belief that effective teaching is only a matter of providing information to the learner, with everything else being the responsibility of the learners and/or their innate limitations. It is common to assume that motivation, and even curiosity about a subject, are entirely the responsibility of the student, even when the student does not yet know much about the subject.

Failure of reform efforts

The perspective on learning that I have described also explains the failure of many STEM reform efforts.

Belief in the importance of innate talent or other characteristics. Schools have long focused educational resources on learners that have been identified in some manner as exceptional. Although the research shows that all brains learn expertise in fundamentally the same way, that is not to say that all learners are the same. Many different aspects affect the learning of a particular student. Previous learning experiences and sociocultural background and values obviously play a role. There is a large and contentious literature as to the relative significance of innate ability/talent or the optimum learning style of each individual, with many claims and fads supported by little or questionable research.

Researchers have tried for decades to demonstrate that success is largely determined by some innate traits and that by measuring those traits with IQ tests or other means, one can preselect children who are destined for greatness and then focus educational resources on them. This field of research has been plagued by difficulties with selection bias and the lack of adequate controls. Although there continues to be some debate, the bulk of the research is now showing that, excepting the lower tail of the distribution consisting of students with pathologies, the predictive value of any such early tests of intellectual capability is very limited. From an educational policy point of view, the most important research result is that any predictive value is small compared to the later effects of the amount and quality of deliberate practice undertaken by the learner. That predictive value is also small compared to the effects of the learners' and teachers' beliefs about learning and the learners' intellectual capabilities. Although early measurements of talent, or IQ, independent of other factors have at best small correlation with later accomplishment, simply labeling someone as talented or not has a much larger correlation. It should be noted that in many schools students who are classified as deficient by tests with very weak predictive value are put into classrooms that provide much less deliberate practice than the norm, whereas the opposite is true for students who are classified as gifted. The subsequent difference in learning outcomes for the two groups provides an apparent validation for what is merely a self-fulfilling prophecy. Given these findings, human capital is clearly maximized by assuming that, except for students with obvious pathologies, every student is capable of great achievement in STEM and should be provided with the educational experiences that will maximize their learning.

The idea that for each individual there is a unique learning style is surprisingly widespread given the lack of supporting evidence for this claim, and in fact significant evidence showing the contrary, as reviewed by Hal Pashler of the University of California at San Diego and others.

Because of the presence of many different factors that influence a student's success in STEM, including the mind's natural tendency to learn, some students do succeed in spite of the many deficiencies in the educational system. Most notably, parents can play a major role in both early cognitive development and STEM interest, which are major contributors to later success. However, optimizing the teaching as I described would allow success for a much larger fraction of the population, as well as allowing those students who are successful in the current system to do even better.

…

Recommended reading

S. Ambrose, M. Bridges, M. DiPietro, M. Lovett, and M. Norman, *How Learning Works: Seven Research-Based Principles for Smart Teaching* (San Francisco, CA: J. Wiley and Sons, 2010).

J. Bransford, A. Brown, and R. Cocking, eds., *How People Learn; Brain, Mind, Experience, and School* (expanded edition) (Washington, DC: National Academies Press, 2000).

G. Colvin, *Talent Is Overrated: What Really Separates World- Class Performers from Everybody Else* (New York : Penguin Books, 2008).

L. Deslauriers, E. Schelew, and C. Wieman; "Improved Learn- ing in a Large-Enrollment Physics Class," *Science* 332, no. 6031 (2011): 862–864; and particularly the supporting online material.

R. Duschl, H. Schweingruber, and A. Shouse, eds., *Taking Science to School; Learning and Teaching Science in Grades K-8* (Washington, DC: National Academies Press, 2007).

C. Dweck, *Self-Theories: Their Role in Motivation, Personality, and Development* (Philadelphia, PS: Taylor and Francis, 2000).

K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman, eds., *The Cambridge Handbook of Expertise and Expert Performance* (Cambridge: Cambridge Univ. Press, 2006).

H. Pashler, M. McDaniel, D. Rohrer, and R. Bjork, "Learning Styles: Concepts and Evidence," *Psychological Science in the Public Interest* 9 (2009): 105.

S. Singer, N. Nielsen, and H. Schweingruber, eds., *Understanding and Improving Learning in Undergraduate Science and Engineering* (Washington, DC: National Academies Press, 2012).

What all Instructors Should Know

Motivation is important for learning and is an essential part of effective teaching[1]

- Show that the subject is interesting, relevant, valuable to learn, worthwhile, fun, … Remember that most students do not have the benefit of your experience and perspective.
- Convey that subject is challenging but all students can master it with effort, and why it is worth the effort.
- Convey that you care about all students' successfully learning the material.
- Avoid: scare tactics, such as saying subject is really difficult; many students will fail, etc. These turn out to be demotivating to many students.[2]

Think of yourself as a "coach of thinking" rather than an as a "dispenser of information"

"Learning" requires intense mental activity with resulting changes in the brain of learner.[3]

Feedback that is timely and specific is critical for learning

- Timely, frequent, detailed feedback that shows how to improve ("formative assessment") should be provided for all students.
- Give marks for what you value (homework, reading, in class participation, quizzes, pre-tests, …). For most students, marks define the expectations and what is important in a course.[2]

Teach students how to learn

- Explicitly model expert thinking, being careful not to skip steps that are now automatic for you. Convey how to best learn the material and skills, teach students how to study effectively and what is required for conceptual mastery and retention.[3,4] These are fairly readily acquired skills that are seldom if ever taught.
- Know & teach using the best (proven) practices for achieving learning.[1, 5]

Dos and Don'ts for the first week

- Explain why you are teaching the way you are teaching, why course is worthwhile, what are your goals and expectations. The first classes set the tone for the rest of the term.
- Explicitly work to establish a desired class culture.
- Don't threaten or apologize for what or how you will teach.

Find out what all your students are thinking; recognize they think differently than do you

- Connect to and build on their prior knowledge, explicitly examine student preconceptions.[1, 3]
- Probe understanding and adjust teaching as appropriate when find many are not getting it.

Lay out framework, goals, & context for the knowledge & skills you want students to learn

- Teach the organization and application of the knowledge, rather than just the facts. This is the vital element of mastery that students have the most difficulty perceiving and mastering.[6]

Approach teaching as a challenging subject that can be mastered[1,3,4,5]

- The ability to teach effectively is not innate – it can be learned much like a scholarly discipline.
- Understand how people learn and what processes facilitate learning-- these are understood.
- Don't be afraid to copy what works. Use teaching practices that have been proven to be effective; they are readily replicated.

[1] The Wisdom of Practice: Lessons Learned from the Study of Highly Effective Tutors, in Improving Academic Achievement, ed. J. Aronson (2002) Academic Press.
[2] CWSEI and CU-SEI student interviews and focus groups, as well as other studies.
[3] How People Learn; brain, mind, experience, and school, Bransford et al. eds, (2000) NAS Press; S. Ambrose et. al., How Learning Works: Seven Research-Based Principles for Smart Teaching, J. Wiley and Sons, 2010
[4] CWSEI guidance for students (www.cwsei.ubc.ca/resources/student_guidance.htm)
[5] Bain, What the best college teacher do, (2004) Harvard Univ. Press
[6] refs. 1, 2, 3, and 5, and many other studies.

Specific strategies for instructional activities

This document gives strategies to achieve the essential elements of effective learning, motivation, practicing to master expertise, feedback etc. You should apply these strategies to all the course components. Most of this material is summarized from the excellent book, *How Learning Works: Seven Research-Based Principles for Smart Teaching.*[1] It is recommended that you buy that book, as it provides more detailed discussion.

- Motivation
- Developing mastery
- Practice & feedback
- Creating self-directed learners
- Creating productive views of intelligence and learning
- Memory and retention

[1] *How Learning Works: Seven Research-Based Principles for Smart Teaching,* S. Ambrose, M. Bridges, M. DiPietro, M. Lovett, M. Norman. San Francisco, CA: John Wiley & Sons (2010).

Motivation

Student motivation is a key ingredient in a successful course. Two major components of motivation, as identified by Ambrose et al., are

I. The **expectation**s that students bring to the classroom, and
II. The **value** that students place on the course material and tasks.

Ways to address students' expectations:

1. **Set attainable goals.** Students are best motivated when they feel optimally challenged – when the course and assignments are challenging, but students feel that they can be successful with some effort.
2. **Let students know your expectations**. Communicate your course goals, and how students can achieve those goals. Align instruction and assessment with those course goals – so that students can practice, and see whether they are achieving those goals. This helps to establish realistic expectations. The use of grading rubrics can help make your expectations of student performance on a task very explicit.
3. **Give students feedback**. Without feedback on their performance, students may lose sight of their progress towards a goal. Feedback is most effective when it is timely (i.e., without a long time delay), targeted (i.e., focused on a specific student performance on a specific task), and constructive (i.e., focusing on strengths and future action as well as weaknesses).
4. **Give students a sense of control and self-efficacy.** Self-efficacy is a very important ingredient to student motivation. Provide students with opportunities to feel successful early in the course. Be sure that your grading standards are seen as fair across students and over time. Provide students some flexibility and choice (for example, on assignment topics). Giving feedback on student progress towards well-articulated course and assignment goals can also enhance students' sense of efficacy and control. Also, help students focus on things that they can control (such as study habits), rather than personal characteristics (such as intelligence). *Avoid* threats and framing your course as competition among students, as these are typically demotivating.

Ways to address students' value of the material:

1. **Highlight the relevance of material and tasks.** Students are motivated to engage with material that relates to their personal interests, everyday lives, and academic or professional paths. Show students how these skills and ideas will relate to future courses and careers. Create assignments that are authentic and relevant; ensure that homework problems can pass the "Why should anyone care about the answer to this problem?" test.
2. **Get students to reflect on what they have learned. e.g., a**sk students to write a short paragraph on what they learned from a class or an assignment, and how it applies to an interesting or important problem.
3. **Be enthusiastic.** Your own passion and enthusiasm can be a powerful motivator for students.

For more information about how to effectively use motivation in your teaching strategies, see Chapter 3 of How Learning Works (Ambrose et al.), and CWSEI 2-pager: Motivating Learning at www.cwsei.ubc.ca/resources/instructor_guidance.htm .

Developing Mastery

According to Ambrose et al., in order to develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned.

Ways to help students learn key skills

1. **Get broad perspectives on necessary student skills.** Decompose tasks by asking, "What would students need to know / know how to do in order to achieve this task?" Use your graduate student assistants in this endeavor, as they more recently struggled with this material. Your colleagues are also good sources of information about necessary student skills, as are professionals outside your discipline.
2. **Identify weak/missing skills and help students practice them.** Early assessments (e.g., a diagnostic test of expected prior knowledge), as well as thoughtful analysis of student performance on assignments, can help you identify missing skills. Depending on the number of students exhibiting this lack of mastery, you can either devote class time and resources to the issue, or provide other resources. Create opportunities for students to work on their mastery of those skills. To address inaccurate prior knowledge (e.g., misconceptions), have students make and test predictions, and explicitly address any inconsistencies.

Ways to help students become more proficient

1. **Give students opportunities to practice.** As with other teaching practices, communicate your intent about the practice opportunities, and make your expectations about students' achievement level explicit.
2. **Use productive constraints to reduce cognitive load.** While practicing a skill, it can be helpful to reduce cognitive load by (a) calling students' attention to the key goals and features of a task (so they are not distracted by extraneous features) and (b) simplify tasks to hone in on key skills. Once they become more proficient, the complexity and scope of the task can be increased.
3. **Assess students on their proficiency.** Test students on how well they have integrated the components of complex tasks. This provides alignment between your goals, instruction, and assessment, and gives students feedback on their progress.

Ways to help students learn when to apply their knowledge

There are a wide variety of strategies for helping students learn to transfer ideas to new contexts, which are described in more detail in Ambrose et al. For example:

- **Discuss the contexts** and conditions in which a skill or approach is applicable, and give students practice in doing this. For example, ask them "Which statistical technique would be used to solve this problem?" or "What questions could this research method be used to investigate?"
- **Ensure that students practice** skills and understanding in many different contexts.
- **Encourage students to generalize** ideas from a specific context to a broader principle.
- **Make use of structured comparisons** to help students identify critical features. For example, you might give two problems that appear different, but use the same underlying principle.
- **Give prompts** to help students make connections between their knowledge and a new problem. For example, "Think back to the bridge we discussed last week."

For more information about how to help students develop mastery, see Chapters 1, 2, and 4 of How Learning Works (Ambrose et al.).

Practice and Feedback

Practice aimed at achieving specific goals and feedback on progress are critical for learning.

Ways to give students goal-directed practice

1. **Explicitly identify and communicate goals for students.** Make your expectations clear – both for student performance in the course overall, and on a given task. These goals can help guide their practice, especially when these goals are stated in terms of what students should be able to *do* at the end of an assignment or a course. Then, use rubrics to more specifically define performance criteria for a particular assignment.
2. **Support students in productive practice.** Give students multiple opportunities for practice (readings, quizzes, in-class activities, homework, etc.) so that they can develop skills and receive feedback. During these assignments, *scaffold* students' development by giving students more support early in learning (e.g., by breaking a task into parts for them), and later remove these supports. Create realistic expectations about the amount of practice required by giving guidelines for the amount and type of practice that will be needed. Instead of guessing how long it will take students to do a task, gather data by asking students how long it took them (e.g., the last item on a homework set could be: *How long did it take you to do this homework?*).
3. **Give students positive and negative examples of performance**. What would ideal performance look like? What types of work would *not* meet your goals?
4. **Modify your criteria as your students become more proficient.** Early in the course, determine an appropriate level of challenge by conducting an assessment of student knowledge. As students progress through the course, refine your goals to meet their changing proficiency.

Ways to give students targeted feedback

There are a wide variety of strategies for giving students feedback, which are described in more detail in Ambrose et al. For example:

- **Provide feedback to the class** as a whole about common errors (you can look for common errors in homework or tests, listen in on student discussions during in-class activities and problem solving sessions, etc.).
- **Focus your feedback** on key elements of the task, so that students are not overwhelmed.
- **Communicate about strengths as well as weaknesses.** If students have made progress, point that out to them—people are often unaware of the progress they are making.
- **Give frequent feedback**, made possible through use of frequent, smaller tasks.
- **Give real-time feedback**. Collecting group responses through colored cards or clickers lets you give feedback to the whole group.
- **Use student-to-student feedback.** Explicit guidelines can make student comments on each others' work even more valuable.
- **Have students reflect** on the feedback. Require students to incorporate feedback into later work or have them explain what they did wrong. Example from Carl Wieman's teaching: each homework set starts with "Q1. Select a problem from the last HW set that you did incorrectly and explain what you did wrong and what should be done differently to obtain correct answer."

For more information about how to give students opportunities for practice and targeted feedback, see Chapter 5 and Appendices D & H of How Learning Works (Ambrose et al.).

Becoming Self-Directed Learners

According to Ambrose et al, in order to become self-directed learners, students must learn to assess the demands of the task, evaluate their own knowledge and skills, plan their approach, monitor their progress, and adjust their strategies as needed.

How to help students learn to assess the task

1. **Communicate the nature of the task and check understanding.** Express the goals more explicitly than you might think is necessary, and what students will need to *do* in order to successfully complete the task. Check students' understanding of the task, and give them feedback on their understanding – for example, you might have them express the goal of the assignment in their own words. Be sure to tell students what it is that you do *not* want as well, by showing common student errors in the past.
2. **Give students criteria for success.** Share the criteria that will be used in student evaluation – for example, with a checklist or performance rubric. This helps students generate realistic understanding of the task, as well as learn to monitor their progress towards success.

How to help students evaluate their knowledge

1. **Assess early and often.** Periodic, timely assessments give students opportunity to get practice and feedback so that they can determine where their strengths and weaknesses lie – in time to make corrections before the exam.
2. **Have students assess themselves.** Reduce your grading burden by giving students tasks and have them check their own work using answer keys.

How to help students plan their approach

1. **Provide a plan.** Scaffold students' self-planning approach by providing them your own model for effective planning. This helps them see how a complex assignment might be broken down into pieces or plotted out over time.
2. **Have students create plans; provide feedback on students' plans.** Students might submit their plan as the first part of a complex assignment. This forces them to externalize their thinking, and gives you the opportunity to give them feedback on that plan.
3. **Compare and contrast strategies.** Problems or tasks can be approached in multiple ways; use of different strategies can help students understand the relative merits, particularly if they are given the task of explicitly determining advantages and disadvantages of different approaches.

How to help students learn to monitor their progress

1. **Model metacognition.** Walk students through your own approach to a problem or assignment, identifying different steps and questions that you would ask yourself to check your progress (e.g., "Am I making reasonable assumptions?").
2. **Provide strategies for self-correction and reflection.** Students can ask themselves, "Is that a reasonable answer?" "What assumptions am I making?" or "Is this task taking me too long?" Students can also benefit from reviewing classmates' work, especially when given a rubric.

For more information about how to help students become self-directed learners, see Chapter 7 and Appendices A & C *of How Learning Works (Ambrose et al.).*

Beliefs about Intelligence & Learning

According to Ambrose et al, these beliefs have a major impact on student motivation, choice of learning strategies and methods, and the achievement of effective monitoring and self-regulation of learning.

1. **Discuss the nature of learning.** Tell students about the various types of knowledge, from factual recall, to conceptual understanding, to applying those concepts. This can help move them away from an overly rigid view of learning ("you know it or you don't.") Address common misconceptions about learning, to move students away from unproductive ideas (e.g., "I'm not a math person.") Discuss the features of learning discussed in this document, such as the impact of practice on performance. Studies by Dweck and others have shown that a student's view of intelligence has a substantial impact on their motivation, approaches to learning, and their academic success. Those who have a view that intelligence is fixed ("There are right-brained people good at math and science and left-brained people who are not") are less successful than those who have a growth mindset ("Learning and mastery is achieved through hard work rather than innate talent."). These studies have also shown that such beliefs are quite malleable if explicitly addressed.
2. **Encourage students to persevere.** If students have unrealistic expectations about how quickly they will learn something, they may not push themselves when they hit difficulties. Discuss how you or others you know had to work to become expert in a field. Focus students on aspects of their learning over which they have *control*, such as their study habits, rather than external factors – such as their level of intelligence or aspects of the course. This helps to increase self-efficacy and a tendency to work through challenges.
3. **Show them the research.** Present research on learning showing how particular types of learner activities and practice are necessary for achieving expertise, and how teaching practices that involve greater student cognitive activity demonstrate greater learning. Show benefits of mentally demanding study strategies (e.g., "test yourself on retrieval and application of ideas", and fully engaged effort to solve hard problems) compared to less effective strategies (e.g., reread and review and practice of easy problems, or split-attention study activities).

For more information about how to address students' beliefs about intelligence and learning, see Chapter 7 of How Learning Works (Ambrose et al.).

Memory and Retention

Introduction – Research on memory

Memory can be divided into two types; the long-term memory which has a large information capacity and can remember information for many years, and the "working memory" which handles memory and processing of new information over periods of seconds and minutes and has a very limited capacity. Information enters (and leaves) the working memory quickly and easily. It is much harder to get information into long-term memory, and accessing it is also challenging due to interference among the different items in memory during the retrieval process. Repeated retrieval and application of the information, spaced out over time, is the most important element for achieving long-term memory. The working memory plays a major role in the mental processing that takes place in the classroom, and other similar time-constrained situations, and its limitations have a correspondingly large impact on learning that takes place in that setting. The human working memory has a remarkably small capacity, typically 4-7 new (e.g. not already in long-term memory) items. The working memory does not just store information, it also carries out basic processing, and so as it is called upon to remember more new items, its ability to process is correspondingly reduced, analogous to a computer with very limited RAM. The very limited capacity of the working memory has profound implications for the design of suitable classroom activities. It means that ***anything*** that puts additional demands ("cognitive load") on the working memory of the student has a cost in what the learner can process and learn. For example, every unfamiliar technical term introduced during a lecture has a significant impact on the capacity of the audience to follow arguments and process the ideas, even if it that term is clearly explained and/or unimportant. Similarly, studies have shown that anything that involves unnecessary input of information or processing during a learning activity has a detrimental effect. Mayer and colleagues have done a series of studies showing how the addition of "seductive details" commonly used by many teachers and textbooks, such as adding amusing anecdotes, attractive pictures, or background graphics that are only peripherally related to the topic, reduce learning.

Strategies to reduce unnecessary demands on the working memory in the classroom

1. Explicitly show how different topics or ideas are linked together, and explicitly show the organization of the class presentation/activities, emphasizing how the parts are connected. This helps the different topics to be consolidated ("chunked") in the working memory of the students rather than remain distinct, thereby taking up less capacity. Novices often do not recognize these connections that are obvious to experts.
2. Use analogies—this maps complex relationships onto existing relationships already in long term memory, so the working memory needs only remember the link to relevant part of long term memory.
3. Use pictures, even simple sketches, to illustrate spatial relationships, rather than relying on verbal descriptions that must be translated into images.
4. Provide worked examples for initial problem solving. Worked examples show the organizational structure and focus the learner's attention on key elements, reducing cognitive load.
5. Use pre-class reading assignments and quizzes to have students review definitions and basic examples before class. See *Preclass-Reading Assignments; Why they may be the most important homework for your students* (www.cwsei.ubc.ca/resources/files/Pre-reading_guide_CWSEI.pdf).
6. Keep the use of unfamiliar jargon to an absolute minimum; remembering each new term has a cost.

Strategies for Achieving Long Term Retention and Useful Access of Learning

1. Provide opportunities and encouragement to students to repeatedly test themselves on retrieving and applying material. The more active the cognitive processing involved in this, the better.
2. Make homework and exams cumulative so that students are reusing and thinking about the ideas multiple times in the presence of new material. Explain why this supports learning.
3. Provide multiple associations ("hooks") between material to be learned and material already in the students' long term memory.
4. Avoid covering material in a separated sequential fashion, where each topic is covered and tested only once and not revisited. While conducive to a well-organized syllabus, this is not conducive to useful learning. Students need to build broader associations and to practice sorting out interference between topics when accessing ideas in long-term memory. The additional cognitive processing required to sort out and suppress erroneous interference when studying interleaved topics acts to suppress such interference when accessing information in the future. Too often students will learn and retain that some concept or solution method is associated with Chapter 4, covered in week 6, but they will not develop the useful expert-like associations of the material with a suitable range of contexts, concepts, and problem types that will facilitate the desired access from long term memory.
5. Provide practice activities that explicitly build specific "expert" associations—those commonly recognized and used by experts. Have an assignment that asks students to explain all the ways a new solution method or principle might be used to solve problems associated with topics encountered earlier in the term. Have the students generate general criteria for deciding when this material might be useful.

References on memory and retention:

What college teachers should know about memory: a perspective from cognitive psychology, Michelle D. Miller, College Teaching, Vol. 59, pp. 117-122 (2011).

Memory and metamemory considerations in the training of human beings, by Robert Bjork, in Metacognition: Knowing about knowing (pp.185-205), J. Metcalfe and A. Shimamura (Eds.), Cambridge, MA: MIT Press (1994). http://bjorklab.psych.ucla.edu/pubs/RBjork_1994a.pdf

Increased interestingness of extraneous details in a multimedia science presentation leads to decreased learning, R. Mayer et al., Journal of Experimental Psychology: Applied, Vol. 14(4), pp. 329-339 (2008).

Learning from Examples: Instructional Principles from the Worked Examples Research, R.K. Atkinson et al., Review of Educational Research, Vol. 70, No. 2, pp. 181-214 (2000).

Recommendations for implementing specific instructional practices

The rest of this transformation guide provides guidance on a variety of instructional practices, both in and out of the classroom:

- Creating and using effective learning goals
- First day of class
- Better ways to review material in class
- Basic instructor habits to keep students engaged
- Pre-class reading assignments
- Tips for successful "clicker" use
- Student group work in educational settings
- Creating and implementing in-class activities; principles and practical tips
- What <u>not</u> to do
- Assessments that support student learning
- Promoting course alignment: Developing a systematic approach to question development

Creating and Using Effective Learning Goals

CU-SEI and CWSEI (2014)

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 (below).

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, Appraise, 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 – compilation of learning goals and other resources from the CU and UBC SEIs

"At the end of my course, students should be able to …": The benefits of creating and using effective learning goals, Michelle Smith and Katherine Perkins, Microbiology Australia, pp. 35-37, (March 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, Journal of College Science Teaching, Vol. 39, pp. 52-57 (2009).

A Thoughtful Approach to Instruction: Course transformation for the rest of us, Stephanie Chasteen, Katherine Perkins, Paul Beale, Steven Pollock, & Carl Wieman, Journal of College Science Teaching, Vol. 40, pp. 24-30 (2011).

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.

1. **Establish Motivation**
   a. 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, …

2. **Personalize the learning experience**
   a. Welcome students to your class – make it clear that you are looking forward to working with them.
   b. 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.]
   c. 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)
   d. 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]

3. **Establish Expectations** (best if also handed out and/or online, not just spoken)
   a. Describe overarching (course-level) learning goals—big picture view
   b. Emphasize that you want them to learn and your role is to support their learning
   c. Explain how course will be conducted, what will happen in class, expectations for out of class work, overview of schedule, and marking scheme

d. 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, …

e. 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 website
   - Give advice on how to study

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

4. Details (syllabus, detailed schedule, detailed learning goals, academic conduct, deadlines, rules …)

a. Don't go into details during first class; give links to more details on course
   - Could give an assignment involving reading these.

5. 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

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/)

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. The best preventative to avoid chatter getting out of hand is early in term pick someone who seems to be among the worst, find out their name, and then 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.

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

1. 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.
2. 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.
3. The reading should be guided with explicit prompts for the students of what to look for while reading.
4. 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.
5. 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.
6. 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.
7. 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.
8. 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.

A longer and more detailed discussion on the effective use of clickers in instruction is given in the SEI booklet "An instructor's guide to the effective use of personal response systems ("clickers") in teaching," see STEMclickers.colorado.edu for this guide and videos on effective clicker use.

Tips for Successful "Clicker" Use

© Dr. Douglas Duncan, University of Colorado, 2008

Including recommendations from members of the Carl Wieman Science Education Initiative

More than 1,000,000 clickers are in use nationwide, and over 17,000 at CU. Data gathered during the past few years makes it clear which uses of clickers lead to success, and which lead to failure. **Success** means that both the faculty member and students report being satisfied with the results of using clickers.

Clickers have many possible uses: Find out if students have done assigned reading before class; measure what students know before you start to teach them and after you think you've taught them; measure attitudes and opinions, with more honest answers if the topic is personal or embarrassing; get students to confront common misconceptions; facilitate discussion and peer teaching; increase student's retention of what you teach; transform the way you do demonstrations; increase class attendance; improve student attitudes. **None of these are magically achieved by the clicker itself.** They are achieved – or not achieved – entirely by what *you* do in implementation.

TECHNICAL POINTS:

- Try and get your school to adopt one clicker brand. Students ***hate*** being forced to buy more than one clicker!
- RF (radio) clickers are easier and cheaper than infrared ones.
- Simpler clickers (e.g. iClicker) have fewer implementation problems.
- Test your registration system before students do. Deliberately make some mistakes and see what happens. Check early in the semester that all responses are getting credited.

Practices that lead to Successful Clicker Use

1. Have clear, specific goals for your class, and plan how clicker use could contribute to *your* goals. Do not attempt all the possible uses described above at one time!

2. You **MUST MUST MUST** explain to students why you are using clickers. If you don't, they often assume your goal is to track them like Big Brother, and force them to come to class. Students highly resent this.

3. Practice *before* using with students. Remember how irritated you get when A/V equipment fails to work. Don't subject students to this.

4. Make clicker use a regular, serious part of your course. If you treat clicker use as unimportant or auxiliary then your students will too.

5. Use a combination of simple and more complex questions. Many users make their questions too simple. The best questions focus on concepts you feel are particularly important and involve challenging ideas with multiple plausible answers that reveal student confusion and generate spirited discussion. Show some prospective questions to a colleague and ask if they meet this criteria.

6. If one of your goals is more student participation, give partial credit, such as 1 point for any answer and 2 for the correct one, for some clicker questions. With some questions it is appropriate to give full credit to all students, such as when multiple answers are valid or when you are gathering student opinions.

7. If your goal is to increase student learning, have students discuss and debate challenging conceptual questions with each other. This technique, *peer instruction*, is a proven method of increasing learning. Have students answer individually first; then discuss with those sitting next to them; then answer again.

8. Stress that genuine learning is not easy and that conceptual questions and conversations with peers can help students find out what they don't really understand and need to think about further, as well as help you pace the class. Students tend to focus on correct answers, not learning. Explain that it is the discussion itself that produces learning and if they "click in" without participating they will probably get a lower grade on exams than the students who are more active in discussion. My students came up with the phrase, "No brain, no gain."

9. Use the time that students are discussing clicker questions to circulate and listen to their reasoning. *This is very valuable and often surprising*. After students vote be sure to discuss wrong answers and why they are wrong, not just why a right answer is correct.

10. Compile a sufficient number of good clicker questions and exchange them with other faculty. The best questions for peer discussion are ones that around 30-70% of students can answer correctly before discussion with peers. This maximizes good discussion and learning. There is value in discussion even if a question is difficult and few know the answer initially.

11. If you are a first-time clicker user, start with just one or two questions per class. Increase your use as you become more comfortable.

12. Explain what you will do when a student's clicker doesn't work, or if a student forgets to bring it to class. You can deal with that problem as well as personal problems that cause students to miss class by dropping 5-10 of the lowest clicker scores for each student.

13. Talk directly about cheating. Emphasize that using a clicker for someone else is like taking an exam for someone else and is cause for discipline. Explain what the discipline would be.

14. Watching one class or even part of a class taught by an experienced clicker user is a good way to rapidly improve your clicker use.

Practices that lead to Failure

1. Fail to explain why you are using clickers.
2. Use them primarily for attendance.
3. Don't have students talk with each other.
4. Use only factual recall questions.
5. Don't make use of the student response information.
6. Fail to discuss what learning means or the depth of participation and learning you expect in your class.
7. Think of clickers as a testing device, rather than a device to inform learning.

If you believe that the teacher, not the students, should be the focus of the classroom experience, it is unlikely that clickers will work well for you.

Be prepared . . . Effective clicker use with peer discussions results in a **livelier and more interesting class**, for you as well as the students! Expect good results immediately but <u>better results as you become more experienced with clickers.</u> This is the usual experience nationwide.

Further information and references will be put in http://casa.colorado.edu/~dduncan/clickers. I'd like to hear about your experiences, good and bad, and perhaps include them in future editions of my book on how to teach with clickers. dduncan@colorado.edu.

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

<u>1. Multiple, brief small group discussions in class</u>

(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.

<u>2. Informal, out-of-class study groups</u>

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.

<u>3. Formal in-class group activities</u> <u>(such as tutorials, concept mapping, labs, …)</u>

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.

<u>4. Formal in or out-of-class collaborative assignments- collective group work and shared marking</u>

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.

<u>5. Learning with fully developed teams</u>

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

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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/

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

CWSEI, 2013

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 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?

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.
   ii. Worksheets [typically 15-50 min] – Write a few 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 or pairs. The difficulty level should be set so that it is very challenging for most students if working individually, but reasonably doable in groups. An approach that works well is to make the first part relatively easy, so that most groups know how to start, and make later parts more challenging. Adjust the difficulty after running it the first time.
   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 the types of tasks students will be asked to complete on a midterm or final exam?

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. For longer activities, assign roles such as discussion leader, note-taker, or reporter based on arbitrary criteria.
c. Make it very clear what students are expected to do. Ask: "does everybody know what to do?"
d. Decide how many copies of the activity you will hand out (if you're handing something 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 with enough copies for all.
e. 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 (the doc cam works well in large classes).
f. Plant good questions: if someone asks you a question relevant to everyone, tell them it is a good one and ask them to ask it when you return to the front of the class.
g. Collect something from the students (a completed worksheet, clicker answers…) so there is clear accountability for doing the work. You don't need to mark them, but check off for participation and look for useful examples to help you learn more about student thinking and difficulties.
h. Be sure to wrap up the activity effectively. Have a few groups explain their answers. It is more interesting if their answers could be different and spark discussion. Finish by giving your expert summary. Avoid giving a detailed solution that would encourage a student to passively sit through the activity, waiting for you to eventually give them the answers.

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. 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 reading and have them answer some relevant questions prior to class.
d. Remember feedback! How are you going to measure and communicate how they've done? Is there a follow-up task 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, particularly if there is student pre-class preparation.

It can be very helpful to bounce your ideas off STLFs, 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*.

What Not 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 CWSEI and CU-SEI and links to other useful resources)

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)

1. 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.

2. 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.

3. 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.

The bottom line?

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://resources.glos.ac.uk/shareddata/dms/2B70988BBCD42A03949CB4F3CB78A516.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).

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!

<u>Steps for developing "suites of questions"</u>

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

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

Homework question:

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.

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

Clicker question using the same scenario as the homework question:

2) Does a **concentration gradient** exist for X^+? If it exists, what is the direction?
a) 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.

Exam question:

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