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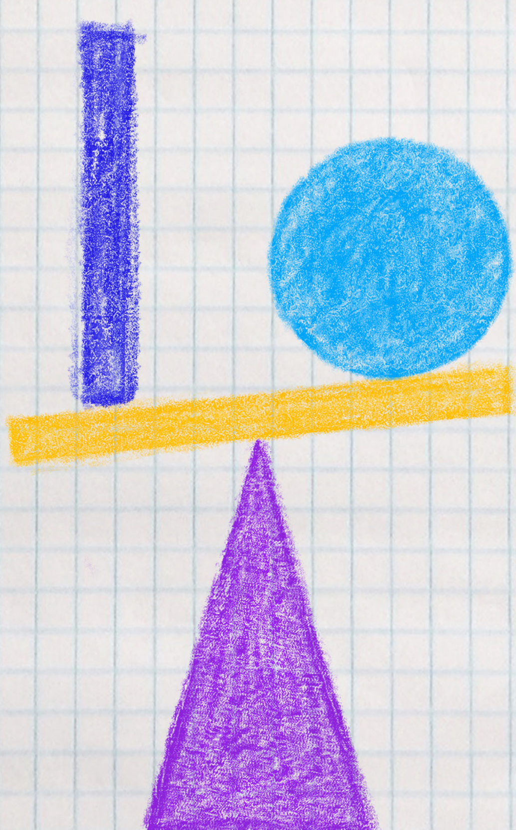
Teach Better, Save Time, and Have More Fun:

A Guide to Teaching and Mentoring in Science

2nd edition



Penny J. Beuning
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Scott A. Snyder
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With an Annotated Bibliography
by Ingrid DeVries Salgado
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Foreword

As faculty members at research universities, we decided to pursue this career because we enjoy the challenges of teaching, research, and integrating these activities. However, many of us lose massive amounts of precious time to "reinventing the wheel," particularly when it comes to teaching and mentoring. Many early career faculty struggle to balance time preparing for class and on other teaching duties with their scholarly work and research portfolios (Boice, 2000). New faculty in the physical sciences often face additional and unique challenges from the rigors of large lecture classes, often composed of diverse student populations with differing interest and capability levels. Furthermore, faculty are often required to design and integrate laboratory exercises with lectures to create an educational whole, which requires marshaling of diverse resources for success.

The Cottrell Scholar Award recognizes faculty at research universities, comprehensive universities, and primarily undergraduate institutions for their dedication and excellence in both teaching and research. In 2012–2013, we asked 241 Cottrell Scholars what practices have enhanced student learning and their own enjoyment of teaching. We gathered information and ideas at the annual Cottrell Scholar Conferences, which were attended by past scholars as well as science education experts and leading policy and government officials. In addition, various other faculty contributed to the ideas that form the basis of this book. We asked faculty to think back to their earliest teaching experiences as faculty members and to reflect on what they might have done differently, as well as to think about what advice they wished they had received when they started their careers. For this second edition, we again surveyed Cottrell Scholars about their experiences with active learning, mentoring, and the transition to online, virtual teaching necessitated by the COVID-19 pandemic.

From the 46 faculty who responded to our survey, approximately 50% reported that they were given no advice or mentoring before teaching their first class; hence this book. We hope that it will be useful as a personal handbook, directed primarily to junior faculty, but with sufficient generality to be relevant to more experienced faculty as well. In contrast to many (very useful!) quantitative measures of "what works," this book is by design and by construction purposefully conversational and colloquial. Along with the text, which weaves together themes that emerged from the survey responses, we include some actual survey responses to personalize the content. It should be pointed out that those named here do not necessarily endorse the entire content in this book; the main text, its organization, and commentary is principally that of the authors. At the end, you will find a resource list and a bibliography that provides brief summaries of some of the resources in the literature that we and others have found useful should you wish to delve further into a particular area.

Acknowledgements

Foremost, we would like to acknowledge Research Corporation for Science Advancement, which provided the funding and other support for this project. In particular, we thank Senior Program Directors Silvia Ronco, Richard Wiener, and Andrew Feig for moral support and advice. Beyond their direct assistance to our efforts, the environment and discussions they provided and fostered at the Cottrell Scholar Conferences and many other venues tremendously aided and furthered our goals. Kathleen Parson and Dan Huff provided support for the first edition, and Angela Hagen helped with the second.

We owe a deep debt of gratitude to Scholars who answered the survey, who provided feedback on the book, and who provided vignettes. Numerous Cottrell Scholars gave generously of their time and insights into teaching and mentoring, much of which formed the overall framework for this book. We are also very appreciative of Arthur Winter for the idea of "Facts that were Problems." Cottrell Scholars Martin Gruebele, Mike Hildreth, Geoff Hutchinson, Mark Moldwin, Jenny Ross, and Brad Smith also provided feedback on the first edition of the book, as did several other reviewers: Colleen Byron, Erin Cram, Moses Lee, Vicente A. Talanquer, Jodi Wesemann, and Victoria L. Williams. We also wish to thank those who contributed to and/or reviewed this book but preferred not to be acknowledged publicly.

We are deeply grateful to reviewers who took the time to give us feedback on drafts of this second edition of the book and others who contributed many valuable suggestions for improvement: Erin Cram, Lisa Elfring, Martin Gruebele, Rebecca Jones, Mark Moldwin, George Shields, and Vicente A. Talanquer. PJB would like to thank the NU ADVANCE Office of Faculty Development for sponsoring faculty writing groups.

Preface/Introduction

“When I taught University Physics I (calculus-based mechanics) for the first time, it was miserable. Although it was the first time that I used ‘peer-instruction’ clickers as a standard part of my lectures, and expected that to directly translate into an improved in-class experience, very early on I realized my prospects for the semester were poor. There were a couple of individuals in the class who consistently emailed me with (sometimes virulent) complaints about the level of work in the class, and I slowly began to withdraw from the class as a whole. As time went on, I found myself increasingly adopting a bunker mentality as the time I was devoting to rear-guard actions began to cut into my research time. Somewhat predictably, my teaching evaluations were as bad as I had ever received as an instructor and were complemented by my realization that very little learning had been achieved either. From where I was, anything had to be an improvement.

The following spring I approached things somewhat differently. I hired an undergraduate teaching assistant to handle all my direct email and began a practice of concertedly interacting with the class, on both an individual as well as a collective level, after the assignment of each clicker question. By circulating through the class after assigning a question, I not only got first-hand information on what problems students were having, but also built, to a small degree, personal relationships with some of the students (certainly it helped me learn their names). This was helped considerably by having the lab TAs present during the lectures as well — they not only had an opportunity for additional interaction with the students, but also were more aware of what was happening in lecture and how best to synch that with the laboratory component of the course.

Not surprisingly, my evaluations that semester were somewhat better over the previous year. Although I didn’t evaluate it numerically, my impression is that the overall learning experience also improved. Certainly, the class performance on exams, which I regarded as comparable (or greater) in difficulty than exams I had given in previous semesters, was markedly better. The obvious question is how much of this improvement was the result of steps taken to make the clicker questions more effective, and how much was simply improving the overall class environment, on both sides of the lectern. I believe it’s actually mostly the latter, although certainly a more interested clientele is also a clientele most likely to approach the course material positively.”
Dave Besson

“Probably my most successful teaching experience was a complete revamp of the Introductory Physics sequence targeted at the Engineering students. The sequence was reduced from a three-semester version down to two semesters. To keep the credit hours high, a mandatory recitation section was added. I got to pilot the sole section of this course, basically creating the whole course structure from scratch. I switched my lectures over to a “Think-Pair-Share” style, and created group problem-solving exercises for the recitation sections. I learned a lot that semester and made more than a few mistakes, since it was only my second semester teaching. It was extremely valuable, however, when the course was put in “production” mode the following semester, with three instructors and almost 500 students. The second time through, things ran much more smoothly, and my lectures were a lot more “seamless.” This curriculum change led to several new initiatives around campus.

For the first time, we initiated a teaching training program specific to physics instruction for all our incoming physics graduate students. This was mostly to put all of the students who run the discussion sections at a higher level of preparedness, but we also included lab instruction, grading strategies, etc. The training is now part of the standard graduate student orientation. The training session usually consists of an introduction given by a member of our campus Learning Center on the importance of good teaching and including some tips for student-TA interaction and time management. We then will have the TAs go through a group learning exercise with one of the faculty playing the role of the exercise facilitator, so that they can see different aspects of how to run a group problem-solving session. We also will typically include a brief lab exercise so that they can get a feel for what the labs will be like, and how we might conduct them. This has resulted in a TA corps that is much better prepared for the sorts of things we are asking them to do.

As an added bonus, other departments have adopted the group-problem-solving paradigm for their recitation sections instead of having them be someplace where a TA merely solves homework problems. The experiences with that course, and the success that it had, largely established my teaching credentials both within the Department and around the University.”

Mike Hildreth

Part I:
Developing and Delivering Effective Courses

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Preparing to Teach

Quick-fire question in class preparation: Do you generally carry chalk or whiteboard markers in your regular bag? You might find it useful to have a dedicated teaching bag that has extra chalk, markers, AV cables, water, tissues or a cloth, etc. Alternately, you could set up a smaller bag to insert in your regular bag for teaching. If something about your classroom or the physical environment of your teaching is subpar, think creatively about how to fix it so that you are less distracted, or even request a different classroom. You could go so far as to have custom chalk holders made for holding the larger chalk used in large lecture halls, for example. If you use a computer, a remote slide-changer/pointer or even a remote tablet are invaluable for allowing you to roam around the room while still going through the course material. Keep in mind that even in the largest lecture halls, students can form groups of two or three with the people near them; you do not need a special classroom to have students work together.

Where do you start when thinking about how to approach teaching? Many experienced teachers recommend that you sit in on courses of effective teachers, keeping in mind that such individuals may not necessarily be those with the highest student ratings at the end of the semester. Your department chair or mentor can usually recommend an instructor or two who would be most appropriate. It is especially useful if the course is at a similar level as yours or even a different section of the same course. Note what the instructor does that seems effective to you. How does the instructor interact with students? How are concepts explained and questions handled? Are relevant examples given? How does the instructor convey enthusiasm? What are the students doing? Are they paying attention or surfing the web on their phones waiting for the class to end? How do students interact with each other, if at all? What preparation is expected of students prior to class, and how are they held to account for that preparation? After sitting in on a few classes, it can be helpful to meet to discuss how the instructor views his or her teaching practices and their effectiveness. Similarly, ask to borrow materials from others, including sample syllabi, lecture notes, demonstration notes, and exams. Then adapt these to your own style and your students' needs and interests.

Because you are an expert in the field, you might be tempted to think that you do not need to prepare very much and can lecture on the fly. In fact, that approach will rarely succeed, and astute students can tell when you are "winging it." Keeping your learning goals in mind is an important way to help you prepare your classes. Be as organized as possible in all aspects of the class. Prepare well for each class, especially when you are going to present examples, work through problems, or do demonstrations. In addition to preparing and organizing the material you will present, prepare the questions and problems you will pose to the students and how you will engage them in this work. Write down your planned active learning work; it will also be helpful to provide written instructions or tips for students as they engage in the activity. This strategy will be a time-saving one, because better, more detailed class notes will save you tremendous time the next time you teach the class. Providing written instructions to students will also help focus them on the work at hand.

While you are teaching the course, at the end of every class (or at least minimally at the midpoint of the term and the end of the term) write down what worked well and what you would do differently next time you teach this course. Note material that caused students to struggle. This will help you tremendously in improving the course the next time you teach it. If your course has a teaching assistant (TA) or assistant instructor (AI), negotiate stability — if possible, have the same student appointed the TA for the next time. This is absolutely critical in gaining the efficiency of teaching the course the subsequent times and in allowing the TA to also use the experience to hone their teaching skills. If you can, recruit teaching assistants from your own research group; you are likely to have a stronger relationship with them and their investment in your success could be higher as well.

Critically, do not try to do everything at once. Instead, keep refining your classes, using your notes and feedback from students and colleagues. This approach will help you continuously improve your classes, keep them fresh, and keep you from getting bored.

> "When I first started teaching, I was under the impression that I could just "wing it" if I ran out of lecture material. I tried taking questions or suggestions for problems

> to work on the board from the students, without any advance preparation. This was not a good idea. The first or second attempt at doing this ended in confusion when a student asked me to do a problem that was both subtle and not stated clearly in the text. After that embarrassing experience, I swore that I would always have way too much material for a given lecture, so that I would *never* come up short. It also pointed out in a rather painful way the importance of thinking through the presentation of complicated problem-solving steps well in advance. The things that might be obvious to me are often confusing for many of the students; shortcuts I might take are not necessarily the path that they would follow to a solution. I have found over the course of the years that providing the students with a clear and logical progression through the thought process involved in solving a given problem, emphasizing general principles that can help them through similar problems, is one of the most effective things one can do to help them learn the concepts. That isn't to say that all flexibility is banished from my classes. I will often have students suggest their own ways of solving a problem I have presented, and following their train of thought, as long as I can see that it won't derail, gives them satisfaction that they have been able to see the solution to the problem using their own process. This is valuable reinforcement. It's possible to do this without a safety net, so to speak, because I have already worked the problem through to my own satisfaction and can be sure that the student's ideas will work."
> **Mike Hildreth**

Work through homework or problem sets that you are planning to assign in advance. Have a TA or one of your students check exams and proofread problems. This process helps you determine what you want to emphasize and ensures that your homework assignments will help students learn the things you would like them to learn; it will also make sure there are no mistakes or "impossible" problems that will deeply frustrate students. Then work through example problems in class and clearly explain the rationale for each step, possibly starting with an already-solved problem as an example. Present the logic of the problem. Work problems from multiple angles, explaining the logic and context of the problem. Use a range of examples, helping students see the generality of a fundamental concept and construct their own understanding. For example, if you are discussing the ideal gas law, examples could include the volume of a sealed plastic bottle on an airplane on the ground compared to in the air, tire pressure as function of temperature, a Mylar balloon, the bends, etc.

Begin each class with a short story or anecdote (ideally containing a relevant and vivid image or metaphor) to motivate the material and then by summarizing what was learned in the previous class and relating it to the upcoming material. End each class by summarizing the material of the lesson and giving a preview of what is to come. This tactic requires some planning but should help students see the themes, narrative, and intellectual framework of the class. Such summaries can easily be done with active engagement of students. For example, you can pose a problem that requires students to apply what they learned already in the class or that combines several topics; the discussion can then be used to make connections explicit and to emphasize the main themes and narrative. Stating the main concepts of each class will also help students prioritize the material, which will lead to deeper understanding of important concepts. Some professors believe that students need to determine for themselves the most important material; however, this task is a difficult one for any student new to a field. Prioritizing material will help focus student efforts in studying and help them organize new material into the major themes you have highlighted — your job as an expert is to help provide that guidance.

Opinions differ on whether the instructor should hand out notes to the class or make them available on a course website, as opposed to providing no notes. By providing notes, students can focus on your explanations rather than on trying to write their own notes. Giving prepared notes to the students can help you be more organized because the notes have to be prepared in advance and have to be clear enough to be useful. On the other hand, others believe that having notes available eliminates the incentive to come to class or to pay close attention to the instructor. One compromise is to provide minimally outlined notes that students complete during class, increasing the incentive to attend class sessions. The physical act of taking notes is also important for student learning and should always be encouraged. In fields in which drawing diagrams is an important skill, for example organic chemistry and some areas of physics, the practice of drawing in class is critically important for development. Another alternative is to provide only oral recordings of your lectures, so students can listen to you speak again later with their written notes in front of them, providing them with additional opportunities to strengthen what was originally presented on their own time. See below under Technology for a discussion of using eLectures and other tools as an additional strategy.

Identify Resources

Determine what services department and other staff can provide for teaching. You can ask them directly, or ask your chair or other faculty about the types of work staff can be expected to do for you or if they can give time to special projects. They may be able to order books for the bookstore and have lecture materials including the syllabus copied. They might also be available to type notes, prepare slides, or analyze course-related data, such as performance on specific exam questions by students. Whatever staff members do for you, remember to give plenty of notice for your requests and to thank them profusely for their help.

Your campus teaching and learning center staff likely offer workshops and short courses, can help identify specific resources, and are often available for consultations. Some run in-depth programs to develop communities of practice. They might also have syllabus templates you can use. In addition, the director of your department's undergraduate curriculum committee and associated professional staff can provide crucial advice as you prepare your courses, including model syllabi and information about the overall curriculum. In addition, these folks have probably dealt with any number of challenging situations in the past and can use that expertise to help you resolve issues that arise.

Most professional societies have an education committee or division that provides helpful programming and workshops on teaching and learning. You might also find it helpful to join book clubs, faculty teaching discussions, online forums, and the like, where you can share ideas and reflect on your teaching. Taking advantage of such resources and building your network will help you continuously improve as a teacher.

Learning Objectives

One highly recommended strategy is to identify your learning goals for the course and plan the entire course around those goals. Such a "backwards design" strategy centered on learning goals will not only help you prioritize material but also will maintain your focus throughout the semester as you decide what you should teach and make the core of your course. Rather than planning a class chronologically, you should consider what you want your students to know or understand and to be able to do at the end of your course and then plan the course material and assignments around those goals. In that vein, it may make sense to consider critical elements and learning outcomes/goals for specific units or topics of the course, especially the first time teaching a course, to break down that larger task into more manageable chunks. This global analysis may also help you decide what types of teaching strategies you will employ. For example, if you want your students to learn and/or improve their critical thinking skills, a critique of a published paper or an analytical essay may be a more useful assignment than a quiz. If your students do not have many opportunities to practice their communication skills, a paper and a presentation or a presentation of a laboratory report may make more sense than a written exam. Your learning goals may also lead you to assign group work or use a specific active learning strategy. Deep learning of concepts and eliminating misconceptions about material and how students can best engage and master it requires repetition. Therefore, using your learning goals to structure the term can naturally lead to that form of repetition necessary for learning, which includes, for example, exposure to concepts from multiple perspectives and working many problems with slight variations. Moreover, identifying these goals in advance will make your life much easier and will allow you to present your comprehensive strategy to your students. The course learning objectives should be shared with students explicitly, so they know how the course is designed and what they can expect to get out of it. Some institutions require learning objectives to be listed on your course syllabus; this is generally a good practice because you will then naturally discuss them with students as you go over your syllabus at the beginning of the term.

> "When I taught general chemistry a second time, I decided to come up with a list of five different concepts that I wanted the students to really understand and to hopefully retain several years after completion of the course. Some of these concepts included: collision theory of reactions, the meaning of an equilibrium, the concept of pH, chemical bonding in molecules, and mass-energy equivalence. My approach now is to underline these fundamental principles as we go through the course. I develop and reinforce these concepts through the duration of the semester and try to test conceptual understanding on exams."
> **Anonymous**

Syllabus

When you present your syllabus on the first day, ask for feedback from your students. You can set the expectation for active engagement by having students discuss some aspect of the syllabus in pairs or small groups, such as identifying core aspects of the course or how prerequisites specifically might help them prepare for your course; you can then have them report to the class. Moreover, write your syllabus to allow yourself flexibility. For instance, you can indicate that the dates of specific topics are tentative or include a disclaimer to that effect. You might also consider allowing students to set their own grading criteria or schemes within certain ranges for specific assignments. The following, however, are critical:

- Set clear expectations at the beginning of the semester and resist the temptation to be too casual, especially if you appear younger than you are or are female. You can be more forgiving later, which will be much appreciated. However, do not be rigid or punitive just for the sake of it; students can face unexpected challenges that hinder their goals as well, and openness to their concerns can be extremely valuable in building *esprit de corps* and belief in your course and you in general.
- Write a defensive syllabus, meaning that you set clear expectations for respectful behavior and student etiquette in general, including email use, policies on late work, cheating, exam rescheduling, engagement in online courses, etc.
- *A syllabus is essentially an agreement between you and the students*. It should anticipate all possibilities as practicable and be the document you reference whenever issues about the structure of the class or its policies arise. Consistent adherence to the syllabus guidelines can do much to alleviate perceived issues of fairness or other problems that can crop up during or after the class. Colleagues who have taught in your department/unit before are often fantastic resources for what to put into this agreement as they have seen so many unusual cases.
- Your institution likely has pre-written sections that they request or require be added to each syllabus to incorporate information about such topics as the honor code or harassment policies, expectations for professional behavior, or resources such as the campus writing center or mental health center.
- Your institution may also have policies about whether the dates of exams or major assignments can be changed or whether major assignments can be given the week before final exams.
- A well-written, explicit syllabus is extremely important to give a more level playing field to first generation and international college students and others who are not familiar with the culture of U.S. higher education. Do not assume that every student, even after their first year, knows that textbooks or old exams might be on reserve somewhere or that the campus has help available for IT or software issues.

Some students will find college to be such a foreign environment that they will not even conceive of the availability of a resource and will be used to complete self-reliance barring a life-threatening emergency. If the information could reasonably aid student performance and is likely used by the best students, include it in the syllabus.

- Be explicit about your expectations for the use of any type of electronics (allowed, forbidden, or allowed under certain circumstances).
- If allowed, you may want to state that you expect all students to complete course evaluations, or offer incentives for participation, especially if low response rates are typical at your institution.
- Write a detailed syllabus and try to stick with the schedule as much as possible. Include deadlines and exam dates. Many college students find their newfound freedom a challenge, and providing structure in your class will help them.

Designing New Classroom-based Courses

Maybe you were hired with the expectation that you would fill a need by developing a new course. Perhaps this task is expected of all new faculty in your department or institution. Find out what is reasonable at your institution in terms of new course preparations. If you are well above the norm, you may want to have a serious chat with your mentors, department chair, and/or dean about expectations for how teaching and course development are related to promotion and tenure and how best to use your time.

In any case, developing a new course can be extremely time-consuming, especially if it also involves the accompanying laboratory section. First, do your homework, both by understanding what the expectations are for this course and by surveying existing, similar courses at your own and other institutions. Obtain syllabi, textbooks, and reading suggestions. Most people are willing to share their course materials, and you might find helpful examples on public websites. Even redesigning an established course, for example by integrating active learning such as clickers or peer instruction, takes a tremendous amount of time. Again, use existing resources and your network as much as possible.

If you are designing a new course, you should ask for assurance from the department that you will get to teach it several (ideally at least three) times. Each time you teach the course, adjustments can be made to correct what did not work well the last time. Do not worry too much about getting everything perfect the first time, because that is impossible. Acknowledging that there will be mistakes that can be fixed in subsequent years makes the task less daunting.

It is the rare person who has the entire course fully prepared at the outset — whether a newly designed course or even just a new preparation of an existing one. A detailed outline, with topics, readings, and homework is essential and gives students a roadmap for the entire term. Try to stay at least one or two complete lectures ahead of the class schedule so that you can anticipate problems and provide the framework for the course.

Designing New Laboratory-based Courses

If the development of a new course or the remaking of an old course involves a laboratory portion, the complexity of the process increases dramatically. All the aspects of developing a classroom-based course discussed above still apply, as consideration must be given to learning outcomes here as well. Designing teaching laboratories comes with the added complications of environmental health and safety compliance and of the cost and accessibility of personnel, instruments, and supplies.

The learning objectives and available resources should be integrated into considerations of the approach. Will students carry out “cookbook” laboratories in which they follow a protocol to obtain a known result? Is your goal to teach techniques, the use of equipment, or other specific laboratory skills? Is the goal of the lab to emphasize and complement concepts taught in lecture? Do you want students to carry out inquiry-based experiments or research? What other skills can or should students learn in the laboratory, which may include reading the literature, keeping a notebook, analyzing data, writing and presenting results, and working in teams? And how will they learn these skills?

Fortunately, multiple journals and online lab experiment manuals contain peer-reviewed experiments that can be conducted in teaching lab settings and are a great starting point for matching the pedagogical goals of your new course. Key to smooth implementation in your own institution is matching the institutional settings and budgets to your class. An experiment that works well at a small institution in a single classroom setting with the professor present may not translate readily to a large institution with multiple lab sections and teaching assistants in the lab. Supply budgets and equipment access can also vary widely. Experiments run in larger public institutions tend to be good models when the budget per student is tight.

Given the rate of evolution of new experimental techniques in the physical and biological sciences, you may not be able to find a suitable precedent from an existing teaching laboratory. The discovery of this pedagogical hole can be the start of the development of original experiments or a framework for discovery-based labs. (This work also counts as a type of broader impacts!) As in a classroom setting, your deep knowledge of a specific research area can give you unique insights and ideas for translating cutting-edge science into undergraduate and graduate laboratory courses that might inspire a new group of students. The challenge is doing so within the time, cost, and space/instrument limitations of a classroom rather than research setting. Sometimes a new method has older precedents whose components are now less expensive than the most recent variant; with some creativity the links to the most recent science can still be made using the older materials. For example, solid-phase resins for biopolymer synthesis and combinatorial library synthesis can be costly, but the idea of using solid phases for reactions can still be effectively conveyed using older bulk resin-based reagents. The increase in cheap sensors and Systems on a Chip processors such as Raspberry Pi also can make simple equipment such as spectrometers available for little cost.

Unlike a research lab setting, the parameter space for experiments — even inquiry-based experiments — has to be tested beforehand in order to anticipate timing and safety issues before implementation in a classroom setting. Undergraduates who have recently completed the targeted lab class can be great intellectual partners as undergraduate researchers in developing your idea. They know the audience well and can potentially get less-filtered feedback on the lab from students than you can. Ideally, an idea would be tested a few times before the class time. If it proves reliable, then documentation for the lab can be written for class handouts for the first test in a classroom. If possible, a majors section of a lab class with limited sections can be used to then test the feasibility of the project. If it still proves reliable and pedagogically useful in this smaller classroom setting, then the next implementation can be in multi-section classes. For publication in a good peer-reviewed journal, the new lab exercise may have to be tested on at least two different groups of students over two different semesters; be sure to consult your Institutional Review Board prior to collecting data, especially if you intend to publish your results. As with a classroom-based class, obtain assurances that either you can teach the class multiple times or that a colleague is willing to test the exercise when they teach. A useful resource for implementing Course-Based Undergraduate Research Experiences (CUREs) is “Expanding the CURE Model: Course-Based Undergraduate Research Experience” (2018) Rory Waterman and Jen Heemstra, eds.

2

Starting and Staying Strong

A good, positive first day of class sets the tone for the rest of the term. Setting yourself up for this great start to the new term requires some planning. Prepare as much as possible before the first day of class so that you can present a coherent, organized plan for the semester. Along these lines, early in the term establish your own infrastructure for taking notes about what worked and what you would change as the semester progresses. This can be a note in your binder of class notes, a document on your computer, annotations in the notes section of your class slide files, or even the syllabus file so that when you open this document to revise it for the next term your notes will be obvious.

Setting the Tone

Do more than go over your syllabus on the first day of class. Start with a story to motivate the class, dive in to content, provide specific examples of what students will learn (an appetizer if you will), or do a review of important concepts with which you expect the students to be proficient. Incorporate active learning at this point; for example, students could work in pairs or small groups to review important background knowledge that they should have and then report back to the class. See below for tips on how to best manage such experiences. Then once students are engaged, you can go through the syllabus for the class.

First-day surveys or quizzes or a combination can be used to learn information about your students, assess their background knowledge, and perhaps help recall material learned in previous courses. You may want to ask students their names and how they want to be addressed, how to pronounce their names, their major, why they are taking your class if it is not required, if they are engaged in research and/or have relevant work experience, and questions about content, elaborated below.

The first quiz of the term can be an online syllabus quiz, which will emphasize the importance of the syllabus and can highlight critical parts. You can also ask them which of the learning objectives are most important to them and why, or if there is anything they expected to be part of the syllabus or course that is not. It may be useful to record a video in which you introduce yourself and go over important parts of the syllabus, which can be uploaded to your course management system and available for reference by students later.

Example of an Intro questionnaire
[for a third-semester advanced organic course]

The purpose of this questionnaire is to help me get a snapshot of you as a class. Please take 5-10 minutes to answer the following five questions **before the start of class.**

1. How would you like to be addressed in class? (Nicknames, preferred names, pronouns are welcome here)
2. What is your major and year in school?
3. If you took Chem 343/345 at UW, who were your instructors? If you did not take introductory organic chemistry at UW, what textbook(s) did you use in your previous organic course?
4. Are you involved in research? If so, with which lab?
5. Please list five objectives you hope to get out of this class.
[Question 5 is the basis of an in-class exercise I use to map the learning objectives for the course onto the ones I've put in the syllabus.]
Tehshik Yoon

When a student requests policy exceptions in the rush of the beginning or end of class, it can be helpful to your own organization and overall management of the class to stall by saying: "let me get back to you." Then, consider the implications, make a decision, and let the student know. You can also ask them to follow-up with an email of their request so that you have a record of their request and your decision, which also provides additional time for consideration. It can be hard to make a good decision under these "quick-fire, cold-call" conditions, so it is certainly reasonable to delay for a bit. You may also want to keep a note of what you did to make sure you handle requests consistently as well as for future reference, as students will talk to each other about different components of the course. A well-written syllabus should anticipate all but the most unusual request.

Be transparent; explain to students why you teach a certain way and why you have specific expectations. For example, "Research (or, in the absence of hard data, "My own experience") has shown that students who come to class regularly perform better and earn higher grades. I would like ALL of you to earn good grades in this class, so I will expect regular attendance." Have references ready to share these data with students. Similar discussions with your teaching assistants as applicable will not only help ensure consistency in the course, but also contribute to the professional development of the TAs. Justify your grading criteria. Let students in on your strategy and how you view assessment.

> "Although I was not given any advice myself, I have some advice to new faculty.
>
> 1. Communicate to your students. Treat them like adults and explain how you are teaching them and why. Justify the grading structure of the course.
> 2. Give the students the ability to earn back missed exam points by redoing the exam problems. They get a second chance to learn, and they think you are nice.
> 3. Be a "hard-ass" at first and become nice later, or else they will walk all over you. I think this is especially important for female instructors, but it is a good practice for anyone.
> 4. Treat the syllabus as a contract with the students. Communicate it to them well. Include all the information needed for the entire course. Give them the opportunity to make changes on the first day. They never have any changes to make, but they appreciate being asked. See the paper from Cottrell Scholar Sarah Keller [J. Chemical Education, which is included in the Bibliography] on writing a good syllabus. I used this article when I first started, and it was invaluable."
>
> **Jenny Ross**

> "I allow students to compose their own grading scheme for a third-year Thermal Physics course within ranges I specify for each aspect, such as problem sets, midterms, final, independent project. In all but one case, the students performed better with their own grading scheme than with the default scheme of the course. This idea came from a similar style of evaluation used by my [former professor] though he allowed students to weight the final exam as little as 0%, which I did not permit."
>
> **Nancy Forde**

One way to set expectations is to directly tell students how much time outside of class you expect them to spend on the material; a typical equivalence is three hours of out-of-class time per one credit hour of in-class time, but even more time might be necessary and it may not be evenly distributed throughout the semester or quarter. And, of equal importance, what will they be doing during this time? You can discuss with students some study strategies that you have personally found useful, such as rewriting class notes after class to help reinforce material and to identify areas of confusion, working extra practice problems, meeting in a study group to work through problems and discuss material that is unclear, attending office hours, and reading the text and taking notes, rather than highlighting. Drawing diagrams and concept maps can certainly be useful for organizing ideas (more on this below). Reviewing content and going over exams is also helpful for solidifying understanding. Science students often do not feel that they need to come prepared to class, especially if they are being lectured to for the entire class time (i.e. passive learning).

It is helpful if students think about the material before class. You can ensure this by giving pre-class quizzes, homework, or short writing assignments online, or a brief quiz at the beginning of class. Alternatively, give other pre-lecture activities online, such as a short video, demonstration, or reading assignment. Students generally appreciate quizzes or practice questions before an exam to help them determine their preparation for that assessment and to help them focus their studying. Even in a laboratory class, mini-lectures and demonstration videos can be provided in advance so that class time can be dedicated to more detailed, richer issues like data analysis and interpretation.

> "One misconception I had comes from the students themselves. I often teach the first semester of introductory physics. Students, especially those coming straight from high school, often have the idea that someone should "teach" them physics. I try to disabuse them of this notion the first day of class, by telling them that I am there to help them *learn* physics, but teaching them physics is not something I can do. Learning is an active partnership between instructor and student. Many of them don't understand that the process of grappling with concepts and figuring out how to apply them requires actual *work* on their part. Each student has to understand for themselves how they learn, and this can be a difficult process. Often, students who didn't have to work hard in high school don't know how they learn best, and it comes as a shock to them when they realize that they really didn't understand a concept or a technique as well as they needed to. They have to figure out how to approach the concepts, and which techniques or ways of visualizing the concepts work best for them. Each person is different in that respect, and the only way they can discern what is best for them is to work at it by doing problems or other exercises, forcing themselves to think their way through the concepts. It's hard to say what is the best way to prepare students for the work that they will need to do, since many of them think, "Oh, I'm fine — that's not my problem" as they start the semester. I was one of those students, and it took me years to figure out what I need to do in order to absorb new concepts. Having sympathy, being encouraging, and pointing out different ways that the students can prepare themselves and self-test their knowledge are probably the most important things one can do to help the students along this path."
> **Mike Hildreth**

> "Communication. Just reminding the students that you are there to teach them and that these methods are the best way for them to learn. Remind them that no matter how stern, entertaining, or smart you are, the actual learning can only be done by them — it is in their hands. Remind them that they will learn best when they apply themselves. Communicate the grading rubric and stick to the "contract" of the syllabus."
> **Jenny Ross**

Help students understand what they will learn and gain in skills in addition to the specific course content. These items can be listed as learning goals or outcomes of the course on the syllabus and should be highlighted when you discuss your syllabus in class. For example, most science classes teach analytical reasoning and problem-solving skills. More specifically, you could indicate that students will learn how to make decisions with limited information or be able to analyze problems to determine the most useful information for solving them, in which case they are learning to disregard extraneous information. Students are likely to improve communication skills in classes in which written reports or medium- or long-form exam answers are expected and you give them feedback on writing or speaking. Group projects or even regular use of think-pair-share strategies will also improve communication skills and the students' ability to work in teams and support each other in their shared educational journey.

Critically, do not assume that your students will have strong backgrounds or know and/or remember material from courses that are prerequisites for yours. It can be instructive to give students a short, well-designed, ungraded quiz at the beginning of the term that covers information and skills that you expect them to have, so you can be aware of and address weaknesses effectively up front. The experience of taking the quiz can sometimes prompt students to use knowledge they might believe they have forgotten and can help students "connect-the-dots" between concepts they had not fully appreciated were related. Importantly, a first-day quiz that is intended to test background knowledge should actually test that knowledge. For example, students could be asked to: calculate a derivative, draw a specific functional group, predict the products of a reaction, or explain concepts important to understand for success in your class. It can also be revealing to ask students to rate their level of confidence in their answers on each of the content questions you ask. This strategy is more effective than simply asking students if they are familiar with something or know how to do something, as they may not realize exactly the type or depth of knowledge that you expect or may be unwilling to admit they do not know. Alternatively, you might discover that students already have some knowledge or skills and therefore you can go into more depth or use class time for something else.

Conveying Enthusiasm

First and foremost, the most effective teachers convey enthusiasm for their subjects and courses and conduct courses in an engaging and professional manner. No amount of electronic gimmickry can compensate for a listless and soporific presentation. One simple way to meaningfully convey enthusiasm and engage students is to introduce relevant examples from the real world and/or recent news and popular culture. Put the material in context for students, both in the context of the world around them and in the context of the other courses they have taken or may take in the future. Use a variety of examples to help students from a wide range of backgrounds. Making course content relevant to the future professions of students can also be motivating.

This goal is the most straightforward in tailored courses (e.g., Physics for Engineering, Chemistry for Health Sciences), but can also be done in courses with diverse student backgrounds and education goals by, for example, surveying the students at the beginning of class as to their planned careers. The science, technology, and health sections of major newspapers or news outlets are wonderful sources of material for this purpose. Major regulatory issues facing the United States or the world at large are also good sources, as are the news sections of major scientific journals. Ask students to bring in or share via the course management site relevant news stories and explain how they relate to the course. This removes some of the burden on you as the instructor, engages students, and gives students a way to earn points other than in exams, which they generally welcome. Most students leave their science courses with little or no appreciation for the relatedness of different areas of science or even different courses in the same field. If you make the connections explicit, that problem can be solved!

One additional way of expressing your own enthusiasm for teaching the subject and of engaging students is experimenting with different pedagogical techniques, which will help keep your teaching fresh. Getting students to interact with each other during lecture, for example, by using group projects or group discussions or debates, can build a sense of community in your classes. Consider making your problem sets and office hours group sessions (discussed in more detail later). Use a variety of presentation media and styles, for example, question-and-answer, lecture, videos, demonstrations, think-pair-share, peer discussions, etc. Not only does this add variety to class time and other times of student interaction, it usually signals to students that you have put effort into effective use of their time. These approaches will also help to ensure that you have fun with your classes.

Motivating Students to Learn

At the most basic level, students are motivated by earning good grades. However, in more general terms, students will learn and retain much more if they are motivated by other factors, such as a desire to learn, a belief that they can succeed, and a belief that you care about their success. This helps explain why classes that are “curved” up to ensure a large fraction of high grades do not always have high student satisfaction; although the curve can ameliorate grade anxiety, it often still leaves the student feeling disconnected from the course material, and even unsatisfied with how readily their goal of a good grade may have been attained. Remind those students who are struggling that this is part of the learning process, ensure them that they are making progress, and give some positive feedback. Convey your belief that students can be successful in your course. One simple tactic, even applicable in larger courses, is to email a student after an exam and indicate to them how happy you were that their work had improved from their previous performance; in short, act like an effective coach, and your student-athletes will respond!

> "How do you motivate students to learn? Many little things that don't slap it in their faces:
>
> - Announcing that computer homework and book homework will be featured verbatim on exams, so do it all to be prepared.
> - Spending a significant fraction of the time, at least one-third of the class time, in the classroom engaging students with questions, demonstrations, and concepts — not just the facts.
> - Being available for office hours and one-on-one mentoring, even though it is very time consuming.
> - Little surprises like an impromptu tour of your lab for students coming to office hours.
> - Giving some complex problems that require multiple skills they have learned to be put together.
> - Having a narrative in the course, like a good play. This is totally missing from current generation textbooks."
>
> **Anonymous**

> "I've never found a substitute for a face-to-face conversation with a student to help that person understand the material, feel more motivated (or less discouraged), and participate more in their own learning. I never get to speak with all of my general chemistry students, as hard as I may try. Last year, I was inspired by the digital warning notices that our Dean asks us to do for at-risk students. After each exam, I sent email messages to students who were (1) consistently doing well, (2) experienced major improvement, or (3) dramatically dropped in score as compared to a prior exam. After that, I interacted more with the best performing students and others sought help. After the third exam, I emailed the students who represented the average and had little variance to applaud their consistency and acknowledge their efforts. This took some time, but I know I am an underutilized resource. While I can keep myself busy, there was enough time to send out these messages. The result was the positive effects of a small amount of personal interaction that we don't usually have in the large classes."
>
> **Rory Waterman**

> "One year our department offered an honors section of intro chemistry for the first time, and I volunteered to teach it. For the most part, the course was a dream — I loved the cohort of students as they were by and large intelligent and self-motivated. Attendance was high and I generally had great buy-in from my students in terms of doing the assigned work and studying (and performing well) on the increasingly difficult tests. However, I had a few students who were becoming increasingly exasperated with their poor performance. They were clearly trying as hard as they could but were spinning their wheels — the material was just not sticking and they were on trajectories for Ds (or worse) in the course. It was past the drop date, and a couple of them were even trying to see if there was a way that the dean could make an exception as they were afraid for their grades. Instead of encouraging them to drop, I decided to get the students together and form a 'support group' just for them. We met at least once a week for a few hours, and worked on problem after problem so that I could catch their mistakes, and so that they could see where they were going wrong in each type of problem in a supportive atmosphere. The three students became increasingly confident (not just in our sessions but in asking

> questions in the lecture as well) and I could feel things improving. Indeed, they improved markedly in the last hourly exam and the final. You can't imagine how happy and relieved they were to earn two Bs and an A(!) in the course, and I was very proud of how they worked to transform their understanding of the material."
>
> **Boyd Goodson**

Your students are most likely not like you, but then again, you may not have been who you remember. As much as possible, state your assumptions and what seems obvious to you. As an expert, you have a lot of specialized knowledge at your disposal and it may be difficult to remember what it was like to learn this material for the first time. Consider looking back at your own class notes from when you took a course to remind yourself of what you learned for the first time at a similar level. Stating your assumptions will help students feel that the class is more within their control and helps establish a culture of fairness.

Draw connections between what students already (should) know and what you want them to learn. Make connections to other courses, as well as to the larger picture of the field. Highlight connections among topics and concepts throughout your course. Using the "backwards-design" strategy outlined above helps you stay focused on the overall picture and weave those themes throughout the course. Assess prior knowledge at the beginning of the term. Making such connections is especially important in introductory courses, whether at the undergraduate or graduate level, because they serve as a foundation for more advanced work.

Have a narrative for your course (and know what it is before the first day of classes!); absent an interesting story line, the course will suffer from a lack of continuity. Structure your course with coherent themes and goals and present material in an inquiry-driven way. For example, rather than present a fact, present the scientific approach, process, and questions being asked in the field, and the stories of the individuals who asked them and whose work led to the establishment of the concept. Explain how experimental outcomes are interpreted with models and how models are built and refined. Be explicit in helping students appreciate the intellectual framework of the course material.

For example, to convey the process of scientific discovery, you could incorporate modules of "facts that were problems" in a class. These modules allow students to analyze data to (re-)discover the scientific facts that you want them to learn, and it will also help them develop critical and analytical thinking skills. Some examples:

- Present the figures from Meselson and Stahl's paper (*PNAS* **1958**, *44*, 671) that showed that DNA replication is semi-conservative. Ask the students to come up with models of replication and to evaluate their models in light of the data presented in the paper that shows the distribution of isotopically labeled DNA during replication.
- Have students use molecular models of the peptide backbone to derive a Ramachandran plot of allowed, or favorable, dihedral angles.
- Have students use balloons as electron pairs in order to determine bond angles of specific compounds.

"In sophomore-level physics for majors at my university, the topics are a hodgepodge. I taught a course with Thermodynamics, Wave Mechanics, and Optics together, which are not so easy to make connections. In Thermodynamics, I had wanted to bring statistical mechanics into the concepts of the Laws of Thermodynamics and the concepts of Energy, Work, Heat, and Entropy. I alternated between macroscopic observations, driven by examples to lead group work and examples that students do, and microscopic first principles. We revisit each topic at both scales. Before the exam, I do a review in a class period where I go over all macroscopic thermodynamics together and all microscopic statistical mechanics together. Changing the order in the re-presentation before the exam allows the students to make new connections."
Jenny Ross

"As anyone who has been thrown in front of a class knows, successful teaching is as much an exercise in sociology and motivational psychology as raw communication of information. I've taught the introductory pre-health professions College Physics sequence at the University of Kansas for about twenty years, with a typical enrollment of 200-300 students per semester. When I started, I had imagined that there would be some burn-in time, perhaps 2-3 years, during which I would hone the trade skills that the course required. After that burn-in time, I expected to coast, reaping the benefits of teaching a high-visibility service course for the department while actually investing only nominal CPU-cycles into the class.

Twenty years later, I find that the amount of prep time has been basically flat since that initial semester. Perhaps most disappointingly, the fractional yearly return from the cumulative effort and investment that has been made in developing and tuning the course content and pedagogy seems to monotonically decrease. Moreover, the script of each season's drama "Physics 114" unfolds increasingly predictably. In Episode 1, before the formal start of the semester, the most eager, interested and enthusiastic students email me to ask me what they can do to ensure success and also mention how excited they are for the upcoming semester. In Episode 2, the class begins, the first homework of the semester is assigned, and the first indications of discomfort among the students emerge. Episode 3 revolves around the first exam, which is a fairly strong indicator of individual student success for the remainder of the semester. The principal dramatis personae of Episode 2, following a harrowing Episode 3, are at that point largely lost for the remainder of the semester. By the end of the semester, the class has stratified into the 'have' vs. 'have-not' populations, which (like Marx's capitalist nightmare) generally show very little evidence of ascendance from the latter stratum to the former. From the faculty standpoint, the 'haves' will generally succeed, independent of, and often even despite, what the faculty do (or don't). Many faculty believe that most of the 'have-nots' are failing owing to their own lack of effort — the faculty slides are impeccable, the animations poignant and the delivery flawless. Although, to some extent this is perhaps true, the disengagement of those students may be avoidable.

For the last couple of years, I've tried to focus on that cohort who have the tools to succeed, but, for whatever reason, end up in the latter category. How is it that students become estranged and alienated (to continue the Marxist analogy) and lose the motivation to apply themselves? Whatever efforts and gestures toward making myself as accessible as possible to the students, there seemed to be an irreducible fraction who, two weeks into the semester, had checked out and were running on life support through the final exam. In retrospect, I had somehow missed, I think, some key points:

1. This particular student cohort requires absolute linkage between the lectures and the homework. This can be achieved in one of two ways — either by following the

scripted slides with online homework developed commercially, or by developing a custom homework system hardwired to the class lecture notes. In my case, with typical academic hubris, I favored the latter approach. Antithetical to the objective of keeping the students engaged is a hybrid scheme, which mixes an online homework system with custom slides, as students will only rarely see the commonality in problem-solving approaches. Unfortunately, this is exactly the maximally counterproductive approach I had used for several years. Ideally, this linkage should also extend to the laboratory, however, at many universities (such as ours), the decision has been made to, essentially, administer the labs as a separate course, which makes this impossible.

2. At the risk of sacrificing academic purism, aim for a high mean on the first exam of the semester (I've also instituted a policy that, if the mean on any exam falls below a 70 percent, an automatic make-up exam protocol is triggered). Making the first exam tough will, for some minority of students, set the standard high for the remainder of the semester. For the particular cohort in question here, however, achievement in the class may suddenly appear to be a bridge too far. Bringing up the grades with a high mean on the last exam of the semester comes too late to be of any use in encouraging self-confidence and success and is often viewed as a token attempt to avoid being torched on student evaluations.
3. Finally, there's a crucial difference between curving a class and grading on an absolute scale: although the grade distributions may ultimately be identical, and the 'A' students in both cases will likely be equally successful, the `B' and 'C' students increasingly focus on simply beating-the-curve rather than comprehending the course material in the former scheme. The tendency toward oversimplifying non-major courses notwithstanding, students, like anyone else working toward some goal, have to have the sense that the goal is achievable, or, at the very least, they're not condemned to wandering in a fog of confusion.

Implementation of these three changes to the fall 2019 curriculum have resulted in a marked difference in the in-class atmosphere, as well as a significant reduction in the number of complaints registered with the department chair. T was a particularly apt case study. This student had taken the same course with me in the fall of 2018 and failed. In the course of a recent interview, she admitted that, two weeks into the 2018 class, she had already concluded that concerted effort in the course was pointless and would focus on avoiding catastrophe. The primary disconnect was between the online homework and the in-class lectures, which appeared logically distinct. Tightening the linkage between homework and lecture and exams allowed this student to develop her own roadmap for success in the class. Ultimately, each student will develop their own strategy for each class; the sooner they are convinced that their strategy will lead to success, the longer they are likely to remain invested in the course."

Dave Besson

Posing and Fielding In-Class Questions

One of the assumptions we often make when students do not have questions is that they actually understood what we taught them. There are many reasons why students may not have questions. Instead of asking, "Do you have any questions?" or "Any questions?" ask "What questions do you have?" and wait for a response. This approach conveys the message that you expect students to have questions. Other ways to elicit questions can be asking, “What do you want me to go over again?” “Are we all clear on X concept?”

Although you may have an unusually engaged class, many instructors have had the experience of asking a question and then facing the ensuing silence for what seems like an uncomfortable period of time. That response is normal, especially in a large lecture class where students may feel shy about speaking in front of so many others. Conventional advice is to wait at least 15-30 seconds before going on. You can also try restating and rewording the question. Sometimes restating the question exactly is helpful, as students get in the groove of taking notes and may not have expected your question or simply missed it. Then, reword the question to help students better understand what you are asking. One colleague provides a supply of lollipops that students can enjoy in class, to reduce the awkwardness of waiting for students to prepare to speak up. In online and hybrid teaching, students can use chat features to submit questions; online polling software could similarly be used to elicit questions from students.

Set the tone early, and get students talking at the start of the semester. Even in classes of 100 or more, students can be asked to introduce themselves or each other on the first day. Or you can take a poll on the syllabus or on their experiences in previous courses. Once the course is underway, there are other ways to elicit student comments and questions. Have the students discuss a topic, question, or problem in pairs and actively solicit questions during the discussion period. When you ask for questions and you are greeted with silence, have some prepared prompts, “In the past, students have been confused about …” or “When I first learned this, I wondered …” The latter method will also remind students that you were once a novice, too. If these are legitimate points of confusion, this will usually elicit nods and even additional questions. This approach may also be a way for you to identify misconceptions of students and then deal with them directly. And, when you do get questions, be sure to tell students that their questions are good ones. From the first time you teach a class, you can start keeping a list of points of confusion that you can use both to improve your explanations and as examples to prompt discussion. You can also use these points to frame debates by presenting several possible answers and asking students to determine the right one(s).

Listen to what students identify as their problems, both with course content and course mechanics. You can solicit this information online, through a course management site, or by using “one-minute” or “muddiest/least-clear point” short essays at the end of class. See section below on Student Assignments and Assessments for more about such strategies.

A fun twist on the end-of-class short paper is to tell students that you will take any question or comment, which can include suggestions for improving the class, concepts that are unclear, or anything that the students are curious about. You can then decide how to answer, depending on the question. If something clearly needs more discussion in the next class session, plan to do that. The "curiosity" questions might prompt you to find some relevant information that provides real-world examples or adds depth to the class. Those questions that are far off-topic can be answered on a class website so that everyone in the class can read about it, but you do not necessarily need to use class time to address these topics. This task need not take much time. Even for off-topic questions, a relatively brief answer with a reference to further reading is probably enough.

> "It is important to find ways early on to engage the students. Since our classes at the undergraduate level are all General Education courses, we have the luxury that we don't have to worry that much about "getting through the material." Recognizing this wasn't immediately obvious to me and took some time. One of the more effective ways to engage the students is to give them points for turning in written questions at the end of class. I will discuss those questions as much as possible at the start of the following class. I will often expand on the question to show students why it was a good question or how it fit in with the material, even if the question may have been phrased poorly. I think it is important not to be condescending about any question that the students ask. I will postpone questions that concern topics to be covered later in the semester, and tell the students this. Of course, the class gets the first opportunity to give answers to these questions and this often leads to lively discussions."
> **Anonymous**

Obtaining Useful Feedback

Ask for feedback from students throughout the course, perhaps with a short online poll, notecards, or clickers. This tactic will help you address problems before they become too large to be dealt with easily and will help you hone as well as amplify the strategies and activities that are working well for students. Most of us do not look forward to receiving feedback, but often instructors learn from early or midterm evaluations that things are going fairly well, and that can be a springboard for future successes. Such evaluations often also reveal annoyances for students that you can easily fix, such as physical plant issues or visibility/sight line issues, but that they would not volunteer unless asked directly. You can also discuss the results of a midterm evaluation with your class and explain to them how you are making adjustments in response to the feedback you received. Students are generally quite appreciative that you took their concerns seriously. They also appreciate that you are giving thought to the way you teach and trying to maximize their outcomes as well.

> "I was thrilled that my class would eagerly engage in discussions during and after clicker questions. I wanted to let people continue their discussions quietly, even after I picked up the lecture again, because it helped make the room feel more energetic in my late-afternoon class. However, several students pointed out in their midterm evaluations that this was distracting and made it difficult to pay

> attention. In the next class, when the chatter continued, I asked those students first if they had any remaining questions, and when they said they didn't, I asked them to please stop talking because it was distracting. One of them looked quite offended, so I explained that this was feedback I had obtained in the midterm evaluation, and if there were questions or more discussion was needed, they should speak up and we would continue the discussion, but if not, the chatter should stop because it made it hard for others to pay attention and learn. Everyone seemed satisfied with this explanation and in fact for the rest of the semester I rarely had to remind students to re-engage with the class at large after discussions."
> **Penny Beuning**

There are a number of other ways that you can obtain useful feedback. A written or electronic midterm evaluation is useful and relatively fast, as in the example above. Some course management programs have built-in instructor and course feedback surveys or allow you to take a poll, although you may want to be sure that you can maintain each student's anonymity. Peer evaluation is often useful; you could ask colleagues from your own, or another, department to sit it on a typical class and provide their impressions. In some departments this is a part of annual faculty reviews. Staff from a campus teaching and learning center or education department may also be available to provide feedback in this way and likely can also help you design and carry out other effective assessments of your teaching and student learning. Many people find it helpful (though also sometimes painful) to watch their recorded lectures. You could appoint a student focus group or student representatives of the class to give you feedback on student perceptions of the class. To avoid accusations of favoritism, you could alternatively ask TAs to fulfill this role, as well as have your TAs try to provide you any "word of mouth" information that they have heard or picked up on during their recitation or laboratory sections. The book "Searching for Better Approaches: Effective Evaluation of Teaching and Learning in STEM" (see Appendix I) has additional information about effective evaluation. Feedback that is more focused specifically on student learning is discussed below in the section on Formative Assessments.

Long-term Maintenance

Teaching a course year after year can provide evidence for aging-associated decay or, ideally, allow for thoughtful refinement of the content and delivery. Instructors often report narrowing content over time to focus on a deeper understanding by students. If you have flexibility in content coverage, this practice can lead to much deeper student learning and make teaching more enjoyable. If your course is a prerequisite or part of a series, it is worth having a conversation with colleagues about what students should know and be able to do when they leave your course, not merely what they "have seen" or what you "must cover." Having taught a course one or two times should leave you in a position to spend less time on your own content mastery, and provide the opportunity for reflections highlighted in other places in this book, such as: Could this problem be converted into an active learning exercise? Do each of these homework problems illustrate a concept or skill the students should master? Where were points of confusion last semester and how can I better teach for student understanding? What practices can I adopt and what examples would make the class more inclusive? How can student-student interactions in my class be improved? Thoughtfully adjusting your course will make it a better experience for students and for you.

3

Utilizing Evidence-based Pedagogy and Active Learning

"What students uncover is more important than what we cover."
Long-held teaching idiom

This section includes many recognized methods of teaching that increase student engagement, along with suggestions for effective implementation. Our suggestion, based on experience, is to start slow and not try to implement too many new ways of teaching at once. By implementing one or a few new practices per course, you will be able to gauge their effects on student learning and enthusiasm and keep your courses fresh for you and the students. Implement changes to your course that you believe have a chance of being successful, as it will be difficult to convey enthusiasm if you are skeptical of your own teaching strategies. Strong evidence exists showing that active learning methods improve student outcomes by increasing engagement with course material and by providing more opportunities for assessment.

Don't Reinvent the Wheel

It is well worth your time to consult with others who have used methods you are interested in trying. Ask them what worked, what did not succeed, what they would change, and how students responded. Did they think it made the students more engaged? Did it help students learn more? How did they set the tone for the semester? How successfully were they able to engage students and do so consistently? It can be useful to brainstorm with colleagues at other campuses, but keep in mind that your own campus may have specific resources for the types of things you want to try. For example, some institutions have centralized support for teaching with technology. Do not feel compelled to adopt someone else's plan wholesale; rather, adapt it to your circumstances, your comfort, and your own strengths and attributes.

> "Getting the students to interact during lecture in small groups seems really important. The students value the chance to explain concepts and discuss with their peers, and I think it gives them confidence and also helps them sort out their own confusions. The learning should be active and continual during the lecture. I use Eric Mazur's Peer Instruction methods, using conceptual multiple-choice questions that focus the discussions."
> **Neepa Maitra**

A common approach is to intersperse chunks of lecture with active learning. Depending on the content, a lecture lasting 10-20 minutes is then followed by an active learning activity, such as group problem solving or responding to questions with a student response system. The exact activity is less important than the active engagement of the students and your enthusiasm for the approach. A substantial number of survey respondents reported that they have adopted clickers or student response systems (65%) or non-electronic response systems (32%), think-pair-share strategies (38%), creative assignments such as student-produced videos (46%), or provided research experiences in teaching laboratories (43%). These practices were adopted primarily to improve student learning (95%) and to add variety to teaching the course (58%). These practices were reportedly received by students either very enthusiastically (41%) or positively (51%). No respondents reported negative feedback from students, although 7% report a "neutral" response from those under their tutelage. Although negative reactions by students were not reported in this particular survey, there is advice below about dealing with resistance of students and colleagues to innovations in teaching that depart from the standard lecture model.

> "Peer learning: Instead of doing examples for the students, I have the students do group work. This can be done with small groups of 2-4 students who are just sitting near each other. I have done this in small rooms and large stadium seating auditoriums, and it works great. I also like to walk around the room and pass by each group to make sure they are on track. Instead of office hours, try evening homework sessions. I have the students who are all working on the same problem get together in a group and work together. These will not only allow content coverage, but enable peer-learning that strengthens students' conceptual and problem-solving abilities. If another student already has the concept, they can educate each other. They are also time-saving (especially the homework sessions) because you can educate a small group instead of one student at a time. Further if another student already has the concept, they can educate each other. Very efficient."
> **Jenny Ross**

> "We use a quasi-POGIL [process oriented guided inquiry learning, in which teams of students work through designed course materials to discover and apply

fundamental concepts] method. We utilize a number of guided activities in class. They allow the students to work on materials with breaks for answering questions and having mini-lectures. In some ways it has a POGIL style, but it is not a rigorous application of the POGIL methods by any means. We do not assign roles to the students. All the activities are not strictly inquiry. Students work through worksheets and periodically check-in to the class. For the "check-ins" we either have students share their answers on the document camera with the class, or simply answer out loud for the class with an explanation. Alternatively we have clicker questions for the whole class that we then have the students explain.

We also use readiness assessment quizzes [RAQ] to help students focus their study efforts and self-assess their knowledge before an exam. For the Readiness Assessment Quiz we again have students present their answers on the document camera and/or we have periodic clicker questions on the correct answer for each part of the RAQ.

I have attached a couple of examples of in-class work for clarification [in Appendix II]. The first is an activity that is used in a typical class. The second is a RAQ that is meant to help the students before an exam. All of these materials have been developed along with my colleague, Dr. Cynthia LaBrake, with whom I team teach."

David Vanden Bout

"We use group problem-based learning in a ~100-student General Chemistry course. We do this in groups of 4-5 students and the students need to talk out their solutions to the problem and draw on dry erase boards and share at different times during the class. The students practice using chemistry language with their peers, and are told to focus not on getting a "right" answer but developing conceptual understanding that they build on. Each of these activities is for a 75-minute period. [Worksheets for these exercises related to molecular orbital theory using Spartan and on bond strength are in Appendix II]."

Linda Columbus

"For several years I wanted to flip my lecture courses in order to spend more class time on active learning, but I worried that students would arrive unprepared, and that this would preclude the value of the class activities. Certainly, some students arrive unprepared, but that was true before I flipped the course, and it doesn't seem to be any more problematic in the flipped format. The lecture videos are easy to make using software that captures my voice and what I draw on a tablet using the Explain Everything app. Students really appreciate having the videos available to watch at their own pace, and if they want, they can binge-watch the whole series before an upcoming exam. Some students will complain that the 30-60-minute videos are too long, but I explain that it takes less time and effort to watch the videos than it does to read the textbook, and the videos are focused on what I want them to learn. I find the greatest challenge to be optimizing the use of each class period to meet the learning objectives. When I introduce a brand-new concept, it is helpful to give the students a brief primer at the start of class before we dive into activities. Even if they've just watched the video and taken good notes, they still find the primer valuable. For activities, I divide the class into groups of 2-4 students, and they stay in their groups until the next exam. This seems to improve participation, while also giving them experience working with different people. For online classes, I used breakout rooms in Zoom. For some topics, I like to give them a few difficult problems with no primer and allow them to struggle a bit while my peer tutor and I roam around the groups helping them along. For other topics, a primer is helpful so students don't stare at the page for 15 minutes.

Students appreciate having videos on how to solve the problems we do in class; this is really just another bit of lecture, and making the videos frees up more class time for activities. I also post video keys of each quiz and exam, showing students how to work through each problem, which gives them clarity, cuts down on students asking questions about the assessments, and provides them a learning resource. It sounds like a lot of work, and the first time through it is very time consuming. But it pays dividends in subsequent course offerings when you can reuse the videos while spending your time each week optimizing the use of each class period to meet your learning objectives. Another major advantage of the flipped format is that I no longer feel rushed to get through a set of topics because they already have my lectures. This allows me to answer more questions and to answer questions more thoroughly. It also allows me to modify activities on the fly to adapt to the needs of the class, which is liberating and makes the class more fun for everyone."
Adam Urbach

Fun, Innovative, and Active Learning

Have fun with your classes. Convey your love of the material by genuinely enjoying teaching it. Make up songs or cheers to help students remember rules; for example, an entire class chanting "PV=nRT" at the top of their voices is unlikely to forget the ideal gas law. Such devices can also serve as memory aids. If you doubt your creativity, there is plenty of material available from both books and websites, including poetry and songs about science (such as the "The Elements" song by Tom Lehrer!). You can also have songs and videos playing as students come into class, as they are packing up to leave, or posted on the course website. Another option is to ask students for their own ideas or to have them come up with something in class. For common terms or concepts, you can give the students your own memory device/mnemonic and ask them if they know of others. For example, two common ways to remember electron flow in redox reactions are "LEO (loss of electrons is oxidation) the lion says GER (gain of electrons is reduction)" and "OIL (oxidation is loss) RIG (reduction is gain)." In organic chemistry, the phrase "Mary Eats Peanut Butter" helps students remember the first letters for methane, ethane, propane, and butane, the alkanes upon which many compounds are named based on having 1, 2, 3, and 4 carbons, respectively.

"When teaching Physics 102, our second-semester, first-year introductory Physics course for Life Science students, I decided to devise song lyrics to help students recall sign and direction conventions in E&M [electricity and magnetism]. I did this in the hopes that these would make it easy to recall the conventions, as there is no way to deduce them... In lecture, I show the videos first, because I have found that many of the students are not familiar with the songs. Also, I find that showing them some three-year-olds singing shamelessly lowers the barrier to their in-class participation. I manage to get all 200+ students on their feet and singing in lecture (though I fear if I brought out a video camera to record this, the majority would promptly sit back down!). I find that the one that they find most helpful is "Potential is Positive 'round a ... + charge." They will come to my office hours with questions about the potential at a given location in an arrangement of charges, and frequently, just saying, in

rhythm "Potential is positive 'round a ..." will elicit a response of "plus charge," followed by "oh!" and an understanding of how to approach the problem."
Nancy Forde

"In The X-Factor of Physical Chemistry in-class project, each group of students uses a short artistic presentation (music, poetry, dancing, etc.) to demonstrate one concept they have learned in the class. At the beginning of the semester, I provided students with a list of suggested topics for their presentations, so that they have enough time to prepare for the performance project they will execute near the end of the semester. Groups of three to five students picked one topic and designed the performance. Each performance was 3-5 minutes long.

I have implemented this "X-factor of PChem" project in class for three years. All three times, students showed amazing talent. Examples from past years include a phase-transition poem, a theater performance on chemical equilibrium, and a rap song on entropy. The feedback was overwhelmingly positive. A majority of students indicated in course evaluation questionnaires that this project motivated their learning. One student wrote in the course evaluation that "the X-factor project was a new way of learning chemical properties that was fun." Some students wished other courses offered similar projects."
Yan Yu

Figures, charts, and drawings are useful learning tools, but they must be used with care. Students may not grasp the important features of a particular scheme or model, so it is important to explain each aspect and provide the conceptual background so that they can understand the depiction. Students can be asked to develop their own graphics or to provide the explanation for a given figure to help them develop and deepen their understanding. Similarly, students may find analogies confusing or may miss the most important or relevant points of the analogy. Analogies should be explained or discussed in detail, emphasizing the most relevant and important points and where the analogy breaks down.

Use concept maps (you can often find examples in textbooks and in Figure 1) that you create or, better, that students themselves devise, individually or as a group or entire class, to clarify the connections between concepts, facts, and fields. Concept maps help organize knowledge by showing connections between key terms, ideas, and information. Novice students may have trouble with this task, but by the later part of the semester, this exercise can help students see the connections between the concepts you have discussed. This approach is also an excellent way to get students to begin an "outline" for discussion sections of research papers.

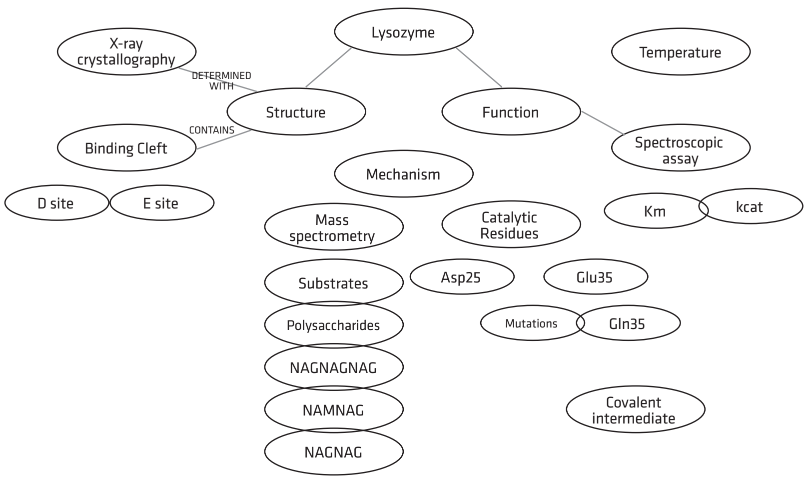
Teaching with the Primary Literature

Teaching students using the primary literature can be effective for students at all levels, including in introductory courses. As is discussed elsewhere in this book, the facts we convey to students are generally the result of years of research that was reported and debated in the research literature. Using this framework in teaching can communicate the excitement of scientific

A

Temperature	Mechanism	Catalytic Residues	NAMNAG
NAGNAGNAG	Lysozyme	Covalent intermediate	Mutations
Mass spectrometry	Structure	Binding Cleft	NAGNAG
X-ray crystallography	Function	Km	kcat
Substrates	Spectroscopic assay	Gln35	polysaccharides
Asp52	Glu35		

B



C

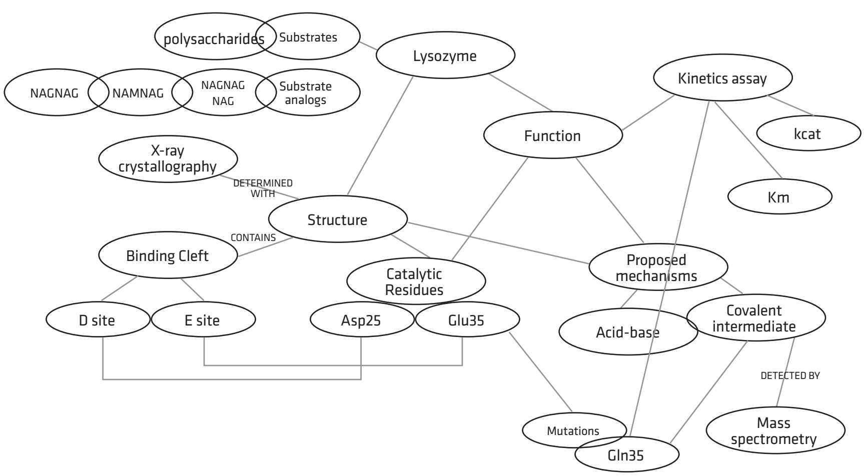


Figure 1

(A and B) Construct a concept map by listing relevant key words and concepts, then organize them in terms of their relationships. (C) Concept map for an article describing the mechanism of lysozyme. Examples courtesy of Linda Columbus.

discovery. In addition, teaching students how to read and interpret primary scientific literature helps them understand how science is done, how scientific facts are developed from inquiry, and introduces them to the real people who have made these discoveries. There are established methods for teaching with the primary literature, as described in the Annotated Bibliography (the CREATE method; *https://teachcreate.org/*). For contemporary work, you could invite the graduate students, postdoctoral researchers, or PIs who published the paper to join your class via online videoconferencing to discuss their work and answer questions. Having the trainees who are co-authors join your class can show the students that discoveries are made by people not so unlike themselves. Reading the literature can also be an excellent source of in-class examples and exam questions.

> "I've written a series of assignments based on the literature for analytical chemistry courses. These assignments are designed to be capstone activities at the end of units on figures of merit (such as sensitivity and LOD), acid-base equilibria, separations, spectroscopy, mass spectrometry, and electrochemistry. Each assignment consists of an out-of-class reading assignment drawn from the primary literature accompanied by objective questions and a set of open-ended, in-class discussion questions. The assignments are designed to require just one class period and can be used before an exam to review important concepts, examine them from new angles, and apply them to new situations. The materials and an instructor guide can be found at *http://community.asdlib.org/activelearningmaterials/interpreting-the-primary-literature/* [cited in the Appendix]. I have a set of assessment questions that ask students to apply their knowledge of working with these papers to a new research study. I've done several iterations of these assignments, so they are quite refined. They are also easy to implement in any classroom space since it just requires a small group of students to be able to talk. Students enjoy learning about new applications beyond the traditional ones we discuss in class.
> **Michelle Kovarik**

Leading Discussions

Set ground rules and expectations for discussions. In the sciences especially, many students are not accustomed to participating in active class discussions, so they may need coaching and direction to best understand how to participate effectively. You can guide the students to set their own ground rules or agreements for discussions by asking them how participants should behave, how disagreements should be handled, and what mechanisms the class can use to ensure everyone has the opportunity to contribute. You should also establish how credit will be given and the criteria for grading the discussion, such as preparedness, participation, and quality of interaction.

Teaching with case studies (*https://sciencecases.lib.buffalo.edu/*) can be a particularly fun approach, as students can adopt the perspectives, and even the voices, of characters in a given situation. It can be difficult to understand all of the subtleties in one reading of a case in class, so have the students read it over more than once, or even better, give them the case in advance. You can also use several short cases which the students discuss in small groups and then have each group of students present their case, the issues it raises, and their proposed solutions to the class for further discussion.

> "**Learning Activity: Debates in Class**
> To allow students more of an opportunity to voice their own thoughts in a course, and at the same time be exposed to a broader perspective on certain topics, I organize three debates during the semester on topics in a science course that lend themselves to debate. Examples include controversial viewpoints in U.S. society on certain aspects of the course material, impacts of scientific discoveries on society, not yet fully established scientific theories, and the financial cost to society of doing the research. Depending on the length of the class period, 3 to 5 student volunteers are asked to serve as panel members. They each prepare a statement on the particular debate topic that they read to the class during the debate. Each panelist's statement is followed by questions and discussion input from the audience (which consists of the other students). As a faculty member, I plan the flow of the debate by considering the topics the panelists have chosen to address, moderate the debate, and guide it in particular directions as students bring up relevant issues that deserve further discussion. I generally do not structure the debate ahead of time, that is, there is always enough discussion that I do not need to "create a controversy" by forcing the panelists to defend certain opposing viewpoints. A challenge that is somewhat difficult to overcome is that the level of preparation for the material can vary widely among panelists and audience, since this is in a general education science course, but I think most students get something out of the debates and they are generally evaluated positively.
>
> Participation credit is a part of the course grade and the debates are one component of obtaining this credit. The panelists gain such credit by volunteering to serve on the panel. The other students gain it by turning in written evidence at the end of each debate on their participation. This can include a brief summary of the questions they asked or other contributions they made during the debate."
> **Anonymous**

Demonstrations and Video Illustrations

Demonstrations in class can convey your enthusiasm and excitement for the material, and provide connections that are difficult to do through words alone. For low-cost and low-technology demonstrations, students can be shuffled around the room as atoms, stars, molecules, mirrors, or proteins, for example. You can even act out concepts with your body and/or props, enhancing the likelihood that the video students will take of you on their phones will go viral. Balloons can be used to illustrate atomic orbitals or concepts of gases and other fluids. Books or websites of science experiments for children can be good sources of simple, reasonably cheap, and safe demonstrations. These can generally also be adapted for laboratory experiments that students could do at home or in their dorms to reinforce topics, keep students engaged, or provide experiments for classes without a laboratory component. If expecting students to carry out experiments at home, be sure to check with your Health and Safety office well in advance to determine what activities, if any, are allowed and how to do them safely. If you have no support staff, you may be able to negotiate for a small portion of TA time to assist in demonstrations or shared responsibilities among different instructors in a multi-section course.

The Predict-Observe-Explain (POE) model helps to ensure that students actively engage with demonstrations. First, tell the students what you are going to do. Then, ask the students to predict what will happen; have them write down their predictions and the reasons for their predictions, then discuss them with the class. After a few reasonable predictions are made, carry out the demonstration, having students observe what happens. Then have the students describe their observations, provide an explanation, and discuss how the original explanations may need to be changed. This approach ensures intellectual engagement with the material that is presented in the demonstration, and is described in more detail in the Bibliography (Crouch 2004).

Videos can be extremely useful for illustrating some concepts and can even substitute for demonstrations if demonstrations cannot be performed directly in class due to cost and/or safety concerns (such as the odors associated with the synthesis of Nylon, for example). Simulations, illustrations, and videos are included with textbooks or available online through other resources, such as the Journal of Visualized Experiments. When using demonstrations or videos in class, be sure to explain the context and how it relates to the course material. In other words, do not make a big boom or smoke cloud just because you can! The predict-observe-explain model also works for videos and simulations. After the demonstration or video, discuss what the class saw, what it means, and how it relates to the course. For online videos, give the appropriate link, if available, so that students can view it again later. For demonstrations, it is sometimes possible to provide a written description or protocol so students can reproduce them on their own (for non-hazardous demonstrations) or a link to more information online. Demonstrations should be large enough to be seen by the entire class or small and safe enough to be passed around. Do not be afraid to do the demonstration or show the video more than once, even after some discussion, so that students can determine where to focus and what the important points are.

> “I learned this ‘remote + classroom demo’ method at a Cottrell meeting from one of the presentations. I apply it, for example, when teaching electronic excitation, relaxation and emission. After explaining the concept, as a surprise one of my postdocs or grad students comes up on the screen via a camera in the lab. He or she shows students a cuvette of mCherry fluorescent protein and a green laser, and asks what the color of the fluorescence might be. I let the students pair up for a minute and give some answers. Usually plenty of people provide a ‘redder’ color than the green laser. Then the postdoc shines the laser through the cuvette (the lab is darkened), and students see the red fluorescence. After that, I continue

my lecture for 20 minutes or so. Five minutes before the end of class, the grad student or postdoc shows up in lecture as a surprise, laser pointer and cuvette in hand. We pass it around and have the students do the excitation themselves (up close it is easily visible even in a lit classroom). They are invited to visit the postdoc in lab if they want."
Martin Gruebele

Integrating Lecture and Laboratory

Important concepts can be reinforced in the laboratory. Ideally, the laboratory exercises should be integrated with lecture topics, so that a given topic is covered in the laboratory at roughly the same time as in lecture. Although sometimes individual instructors are responsible for the content of both the laboratory and the lecture, in large or multi-section courses, you may have little control over the laboratory exercises, methods or material. If you meet with the laboratory instructor or coordinator before the start of the term and obtain a copy of the lab materials as well as a schedule for the labs, you will then be prepared to discuss how the work done in the lab parallels and reinforces the material students are learning in lecture. Share your syllabus with the laboratory instructor so that they can see your order of topic presentation. Be explicit about these connections. Inevitably, labs get out of sync with lecture; keep this in mind and remember to give previews or reminders of the lab exercises that are related to your lectures but not in synch. In addition, make sure that laboratory personnel are conveying the same message on topics as you are; nothing could be worse than having them "negatively" reinforce something you are trying to teach by contradicting your lessons and/or key points.

Discovery-Based Laboratories

The laboratory can be the ultimate active learning experience. However, this opportunity can be squandered by lab exercises that involve following a recipe or set of instructions with little thinking involved. Some so-called "cookbook" labs may be necessary because, in addition to theory, students need to master the techniques of their field. Complementing them with labs in which no one knows the outcome in advance or, in addition, the approach or analysis is not clearly specified, will allow students to apply their knowledge in solving an actual problem and confronting a scientific problem in the true way that researchers do. You will probably have to train your TAs in how to teach such a lab to students, including how to explain background and to convey expectations for the lab. One way to increase the chances of success is to design projects so that there are several checkpoints on progress; for example, in a half-semester-long research-based lab, students could submit a brief progress report every week or two so that potential problems can be addressed early. Project labs are classes in which the entire semester is built around a research project, and these can be intense integrative learning experiences for students. The CURE (Classroom Undergraduate Research Experience; *http://www.grinnell.edu/academic/csla/assessment/cure*) survey is one tool that can be used to assess student experiences specifically in research-based courses.

> "As an example from our upper-division courses, we've recently re-organized our Department's physical chemistry curriculum, including the lab courses. The lab courses now mirror the "introductory" & "in-depth" (as opposed to "classical" / "quantum") two-semester breakdown of the lecture classes. While the first semester lab course is merely a selection of the seven most relevant (and non-overlapping) instrument-centric physical chemistry experiments that we had in the previous structure, the second-semester course is different: In the second semester the students perform a wide range of experiments (and calculations) supporting system-oriented modules — each of which lasts for several weeks. In each module, a single molecular system (or family of systems) is studied by multiple methods in an open-ended fashion (with the larger goal of answering a few main questions), allowing the students to discover what kinds of information can be learned using different approaches (and how they can complement each other to tell more of the "whole story" about a given molecular system). Some of the instrumentation used is in the physical chemistry lab, while some is in the (NMR/MS) facilities on campus, and some of the instrumentation is in the labs of individual faculty. Instead of writing traditional lab reports, students write manuscripts in journal format (or, for the last module, give a team oral presentation). The idea is to present a lab environment that is more like "real research," while also providing students with an additional pathway into undergraduate research opportunities."
> **Boyd Goodson**

> "Students engage in independent projects in both lecture and lab classes, with the latter particularly focused on following through a research proposal and obtaining results (Biological Physics lab course, our fourth-year senior lab course). The lecture class in which I have done this is Phys 344, our third-year Thermal Physics course. There, students were able to choose to present a poster on a topic related to thermal physics, e.g. a person, a concept or a device involving classical thermodynamics. Projects ranged from building heat engines, explorations of Maxwell's Demon, and biographical presentations of a physicist's life and scientific contributions."
> **Nancy Forde**

Integrating Research with Teaching

It can be both fun and profitable to integrate your research into your teaching efforts. The benefits include conveying your enthusiasm, sharing your research with students, introducing students to some of the real-world applications of what they are learning, or helping lay the groundwork for new areas. This integration can be as simple as discussing your own research when it relates to topics covered in class or specifically introducing a brief discussion of your research to let the students know about your work. If you assign research papers or proposals, some of the topics could be related to your own research. You could even develop a discovery-based laboratory related to your research, but make sure you are not depending on this for critical results. Having a TA with an interest in the outcome of the lab will also help with effective implementation. Such efforts can pay off both in the insights you might gain and in helping you recruit interested, motivated students to your group.

An important point here is that (perhaps surprisingly!) many students do not have good search strategies for finding information and do not have the skills to evaluate information they find online; the first answer is often the one that students will accept, though as we all know, it is not necessarily the best or the most accurate. If you provide a reference to a website for further reading, you can help ensure that students are getting good information. You might even discuss how to search for information and triage results, or even consider demonstrating your own search process.

Dealing with Resistance

Some students will resist active learning methods, but consider that lectures are comfortable and familiar. Additionally, active learning demands more of students during class and is more work for them in general. Some students appreciate and enjoy being challenged, but others may resist the extra effort required on their part and want only to sit and be passive learners. We recommend the strategy mentioned earlier of being transparent about your approach; again, explain why you are doing what you are doing, and what you hope will be gained. If you encounter resistance to innovations in teaching by students (or even colleagues), approach this like the scientist that you are and be prepared to collect data on student attitudes as well as their learning. Other strategies that people have found useful are to lead by example and to talk up potential advantages as well as to be persistent and positive about the possibility of change.

> "Lead by example. When techniques work, people take notice. However, don't only rely on teaching evaluations. Collect the data that demonstrates student learning and share it with your colleagues as well as your students. Student satisfaction is not the only important criterion. We don't hire personal trainers because it is fun to go to the gym. We hire them because they motivate us to perform beyond what we would do on our own. It may not be fun at the time and it is often hard work, but, it is the results that matter — whether it is learning in the classroom or becoming stronger through the help of a trainer."
> **Andrew Feig**

> "I really haven't had major problems in this particular area. When I wanted to do something different, I just kept talking about it and voicing the potential advantages. I was persistent but always positive. To be fair, I've had it lucky, as my colleagues have been every bit as likely as myself to suggest new approaches, and we try to work together to bring about the best possible result. More often (at least for me) the hard part is actually making the change happen. Whether it's obtaining resources for improvements to upper-level lab courses, or gaining approval from other departments (or administrators) for lower-level courses that include non-major students, gaining support and approval from within one's own department

> can be the easy part. Finally, I would note that just because you've succeeded in getting a change implemented, it doesn't mean that future budget pressures won't work against you to return to the previous status quo. Perhaps not surprisingly, we've recently found that the best protection against this kind of pressure is data from ongoing assessment. In one case, we were recently able to show that students participating in a new course design had significantly better outcomes than students who did not participate; these types of fact-based arguments can be persuasive when your innovations are threatened by credit-hour bean-counting or other types of financial pressures."
>
> **Boyd Goodson**

> "It's hard to argue with someone who's well prepared. Prepare the material and make clear arguments for why you want to do things the way you do. I find that students appreciate that you're giving thought to your approach, even if they disagree. I don't have much experience getting colleagues to adopt new approaches, but generally I think most faculty will go along if they think that it will make their job easier, so focus on providing adequate support and making it easy."
>
> **Steve Dodge**

Try to incorporate these methods in your courses seamlessly. For example, instead of saying, "OK, now we're going to do Think-Pair-Share. First, Think about this problem. Then, form a Pair with your neighbor," tell your class, "Take a few minutes to think about this and then discuss with your neighbor. After 2-3 minutes, we'll talk about your discussions as a class." This will make your efforts seem less gimmicky or contrived and far more natural, achieving the end goal desired.

4

Teaching with Technology

How much or how often should technology be used in your classes? In general, you should use technology when you think it will help students learn or help motivate students to learn. Problems with technology during class can be distracting, and if student grades depend on use of technology (for example, with clickers or online assignments), technical problems can engender student angst and anger. It is critical that if you do implement technology, do not let it limit your flexibility or get in the way of your teaching. Additionally, some technologies can be quite expensive for the institution or the student. Because different systems may be incompatible and technical support may be limited, it pays to ask around for advice about specific technologies. Use of technology is generally facilitated by well-equipped classrooms, although this is not absolutely necessary as many systems now rely only on personal electronics such as mobile phones and laptop computers.

Recorded lectures can help students learn. Many instructors use lecture capture technology to synchronize their voice with the visual materials; others record and post podcasts for students. These can be recorded during class or in a separate event. Although it can be time-consuming to make and post the recordings, the availability of such materials can save time because students can answer their own questions by going back to the recordings. Such recordings can also improve student learning by saving class time for more in-depth discussions. Similarly, class wikis enable student questions and mundane issues to be addressed in real time. Some instructors use Facebook, instant messaging, or even Twitter to facilitate student questions and discussion. Another option is a collaborative discussion forum such as Piazza, which allows for student discussion as well as the insertion of formulas and symbols. Many course management systems have built-in capabilities for discussion as well. It is worth surveying students to find out the best way to facilitate communication. If using a third-party, non-institutionally-sponsored product, be aware of regulations governing student privacy.

> "I approach teaching, like every other part of my job, from an experimental point of view. The first time I taught sophomore organic chemistry, it was all I could do to prepare good lecture notes, write quizzes and exams, and hang on to my sanity. But once I had the general structure of the course down, with a solid set of notes prepared, I had the time and mental space to start tweaking the course. Every year the course is a little different from the year before, and I keep the changes that seem to have worked well. I began using Instant Messenger pretty early in my teaching career to supplement office hours. A few years ago, I noticed that the number of people who would contact me by IM was considerably lower than in previous years, and found out from my grad students that "nobody uses AIM [instant messenger] any more, everyone uses Facebook." So I started using Facebook to answer students' questions in a publicly accessible forum. This became wildly popular and has taken on a life of its own. By the end of the semester, my students are using the class Facebook page to set up study groups, answer each other's questions, and chatter about chemistry-related but class-irrelevant news stories. It's been really rewarding, and it also has the added benefit of cutting down dramatically on the number of individual emails I get from the class."
> **Anonymous**

Online Homework and Assessments

Online homework and quizzes help students learn and help the instructor understand how well the students have mastered the material. Some publishers provide online homework with textbooks, saving you the effort of developing the content. Audience response systems (clickers) can provide the same advantage in real time. Some online homework systems will allow multiple instructors and TAs to access homework data and track student progress. Similarly, standardized exams can provide the opportunity for extensive analysis of the types of problems with which students or subsets of students struggle.

> "For introductory chemistry, our department (not just me) has recently instituted a number of changes, including:
>
> - Mandatory 1-credit computer workshop course, where students work on computer-based problem sets in small classes under close supervision of hand-picked TAs. Clickers (which we use for real-time assessment, but which also provide the added bonus of taking attendance).
> - The introduction of an additional Honors section of the course, taught at an accelerated pace but also delving more deeply into certain parts of the material. We also 'liven up' the material by presenting 'vignettes' at the beginning of some lectures entitled "great moments in chemistry-relevant research" (from which

> students must select final essay topics in order to receive honors credit). This course is for chemistry majors and high-performing science majors only. These changes are assessed yearly in aggregate, and broken down by population."
> **Boyd Goodson**

Simulations

Simulations and interactive computer programs can enhance student understanding. Simulations can enhance learning by helping students 1) visualize a process, molecule, material or reaction, 2) work through a problem, or 3) even see how a particular reaction or process might change if parameters are perturbed. Some textbooks come with electronic supplements or websites that provide simulations connected to particular topics. As with demonstrations, it is important for you as the instructor to consider what students should learn from their work with simulations and structure assignments or in-class activities accordingly. There should also be follow-up discussion of the results of the simulation.

Student Personal Response Systems, e.g. "Clickers"

Mentioned previously, personal response systems generally consist of a phone, laptop, or remote-control-like device through which students register responses to questions posed by the instructor. Although nearly all students already have smartphones, this approach can be risky. For one, you are inviting students to use phones during lecture, which can introduce numerous distractions. The other, more significant issue is that students might not have adequate or consistent reception or Wi-Fi in your lecture hall, in which case you will have to find another way to obtain that feedback or give the assessment. The responses are collected electronically and recorded and/or displayed. These systems provide one way to gauge student comprehension in real time. Many universities have adopted specific systems for campus-wide use that provide institution-specific interfaces to the learning management system; find out the norm on your campus so that you do not make students buy multiple different devices or programs of different types, both from the perspective of cost and to ensure that you have reasonable technical support.

When students can clearly see how they compare to the rest of the class, it will be hard for them to accuse you of being unfair. Student accusations of unfairness generally fall along two lines: that you are evaluating them more harshly than others, and that your questions are unreasonably difficult or "tricky." When student responses are displayed for the entire class, it will be clear how each student compares to the entire class. If you do write the occasional confusing question and you see that in the student discussion or responses, admitting that it was confusing or poorly worded and quickly and briefly apologizing will generally improve your standing with students. Ambiguous questions can also serve as the basis of discussion, when you can ask students to probe more deeply what is correct or incorrect about the question and answer or how can the question be improved.

Should response systems be used to monitor attendance or just to give feedback to students and instructors? It can be less technically involved to use clickers only for feedback or for "just-in-time teaching," rather than for taking attendance or factoring into grades. Taking attendance and grading require some kind of registration system of each student's device and integration of the registration information into a record-keeping system, such as an online gradebook, whereas using them only for in-class problems or surveys with no credit attached to the responses generally requires no such registration. However, you may want to use response systems for attendance or grading purposes as an incentive for students to come to class and participate by answering questions. One effective way to do this without being too punitive is to offer a grace period at the beginning of the term to allow students to get used to the system, as well as offering the ability to "drop" a few days of attendance from the graded days. Some people give a specific number of points per problem or a fraction of a point for answering a question, with a full point awarded for the correct answer. Unless you have the entire semester planned in advance, it is wise to normalize the total number of student response points to some fraction of the total grade so that you are free to use as few or as many questions as you like throughout the term.

Many textbooks for introductory courses (especially from major publishing houses) come with student response questions as part of the instructor materials. Even if yours does not, you may be able to acquire a set of questions from your publisher if they are available for a different text at the same level. Other sources of questions include test banks, online quizzes or homework, or STEM education journals. Writing such questions from scratch can be quite time-consuming, although creating a good library of questions will pay off in subsequent years.

There are numerous other lower-tech methods to implement the instant or near-instant feedback feature of personal response systems. Note cards with letter choices (A, B, C, D) can be handed out with the students holding up cards to indicate their answers to posed questions. This approach has the benefit of being cheap and easy; students can quickly generate a set of cards, and you do not have to rely on students remembering to bring a device to class every day. An even simpler technique is to ask students to raise a number of fingers to represent their answer to a multiple-choice question or to vote on a limited number of answers. Whatever method you use, you should discuss the answers given before moving on, so students can confirm the correct answer and understand why it is correct. It is often helpful also to have the students discuss the question and their answers and vote again after the discussion, especially if your polling revealed a large proportion of students are confused.

eLectures

"My first time teaching a large (approx. 200 students) section of our Organic Chemistry I class was referred to as the "commuter section," since it met between 5:30 and 7 p.m. and since many of the enrolled students had either part- or full-time jobs and were older than typical college undergraduates. Such a student population posed several challenges: they often simply had to miss class and could not study as regularly as traditional students. In addition, many of them had either longer-than-usual college careers or had taken a break from school, and their study habits often suffered as a result.

With these challenges in mind, I decided to set up an extensive class website that could assist them in keeping up with the course material while not sacrificing their work and family obligations. In addition to uploading the usual items found on course websites — class syllabi, sample exams and quizzes, scanned lecture notes — I wanted to create a more comprehensive and interactive tool that would approximate the experience of my lectures through digitized recordings of my voice and writing. For each of these eLectures, I identified 5–10 key concepts that I covered in an actual classroom lecture. Then, in the silence of my office, I recorded approximately five-minute-long video segments that explained each of these topics. Using a tablet computer, I could simultaneously capture both my writing and voice, and watching the resulting video looked similar to watching me lecture and write on the board; these were created using Camtasia Studio. I intentionally avoided a rather common practice in the use of tablet computers: recording my actual lectures. I had three main reasons for doing so: (a) since I lecture with chalk and board, being tethered to a tablet seemed very restrictive; (b) lectures have a lot of "dead" time — students settling into their seats, me erasing my board, answering questions about the exams or the curve, etc., and (c) a recorded lecture presented a 90-minute-long video file which was difficult to navigate to an exact point of interest. With shorter segments separately recorded, students could easily find the topic they were looking for. Afterwards, I created an interface (found at *www.chem3331.com* > *Lectures* > *eLectures*) which allowed the students to easily email me while listening to an eLecture, post a comment or question on the course Facebook page, or click on external links of interest. These external links (mostly to Wikipedia articles) were context-sensitive; for example, when I talked about hydrocarbons, I included the links to methane, propane, petroleum, etc. (Figure 2). The student response to this tool was overwhelmingly positive, although I still — five years into it — have a difficult time persuading all enrolled students to consistently use eLectures. Some of my colleagues at other universities recommended my website to their students. In one of the anonymous end-of-semester evaluations, a former student of mine wrote: "I have a full-time job and I am a part-time student. Prof. Miljanić's online resources really aided me on days when I had to miss lecture. His online lectures are as if you are sitting right in your seat in class. He really understands the concepts and makes every attempt to break it down to a much more tolerable level."

The creation and use of this electronic resource have not been without challenges. Initial setup took an extremely long time: I estimate that for each 90-minute lecture, approximately eight hours were needed to create the eLecture equivalent. One of those hours typically went into the preparation of materials and splitting it into appropriate segments. Three hours were needed to record all

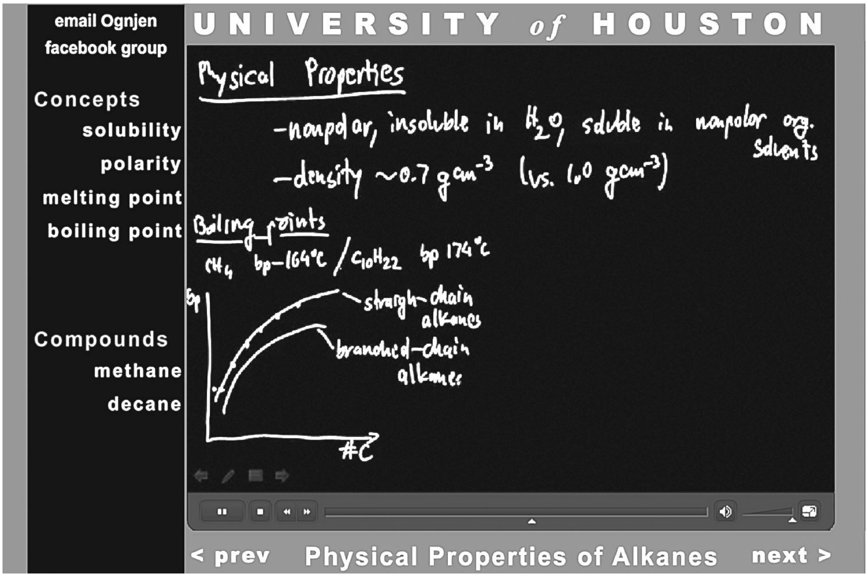


Figure 2

A screenshot of a typical eLecture. The central panel simulates the blackboard, where my real-time writing can be followed while listening to my voice explaining the concepts. The panel on the left provides hyperlinks to related concepts in other eLectures and on the web. In the top left corner, two links allow students to email the instructor, or ask a public question through the course Facebook page. Buttons on the bottom allow navigation between different concepts in the eLecture.

of the segments, and probably another two hours were consumed by the creation of the interface; a final hour was taken up by listening and proofreading the finalized product. This time investment is needed only in the first iteration of the course (updates during the subsequent years were quite minimal), but was a huge time drain in the first year — especially for an assistant professor struggling to simultaneously get a research program going. An additional issue is being presented by the changes in technology.

I recently tried to take advantage of the fact that all my lectures are available online and to instead use lecture time to answer questions and work on example problems. Therefore, I asked the students to watch eLectures before the lecture and then come to class prepared with questions and preliminary understanding of the materials. Disappointingly, less than 50% of the class did as I advised, and some justified this by the fact that listening to my lectures and to the eLectures would take too much time. So, clearly, this tool is not a panacea.

At the end, I should point out that these eLectures probably would not exist in their current form were it not for the wholehearted financial and technical support of my College and University, which included a tablet computer, a summer stipend, server space, and technical assistance. It was also very rewarding to receive the 2012 UH Teaching Excellence Award, a University-level distinction that specifically cited the use of instructional technology to advance student learning.

What does future hold for eLectures? I see them as a useful model for future distance education tools. As the state support for higher education continuously decreases, and student enrollment continuously increases, public universities will

be hard-pressed to deliver high-quality education at a low cost. To counter these trends, this and other electronic resources could be used to deliver a basic level of knowledge to an essentially unlimited audience for free. While these resources still don't come close to replacing a living person as a teacher, they may soon substitute for (overpriced) textbooks as the chief tool for the delivery of static information. In the era of smartphones, where all of the world's information is literally at our fingertips, the role of a teacher is now essentially changed from a guardian of knowledge to that of a guide through knowledge. Technology fits into this view as a vehicle to deliver raw information quickly, cheaply, and effectively over large distances; the faculty should instead focus on helping their students personalize, interpret, and apply that information to the career they see as best fitting them."
Ognjen Miljanić

Tablet PC, Electronic Inking

One of the benefits of overhead transparencies was that the instructor faced the class while writing notes. Although few of us use this technology any longer, that particular feature can be replicated by using a tablet PC or electronic inking technology. The instructor can write notes that are projected onto a screen while still making eye contact with the students or even walking around the room. The lecture outline could be a set of blank or mostly blank slides, into which movies, animations, and other multimedia features can be embedded.

"I was using an iPad as I was walking around the large classroom. The iPad was connected to my MacBookPro, where my lecture had been previously prepared with Keynote. There are a couple of advantages in walking around the classroom. First, you certainly achieve the goal of engaging the students better than by standing at the podium facing the students. As you walk around during the lecture (20 min) you get between them (hopefully, the classroom allows for that). It is important to carry a laser pointer with you as you walk around the lecture hall, as one will need it. Second, by walking around (and behind) the students, there will be less temptation from most of them to open up their laptops/tablets/phones to go on Facebook, Twitter, or shopping online during lecture. If Active Learning is the adopted approach, then lecturing while walking around the classroom really helps.

A few things that are worth considering:

1. When connecting the device, such as an iPad or iPhone, to the laptop, it is best to use Bluetooth capability. It is very reliable, whereas the connection with the WiFi can have severe shortcomings, depending on the location, type of connection, security issues, etc. I was always having trouble connecting the two devices at the beginning of the lecture with WiFi, and after I discovered the Bluetooth connection, it was perfect.
2. To run the Keynote presentation from the iPad or iPhone, the minimum required app is "Keynote Remote" (iPhone app). It is free and simple to use. It also shows the presenter's notes (although on an iPhone the screen isn't big enough to really make good use of them), and it allows one to control the presentation forward or backward, but not much else.

3. Other, much more powerful tools are "Doceri" (interactive whiteboard for iPad) and "Airserver;" when I looked around there were apps/software that also allowed one to record the lecture, but since it was the first attempt for me, I decided to keep it as simple as possible. For the next term, I will look into something more interactive, and possibly into recording the lecture. Having the ability of using the iPad as a whiteboard and marking directly on the lecture slides is a powerful capability."

Danilo Marchesini

5

Student Assignments and Assessments

Assessments are generally classified as formative, which are used to gauge student learning to adjust teaching and improve student learning on an ongoing basis, or summative, which are used to evaluate students at the end of a section or term. Both types of assessments should support your learning goals.

Formative Assessments: Getting and Giving On-Going Feedback

Formative assessments should be used regularly to assess student learning and to adjust your teaching as needed, by reviewing material, changing your approach, or emphasizing key points. Formative assessments are low stakes; they carry no or a small amount of credit. The goal of a formative assessment is to encourage participation and provide feedback. Student response systems, described in the previous section, are often used for formative assessments, since the student responses can allow the instructor to assess student learning and make adjustments to instruction in real time.

One easy and informative assessment is to give students a few minutes at the end of a class to write a short paragraph, often referred to as the "minute paper," about the main point of the material discussed in that class period. Reading these responses will help you understand how students perceive the material and if they were able to understand and/or appreciate the main points. A similar exercise is to ask students to write briefly about what they thought was the clearest point and the least clear (i.e. "muddiest") point of the class period. This type of feedback can also be acquired through a web survey or with course management software. Concept maps can also be used in a formative manner to gauge how students view the connections between topics. We advise regular use of formative assessments to gauge student understanding throughout your classes.

Summative Assessments: Exams, Homework, and Grading

Summative assessments are used to determine student learning and skill development at the end of a defined instructional unit. These often carry a large share of the points in a class. Homework can also be formative if sufficient feedback is provided to students; one way to do this is to use class time to go over homework problems in depth, especially on problems where students are having trouble. In addition, exams can be formative when they are designed to be used as learning experiences; examples are discussed later in this section.

Be explicit about your grading policies. How many points are distributed to which kinds of assignments? Will late work be accepted and what are the penalties? How many points are allotted for each part of an exam or homework set? Can partial credit be given? One way to cut down on requests for regrading or arguments over points is to tell students that any request for you to look at an exam or assignment again will result in you going over the entire exam or assignment, which could result in actually losing points if you find an error that was in the student's favor. You could require students to submit a paragraph about what they want regraded and why. Others have a policy that the likely change has to be more than a certain percentage of the points to justify a regrade.

> "Exam re-dos. This seems like a cheap gag, but it is effective and a positive with students. Also, if implemented correctly, it doesn't actually affect the final grades, but it really affects how the students see you. I grade the exams quickly, within one week, then I give them a week to redo the problem they lost the most points on. They can only earn back half the points they lost. Since they cannot earn all the points back, there is not any real change to the scale, but they feel better. Further, they had a second chance to look at these problems and the concepts. It is a win-win."
> **Jenny Ross**

To save time writing exams, ask colleagues for old exams. However, be aware that some student groups might harbor banks of old exams, so be sure to change the questions; similarly, several commercial internet sites and other sources have become repositories for such questions, making any problem potentially searchable. If you have TAs, you can also ask them to help develop exam or quiz questions, which will save you time and help in their development as educators. Another creative exam strategy is to have one "question" on the exam for which students write their own question and answer it; they are graded on the quality of the question and the response.

You can have students submit and then critique other students' problems before you write your exam; this process will also give you a sense of the intellectual sophistication of the class before you write your exam. Questions could be submitted in advance of an exam as a homework problem, too. One suggestion, however, is to make sure that you are responsible for the final draft of the exam itself; in addition, consider not showing the exam to your TAs in advance, as this allows them to run review sessions or other help sessions without knowledge of the exam content so that there is no chance for any unfair advantage to the students who do seek extra help from a given TA.

To be as fair as possible, grade one problem (or one page) for all of the exams at one time. If you have graders, each grader should be responsible for the same question(s) on all of the exams from the class. This way grading should be consistent from student to student and, if any particular question was unclear, it will be easier to detect. It will also be easier to determine if particular concepts are giving a large proportion of students trouble and make cheating easier to detect. To minimize bias and the effects of fatigue, grade only one problem or one page in every exam from the top of the stack to the bottom, for example from A to Z by student names, then grade the next question in all of the exams but in the reverse order, from Z to A. Use grading rubrics to define specific skills or answers that signify high/medium/low levels of competence. Devise your rubric in advance as specifically as possible: how many points for a particular part of the answer, what deduction to give for units or calculation errors, etc. It might also be of value in establishing that rubric to look through 10-15 exams on your own to see if a consistently "wrong" answer is being provided; it could be because your question was not well worded and additional answers might be worth considering for full credit as a result. Then, as you actually grade the first few exams, make notes for aspects of each answer that earn or lose points. This will help maintain consistency in grading. The same goes for problem sets; students will certainly compare marks with each other, and will be frustrated if similar (or the same) answers are not marked consistently.

In large lecture classes, multiple choice exams may be unavoidable. It may be possible to give some multiple choice questions to save time and some problems or short or long written-answer questions to make sure students can solve problems by asking them to show their work. Multiple choice questions have some benefits, in that a large amount of data is generated that can be used to determine where student misconceptions lie. However, writing good multiple choice exams is not easy; all wrong answers should be plausible without writing "trick" questions. If you find as you are grading that you have worded a question in a confusing manner based on student answers, a kind way to deal with this is to give all students all or some of the points available for that question.

Asking students on a final exam to list something that they will take away from your course (for some small part of the grade, for example one-half or one percent of the exam points) can provide you with important insights into student perceptions of your class as well as complement student course evaluations. The answers can be surprising. Similarly, you can use this mechanism to gain feedback about topics students would have liked to have discussed or things they would like to change about the course. This would not be anonymous feedback unless you structure it as such. Bonus questions are also a nice way to connect extra topics in class. A good way to use such questions is to incorporate extra topics that were presented in class, but might be slightly beyond the main scope of the evaluative components of the course, such as the importance of a key discovery or the significance of a Nobel Prize. This might even encourage and reward classroom attendance!

> "**Exams as learning experiences in Introductory Physics:** Exam scenarios, which are summaries of background-type information that would be given for exam problems, are provided to students at least five days before the exam date. Students can discuss the scenarios with each other in groups to work out possible exam problems related to the scenarios. Students then take the exam individually. Immediately following the exam, students work together in small groups to generate solutions; each group works on only one exam scenario, which typically includes up to three related questions. Since students have already worked on the problems individually, it only takes the group about 20 minutes to produce solutions to their scenario. The student-generated solutions are posted on the classroom walls for a gallery stroll where students compare and discuss the various solutions offered. The instructor, graduate teaching assistants (TAs), and undergraduate learning assistants (LAs) are all available for consultation while students work on their group solutions and during the gallery stroll. Students receive credit for producing a solution as a group (equivalent to normal group problems) and exemplary solutions are posted on the course website as part of the official exam key. Student feedback indicates that students value these activities and find that they reduce anxiety before exams and contribute positively to learning. Students with less fluency in English and those who process information more slowly seem particularly appreciative of this structure. This structure also makes exams more fun and engaging, as students discuss and debate solutions during the gallery stroll."
>
> **Jordan Gerton**

An exam wrapper is a general term for surveys or quizzes that direct students to reflect on their exam performance in order to adapt their study strategies and learning. These usually explore how students prepared for the exam, how they did on the exam, and how they will prepare differently in the future. Such exercises can be important for student metacognition and self-reflection.

> "After an exam, I photocopy them. I then grade them and email the students both their copy (before grading) and their score (but not any information about what they missed). They then need to identify what problems they missed, what learning objective was being tested in that problem, why their original answer was wrong (e.g. what common conceptual mistake did they make) and what the correct answer is. Although this is done outside of class it is an active learning activity

because students are encouraged to work together in figuring out what they did wrong (though their submissions need to be their own work). Because they can earn back up to half the points they missed on the exam, discussion groups are very active! This is by far the most popular activity that I do. It also enables me to give more difficult exams, showing students a broader range of what they should be able to do with the physics that they are learning, without worrying about destroying student scores. I have also found that even years later students remember specific exam questions and how they changed their way of thinking about a particular concept."
Eric Hudson

Experienced instructors recommend giving regular assessments to students throughout the term so that the students have plenty of opportunities to receive feedback. High-stakes situations in which the entire course grade rests on one or two exams do not encourage productive study habits or take into account events that can disrupt students' lives and ability to prepare effectively.

"Group quizzes: I give weekly quizzes in my Introductory Physics class of about 45 students. During the first half of the class they take the quiz on their own. They then change from pencil to pen and resolve the quiz as a group (6 students each). Finally, once the group quiz is turned in, they are given full solutions and a grading rubric and they grade their neighbor's quiz. This turns the quiz into a learning activity with active discussion."
Eric Hudson

Encourage students to engage with the material and move beyond memorization. Provide students with a figure from the primary literature and ask them to provide a figure legend. Have students explain why a wrong answer is wrong. Ask students to connect what they are learning to something in the real world. Independent research can motivate student learning. In laboratory classes, the focus should be on obtaining real results and can include first devising and proposing a research project that is then carried out throughout the term. Student presentations in poster or oral sessions at the end of the project can be fun for students and instructors and will help students learn skills of data presentation and effective communication.

"I teach an 80-seat thermodynamics course to seniors majoring in biochemistry. This is the smallest class I teach all year and it is often the smallest lecture class that my students have taken for any course required in their major. The goal of my active learning activity is to address the problem that many of my students have little experience working collaboratively on problems to which there may not be an obvious answer (which is what practicing scientists do every day). After having taught thermodynamics for over a decade, I have a repository of previous exam questions. I post each question in a separate Google Doc within a Google Drive. I then assign my students a homework set in which the first four problems are stated as follows:

"PROBLEMS 1-4) Use your university account to access the practice problems from the Google Team Drive. Recall from the syllabus that about half of the points on your midterm will come from problems like these practice problems (either exactly the same or minor permutations of them). Each problem and Google Doc has a unique, identifying name. (a) Choose 4 problems and work each one. Turn in your solutions with your homework. Write the identifying name above each solution. (b) Go to the Google Team Drive, find the Doc corresponding to the questions you chose, and type in your final answers. Feel free to describe your approach to the problem and solicit feedback from the rest of the class. Recall from the syllabus that I will not give you the answers to the practice problems. How will you know if your answers are right? You will compare with your colleagues who have chosen to work the same problems. That's what practicing scientists do. It is also how graduate students study for their qualifying exams. By the end of this course, you'll have a set of skills to help you succeed in those situations."

At first, students share only the bare minimum of their answers, and they are cross that I have not provided answers. They initially do not like to show other students how they did their work for two reasons. First, they don't want other students to know if they did the problem incorrectly. Second, many of the students in my course want to attend medical school, and many of them think that the best way to do so is to have grades that are higher than their peers (which means that they want to keep correct answers to themselves). After student responses have amassed for a few days on the Google Docs, I start leaving notes like, "It looks like the answers are starting to converge to this problem," or "Too few students have contributed to this problem for me to determine if the answers are converging," or "Many students who have done this problem have found different answers — if several of you would like to share your approaches, then you could figure out what might be the best way to do this problem." A significant number of students then start sharing their calculations and helping each other understand where they made mistakes. After seeing examples of how other students (even the very best students) make mistakes, the shy, struggling students then start posting notes like, "I have no idea how to start this problem — can someone help?" When a student posts a particularly clear explanation, many other students reply with kudos and thanks. In my student evaluations this year, several students said that the online practice problems contributed the most to their learning. I think it also contributed most to their sense of camaraderie and did the most to help them build friendships. Although I had been making my exam problems available for many years, the student response dramatically improved once I embedded the problems in an online platform in which student comments were automatically grouped with each problem. Previously, I had asked students to reply within an online threaded conversation, which proved inefficient and unwieldy. Online practice problems work well for large classes, do not require any special classroom space, and allow students to contribute at any time, thereby serving students who are juggling constraints of commuting, jobs, and family obligations."

Sarah Keller

Concept inventories (examples in the Bibliography) involve assessing student knowledge of underlying concepts and are available for different subjects. These can be useful for assessing student learning because often students know how to solve problems but lack an understanding of the underlying concepts. Using concept inventories also eliminates the instructor tendency to teach to their own tests.

"In my Introductory Physics class, I embed a sequence of Knight-style (Hoellwarth, Moelter, and Knight 2005 American Journal of Physics 73, 459) concept problems that get progressively harder, with a challenge problem at the end. We do the first problem together as a class, then students work individually and see how far they can go, checking in with their group every so often. Another approach for problem solving is to work very difficult problems in sets of three where students "see one, do one, teach one.""
Ashley Carter

"In my upper level Biochemistry class, I have students present and critique papers from the primary literature. The first year these presentations were not very good — for one thing, enrollment was too high to allow any one student to get into too much depth, and for another, students didn't seem to know how to give talks. The next year, the class was smaller, and I gave a short introduction to what I expected from the presentations in what I thought was great detail. Yet, I found that students had a hard time implementing practices that would allow them to give an effective presentation. The next year, I gave a similarly detailed introduction, but I also required every student to meet with me the week before their presentation to go over questions and their presentation (slides and the talk). The talks were much better, and more importantly, the students learned a lot more about how to give an effective presentation. If enrollment is high, I have some students (mainly the younger students) give the presentations in pairs, so that each paper can be discussed in sufficient depth. The class gets a lot more out of the presentations, too. This approach is time-consuming, but it is completely worth it. The presentations are spread throughout the semester, so the work is distributed and fairly manageable."
Anonymous

"The first pass through my junior/senior biochemistry class was pretty rough. I had very high expectations on what the students would retain from previous courses and how much material I could cover in an hour. I felt the need to present facts for them to absorb as if that were all that teaching were. If I successfully presented them the material then of course they would learn/remember it. Class performance on the exams was abysmal (not surprising in hindsight) and the students all but rebelled because they thought their GPAs were about to be ruined. I recognized that what I was teaching would be quickly forgotten because it focused on simple factual recall more than higher order learning. So, I shifted to a very different type of course where the problems posed to the students required them to analyze data and draw conclusions, much more like what we do in the lab. The final transition was to have that process happen in class too, not just on problem sets. This led me to an interactive class where each student was given a pet protein that they would have as their own for the whole semester. It would be their example system to work on every time we did something new. In this way they got ownership of the assignment and they could compare their protein to that of their friend in the hall before class. When we talked about their protein in class, they would say something about it to everyone. It made the subject real and it made it unique for each student. It also was a lot closer to what they might do in the future in that they had to make a leap from a model system to a specific example. Most importantly, it gave them confidence in their own learning and gave them skills to look at things differently. They were not just being evaluated on learning facts and regurgitating them on exams. They could see that on the exams, they had to use the skills of data analysis they developed and it was okay

> not to know all of the facts. They could still get to the right answer by having that deeper conceptual understanding of the material."
>
> **Andrew Feig**

Writing

"How do I know what I think until I see what I say?"
E.M. Forster

The process of writing improves student critical thinking; therefore, writing should be incorporated in classes as widely as possible. In large classes, this goal may only be feasible with well-trained TAs, either through in-class assignments or laboratory assignments. Writing-intensive assignments in laboratories can be helpful for learning critical thinking and improving written expression skills. Writing assignments should include revision, either in revising a particular document or expecting improvement of specific skills in subsequent written assignments throughout the term.

Grading student writing can be challenging, in part because of its inherent subjectivity. There are a number of ways to save time as well as improve the quality of your feedback and therefore of student work. Develop a grading rubric and share it with students in advance so they know how they will be evaluated. A few shorter assignments earlier in the term can focus on grammar and sentence structure; these can help sharpen student writing so that later assignments have fewer mechanical problems. These assignments can also serve as an early warning system to direct students to a writing center when needed, especially to help with mechanics so you can focus on discipline-specific writing issues. Short assignments that focus on developing arguments can build to the ultimate assignment of a research paper or proposal. Another way to scaffold writing is to have students build up sections of a paper in individual assignments with feedback as they go. Students often arrive at college (and even graduate school) not knowing how to write a research paper, so giving them examples of papers that represent your ideal can be helpful to them, especially if they are annotated to show what makes these examples effective. Some online grading tools can provide canned grammar lessons and allow you to set up some standard comments; these allow you to provide fairly detailed and extensive feedback without spending too much time writing comments. Provide detailed feedback on student writing only if you expect students to use it, like in submitting a revised draft or submitting the work externally. Similarly, don't assign writing for the sake of having students write: Be sure to provide some feedback on student assignments.

One or two rounds of peer review before you grade papers can substantially improve student work and save you time in grading. Give the peer reviewers the grading rubric by which to evaluate the work and provide some ground rules for your expectations, including guidelines for professional and respectful feedback. In addition, requiring students to submit a reasonably complete draft of a paper for peer review gives them time to revise well before the final assignment deadline, independent of the review process.

6

Leading Large Lecture Classes

The previous sections provided insights on how to design an effective course, lessons that apply equally well to small or large courses. Here, we focus on how to take what you already know about teaching and apply it to tackling some of the unique challenges presented by a large class environment. One particular challenge of teaching large classes, however, is that the preparation and time demands of teaching do not scale linearly with class size.

> "One of the most difficult aspects of teaching I have encountered is facilitating the teacher-student interactions in a large classroom (~150 students). I think the more the students can interact with the professor directly the better, but being at a research university, interacting with every student is impossible. In addition, even when interaction is available, not every student wants to interact with their professor for a variety of reasons. I have found that some of the students who do not put the effort into the course hide in the anonymity of a large course and are not held accountable for the grade/performance correlation. Over the last few years, I have implemented a few ways for the students to interact with me directly. I have formed groups (usually based on assignments) on online discussion boards in which the students and I can communicate. The students feel they are getting individual attention and I understand what the common misconceptions are in the assignments which I can address in class. In the biochemistry laboratory course, I replaced a few traditional lectures with group meetings (~6-10 students) to discuss data and problems encountered in the laboratory. In the biochemistry lecture, I have 20-minute discussions a few times during the semester on a reading (focused on the scientific process) and even though only 20% of the students get to comment or speak, the classroom becomes more intimate and I can listen to the students rather than them listening to me all the time. In most of my courses, I will use a think-pair-share format using a case study and questions that ends with

a few students coming to the board to show how they answered the questions. This highlights individuals and introduces accountability to the students. In addition, when the pairs are interacting, I can go around and talk to groups, providing more teacher-student contact time."
Linda Columbus

Remember, It's Entertainment

Although all excellent teaching involves some degree of entertainment to maintain students' attention and build their interest in the subject, in a large lecture class this component is perhaps one of the most critical. To maintain students' rapt attention, whether you use chalk, a smartboard, or slides, remember that you are leading a large number of students in their instruction, one which seeks audience participation and active learning despite its size. To give that concept a deeper meaning, consider that at some schools an individual student might be paying $100 per hour of instruction. With 200 students in your class, is your class actually worth $20,000? To make sure it is, have your entire class session planned ahead of time. For your first few classes, it might actually be worth doing a dry run. Make sure you convey confidence and stage presence, and that you project your voice sufficiently both so that people can hear you and so that you command authority. Use a microphone if it seems even remotely possible that someone in the room will not be able to hear you. Develop a sense of how large you need to write on the board for it to be visible from the back of the room. Keep in mind at the close range you will be writing on the board, it can be difficult to catch mistakes, so practice and prepare well. Although that will obviously take up time you could spend on something else (like research), a few practice sessions will help to hone your sense of timing.

Now, with the mechanics covered, how do you engage the students? With 100 people or more in the audience, it can be challenging to have a lengthy discussion period or be able to answer a lot of questions on a consistent basis and still maintain control over the direction of the course and its content. Moreover, it is likely that your students will have diverse backgrounds and career goals, meaning that each may hope to gain different things from your course. Thus, your challenge is to find ways to relate the material to your students' everyday lives so you are most likely to engage them all. Have students imagine a world without the knowledge you are sharing; e.g., in an introductory course on Electricity and Magnetism, have the students speculate on how things would look without Faraday's invention of the electromagnet. Brief discussions of the people who made key discoveries and the times in which they lived, including what was not known at the time, can also help break up the class without sacrificing too much time. Doing this in each class session will not only keep students interested, but will help to build interest in the material. Consider how best to use active learning techniques such as student response systems (see above), think-pair-share learning strategies (see above), and possibly having some students work out problems on the board, to help your students stay engaged in other ways as well, and to provide feedback on student mastery of key concepts.

Show them that you care. There are several ways to do this. You can tell them explicitly that you care that they succeed in your course. An effective approach is to learn student names. Most universities provide photographs of class members that you can look at before the first class and throughout the semester. If you learn 15-20 student names from their pictures, you may be able to call on some of them by name, even on the first day. Ask the students to introduce themselves before they ask a question or contribute a comment. Although you might not remember all of them, these strategies can help you learn 80-120 names in relatively short order. You can have students make their own name cards that they place in front of them or hold up when they speak to help you learn their names; cardstock name tents are easily obtained or file folders also work well. Walk around the room during class, using a wireless microphone if necessary. This accomplishes two goals: It brings you closer to students, and your presence will greatly reduce non-class-related activities like web surfing or reading non-class materials.

Now, how can you measure success? Classroom attendance is perhaps one of the best vehicles. If half your students are not routinely showing up, then they have perceived that your classes are not helping them with their exams, or that they can learn everything on their own without your assistance, or that perhaps you need to make your classes more engaging.

> "The first time I taught a large general chemistry lecture course, I felt that I was reaching only a small subset of the students. There were 385 students in the lecture and I had a hard time engaging most of the class with a constant low background of chatter and attendance rates that hovered at 60%. I was further completely unprepared for the barrage of emails asking for special considerations for pretty much every homework, quiz, or assignment. I was teaching one of four lecture sections and I struggled to keep up with the other lecturers who had taught the course several times before. I was more focused on covering the same topics as the other lecturers (we had common exams) and did not have a clarity of purpose regarding what I wanted the students to learn. Without knowing any better, I went along with the other instructors in administering a standardized exam as the final even though the content of the exam did not very well represent concepts we had emphasized all semester. Several students recognized my good intentions but bitterly complained about the exams, and my teaching evaluations were mediocre at best. Last semester I had the chance to teach the course again and I drastically modified my teaching style and the structure of the course. I insisted on being given full autonomy for my section so I would not have to coordinate with other lecturers. I drastically reduced the course content and emphasized five concepts and five critical skills I wanted students to take from the course. I reinforced some of these concepts and skills in almost every lecture. Very early on, I set the tone for interactive lecture sessions with frequent problem solving sessions and discussions and emphasizing the need to eliminate chatter. I made it a policy to not lecture

more than 10 minutes at a stretch — making sure to take frequent breaks to review problems, poll the class, or show a video or animation. I made an effort to learn the names of as many students as possible and called upon them routinely. Before and after lecture, I made an effort to go into the "audience" to especially chat with students doing homework. My course syllabus clearly outlined the assessment scheme and I took great pains to review (and highlight) content before the exams and to go over common mistakes after the exams. I emphasized chemistry concepts over "trick questions" or numerically difficult questions on tests. Numerically, my teaching evaluations turned out much better, my attendance was significantly higher, and I had a large number of students asking if they could do undergraduate research under my supervision."
Anonymous

Maximizing Student Interactions Through Office Hours and Email

No matter how well you teach, students will always have questions, and one of the main challenges is how best to address them. Using email alone will likely consume far more time than you will ever imagine for a large class; moreover, many subjects are difficult to explain without the ability to draw things or work out equations together. Thus, office hours, provided they are used efficiently, can limit email exchanges and be one of the most useful means to provide help to students at a bare minimum expense to your own time. Here are some thoughts on how best to use your office hours:

- Hold them every week, but change their timing, as students have varied schedules and this flexibility allows for most to come to your office hours at some point or another. Perhaps have one fixed hour and one or two variable hours; check your institutional policies about office hours.
- Schedule them intelligently around exams, problem sets, etc., so that students can get help at the key times they need.
- Make them group sessions. Most students have similar questions, and rather than answering the same question one at a time, twenty times total, you can do it swiftly if you have your sessions with all students who are interested. For those who really want one-on-one help, you can always offer individual appointments. Few students are likely to take you up on that offer, but they will be appreciative of it. Some of the strategies discussed above on having course wiki pages, real-time feedback, and other internet-based approaches also work well.
- Consider time before and after class as extra office hours as well. Spending 15 to 20 minutes after class to answer questions aids student learning, and, again, pays dividends in saved time down the road.
- Be patient. Show students that all questions, no matter how basic, are worth your explanation. But, with that said, follow the advice given in the first of the Star Wars films as the Rebel Alliance is battling the Death Star: "Stay on target." Sometimes students monopolize office hours, or ask questions that are far beyond the scope of the course material. In these cases, express interest in the question and offer to discuss the matter personally with them later on. This will keep things on track, and avoid creating further confusion for students who are already struggling with simpler concepts.
- Be happy to be there (or at least fake it). We all have other things to do, whether it is writing a grant, a paper, or training a researcher. But for that hour or hour-and-a-

half, make sure you convey that this is the one place in the world where you WANT to be, and that you are thrilled to be answering questions. Your distraction, impatience or lack of enthusiasm will make students feel like an afterthought.
- Explain the purpose of office hours. Some students do not understand that office hours are time you are setting aside solely for them. If students cannot make it to office hours, ask them to schedule an appointment rather than to just drop by, explaining to them that if they have an appointment, you will make sure your schedule is open at that time and will be ready to dedicate the time to them. Drop-ins outside of normal office hours create unnecessary disruptions and distractions for you, and so students should be encouraged to schedule appointments. Videoconferencing tools can make an evening or weekend office hour more manageable and may be helpful to students with complicated schedules.
- Consider re-branding your office hours as problem-solving sessions, student hours, coffee hours, or something similar. Some students find the idea of office hours intimidating or an admission of weakness and avoid them.

So, what about email? You will certainly have to address some student questions this way. Be prompt with your answers, answer student concerns no matter what, but also be cognizant of when you are answering those emails. You do not want students to think you are available 24 hours a day. For instance, if you teach on the East Coast and are responding to a student query while traveling on the West Coast at 10 p.m., your students will think you are available at 1 a.m. since that is the time stamp they will receive. In the 2–3 days before an exam, let them know the ground rules for when you will be willing to answer questions, and also let them know if you will be out of email contact for some time so that they can plan accordingly. You might tell students that although you aim to be as prompt with your replies as possible, you generally respond to email within 24 hours, or 8 business hours, or some similar set amount of time, which should also encourage them to plan ahead. To help segregate class-related work from other responsibilities, ask students to include the course number or name in the subject line of emails. That way, you can periodically search for course-related messages and make sure they are not missed in the glut of daily emails. You can also use TAs to screen and possibly manage class-related emails.

As noted above for office hours, often many students have the same or similar questions. One effective strategy for handling these multiple similar requests via email is to copy the original question and your response from the first email request on a given topic and post these on a course blog or course website that is accessible to everyone in your class. Remove any identifying information about the student and, if necessary, reword the question to make it generic. Let students know early in the term that you will do this for emailed questions and remind them to check the course website before sending you a question. Not only will this save you time, it demonstrates your commitment to fairness as you make these answers accessible to everyone in the class. This can also be a good way to show students that others often have the same questions they do. Many course management systems have a "blog" or "forum" feature where all of the students can share questions and answers. If used appropriately, these tools can dramatically cut down email traffic and allow the students to help each other.

Using Your Teaching Assistants

Hopefully, with a large class you will have some teaching assistants available, not only to grade exams and problem sets, but also to lead recitation sessions that will provide students with more help and opportunities to learn. Your teaching assistants are your first and best line of defense against mass confusion and frustration and the best support tool available for having and managing an effective course. For best results, consider the following:

- Messaging is important — just as in politics, you do not want one of your teaching assistants saying something that is counter to what you have taught or presented. Make sure your teaching assistants know your "talking points" by giving them your notes ahead of time, having them attend your class, and making sure they understand the material well, since they might have diverse undergraduate training of their own. If TAs attend your classes, they will know which concepts you have stressed or simplified, and will not contradict what you are trying to convey.
- Get feedback from your teaching assistants — since they are at the ground level, they will often hear student comments, concerns, etc., that you are unlikely to hear. Make sure you talk with assistants regularly to get their feedback. Ask them for student FAQs, what students had trouble with from the last lecture, etc. This feedback will improve your lectures, and clue you in on areas where there may be broad confusion that you can address in the next class.
- Grade with your teaching assistants — any time you have a major exam where the questions are not multiple choice, spend at least 30 minutes grading with them. It will help them answer questions, ensure consistency, and avoid many problems down the line in terms of regrades. It also builds esprit de corps with your teaching assistants and shows them that you are invested as well in the course in ways beyond teaching itself. Again, this is taking up some of your time, but it will save you so much more down the road that the investment is well worth it.

Learn from the Efforts of Others

There are a tremendous number of resources available that can provide some insights into the concerns of students for a given course well before you ever teach it for the first time. As highlighted above, your faculty mentors, other faculty who have taught similar classes, members of the respective curriculum committee, and your chair, as well as your teaching and learning center, are all excellent resources. Your campus might also publish end-of-semester evaluations for all members of the community, or other faculty might be willing to share one of theirs or at least discuss their feedback. You will find embedded within the comments many things on the minds of students such as fairness, engagement with the material, teaching approaches in the past that have and have not worked in the class, etc. Simply by reading these synopses, you can glean a number of things to consider prior to designing your course at your college or university. Keep these principles in mind when reading your own (official) course evaluations. The most emphatic comments will often be at the extremes of the spectrum of opinion, and it would be unwise and unnecessarily stressful to completely redesign a course based on one negative comment. Instead, as with any type of feedback, invest most of your energy on criticisms you believe are valid and important for improvement. Brief discussions with trusted mentors and colleagues who have taught the course before can also be invaluable.

7

Time-Saving Tips in Teaching

"Don't mistake activity for achievement."
John Wooden

As a new faculty member, time is your most valuable resource. How you manage and allocate time will determine your success to a large extent. It is critical to be efficient and effective. Try to keep blocks of time open for research and writing by grouping meetings, teaching, etc., together as much as possible. This section will focus on a few specific tips that can help to save time, including suggestions for not reinventing teaching methods.

For nearly everything that you do in teaching and mentoring, someone will have previously done it or something similar enough to be useful. Embrace the philosophy that imitation is the sincerest form of flattery, with credit where appropriate of course. As Picasso himself once noted, "A good artist borrows, a great artist steals." Search online, use open courses/open learning initiatives, and your network of colleagues including laboratory and teaching staff at your own and other institutions to get ideas for exam and homework questions and for how to present complicated ideas, use analogies, design visual materials, carry out demonstrations, structure courses, design group projects, etc. Even if you rework much of the material or have a different overall philosophy, having a place to start often takes less time than beginning de novo.

In addition to drawing on the memories of those who have taught your course in the past, draw on your own memories. Use your own notes from when you took the same or a similar course as a student. How was the material presented? How much was covered at once? What is not clear in your notes? Where did you have difficulty and why? What courses did you TA as a graduate student or teach as a postdoc? What active learning methods were implemented and how did they work? Having a framework in place will make it easier to experiment with your courses to accommodate different learning styles and interests.

Having an excellent textbook that contains clear, thorough explanations and complete, well-designed supplemental materials can also save tremendous time. It is hard to find the time to review many different textbooks, even if you have the authority to choose your own book. Online textbook reviews can be a good place to start, as well as talking to other faculty members. Publisher representatives can also be a good resource. They want your business, so it is in their interest to give you the product that you want without wasting your time.

As is emphasized elsewhere in this document, take thorough notes the first time you teach a course. Document what worked and what you would like to do differently. Keep a schedule of what you did each day of the course and when homework, exams, and other projects were assigned and due. Keep exam and homework keys and grading rubrics. Record when labs were held and how well they correlated with lecture. Make notes on your interactions with your TAs. If there are errors in class notes, exams, or any other course materials, fix them immediately. If your grading rubrics or exams did not fully reflect your priorities, document this fact as soon as issues come up. You will almost certainly forget these details by the next time you teach the course, so having detailed notes will save you a tremendous amount of time and will help you improve the next iteration. Rewriting notes for the entire semester every time a class is taught can keep the material fresh and prompt questions to ask throughout the class. Even if you do not engage in this practice of note rewriting, a thorough review before the term and before each class will help you feel prepared and should prompt ideas for innovations in teaching. Use your teaching evaluations to identify specific suggestions and general issues that students had. Determine what students found to be effective and maintain or improve those practices. Also consider translatable knowledge; many of the impressions you have and improvements you make will transfer to other courses you will teach.

> "I took a weeklong course design workshop offered through the Faculty of Education early in my career. It was team-taught by an Education Faculty member at my home institution and a physicist from another institution, and I was lucky enough to pair up with another young faculty member who had been trained as a chemist before joining the Faculty of Education. Collectively, these experts in both education and science were able to challenge my rather orthodox views on what constituted good science education. The theme of the workshop was learning objectives: what they are, how to develop them, and how to align the course activities and assessments with them to produce a coherent course design. They also discussed student-centered learning techniques that I thought were interesting but mostly unworkable in a physics classroom. I've since adopted the

> course design principles that I learned in this workshop to make changes both in several courses in my department and to whole areas of our undergraduate curriculum; I have also cautiously adopted more student-centered techniques in my personal teaching habits. All of this has helped me become a better teacher, and allowed me to play a leadership role in curricular reform in our department. More recently, as chair of our graduate program, I have used design principles to develop major changes to our MSc and Ph.D. requirements. In the next few years, I hope to help redesign the laboratory course curriculum in our department."
> **Steve Dodge**

Teaching workshops can be helpful and can save you time. Look for hands-on workshops that involve things you need to do; for example, actually planning a new course while learning the principles of course design, as in the example above. Attending a teaching workshop or seminar at a professional society meeting gives you the opportunity to meet others with common goals and interests. Attend at least one at your home institution that is focused on local resources, services, and/or requirements, though recognize that these are often more general in flavor and may be targeted more globally to faculty in different disciplines, including those outside of the sciences. Backwards-design course planning, addressed above, can be a time-saving strategy because it helps you stay focused on core skills and knowledge that the students should develop rather than being distracted by trying to cover vast content areas.

> "I have gradually decreased the number of 'facts' in my lectures, and replaced them with letting the students interact with one another in the 'process' of science. I literally teach about half the 'facts' that I used to teach 20 years ago, but I think the students come out understanding better how to learn about how nature works. Anybody can look up facts online. Putting them together in a grand pattern, organizing this pattern with a small number of models, and learning how to improve/replace these models as more facts are added to the pattern, is much harder. Among other things, this requires students even at the freshman level to always be shown how facts fit into a pattern, and how models explain the pattern. For example, I would never teach the ideal gas law equation, or how one could apply it numerically, without also deriving it from simple assumptions: the average energy per particle is the same over time, this is due to random energy exchange during collisions, but the collisions are quick enough that particles mostly move freely. These three assumptions are sufficient to derive the mathematical formula, given some definitions such as pressure=force/area, etc., that are just intuitive enough that students can be reminded of them relatively easily. Every time I finish the derivation, and the familiar formula suddenly pops up in front of them, I see their eyes widen in surprise: "Oh, so I can use F=ma and random distribution of energy among particles and get PV=nRT; it's not just another 'fact,' it is an inevitable consequence of other things I know.""
> **Martin Gruebele**

8

Identifying and Overcoming Challenges and Misconceptions in Teaching and Education

One assumption that new faculty members sometimes make is that students will automatically respect them because they are faculty members. That is often far from the case. Even being a National Academy member or a Nobel Laureate does not lead to instant levels of awe from undergraduates! One simple way to increase respect is by acting the part. In other words, act like the professional that you are and serve as a role model for students. Are you on time? Are you ready when class begins? Are handouts and problem sets delivered on time? Are exams returned in a timely manner? Your contributions on these fronts set the overall tone. It is also important to set explicit expectations for student classroom behavior, such as use of electronics, eating (and picking up trash), and coming and going throughout class.

Students seem to think that they are invisible and that faculty members do not notice what they are doing during class or even whether they are present. Most students are receptive to explanations that specific types of behavior are distracting to you and to other students. Depending on your philosophy, one approach is to explain that certain electronic devices are a distraction and must be powered off during class; however, if a student is expecting an emergency call, they must tell you before the start of the class in which they expect to need a phone. Even if you relax the policy later, stating it up front will send a strong message about the environment of your class. Sometimes students will ask what the consequences will be of violating policies. It can be risky to deduct points for non-academic concerns, although one solution is to have a small number of discretionary points that are for positive participation in class. Another response can be that you simply expect everyone to adhere to the stated standards of behavior.

Another common assumption is that students are like us, learn the same way that we did, are as motivated, and have as much facility with material from previous courses as most of us did. Lecturing does not work well for everyone. Using a variety of delivery modes, discussions, multimedia, and other ways for students to interact with material will lead to increased learning by a wider range of students. Moreover, clear lecture presentations and explanations are necessary but are not sufficient for learning. Real learning should be differentiated from information transfer and simple classroom attendance. Much student learning will occur outside of the classroom, so a role of the instructor is to direct student effort and provide feedback and structure to students, as well as to motivate them to put in the effort to learn outside of class. However, some students may still think you are not doing your job if they need to study outside class. Other students may think they are not smart enough if the material does not come naturally to them and they need to spend a lot of time studying, or if they cannot learn everything they need from the textbook (especially if your course goes beyond the book). You should convey that students who succeed in your classes spend plenty of time on the material in addition to class time, even providing a number like two hours per hour in class, which may help them recognize the importance of studying outside of class, as well as convince them that needing to study does not mean that they are not "smart."

Get a sense of where teaching and curricular issues are discussed in your department or institution. How do policy decisions that impact teaching get made, and how do you address such issues in your teaching? Where do people share ideas about teaching effectively? In some departments, faculty meetings are venues for such discussions. In others, this happens elsewhere. In some, sadly, it may not happen with any frequency at all. In the latter case, you might canvass with others to try to develop such a support system.

To conclude, some faculty members at research universities think or have been told that teaching well does not matter, or that teaching does not matter as long as you are not awful at it, in terms of your career progression including the critical steps of tenure and promotion. This proposition is false. Although you may experience no explicit reward for excellent teaching, especially if you are also a strong researcher, caring about, investing in, and being a good teacher will generally increase your status in the department and the university. Even though you may encounter colleagues who do not seem to care about learning outcomes, few people want co-workers who do not care about a major part of their job. From a practical standpoint, many research proposals now require discussion of "broader impacts" and are often rejected on the basis of a weak or otherwise insufficient pedagogical component.

9

Teaching and Learning Online

Distance learning has been an important part of the educational system ever since mail delivery systems. Classes by radio, television and/or correspondence have decades of history, but widespread internet access and inexpensive cameras and recording equipment make putting all or parts of a class online far easier than ever before. Many teachers had to turn to this mode of instruction without warning when pandemic conditions closed schools and universities around the world in spring 2020. Teleconferencing software such as Zoom became such a household word that it turned into a verb! But “zooming” has its challenges. The body language cues an instructor picks up on to know whether the class is engaged, bored, or overwhelmed are largely missing. Continuous internet connectivity is not guaranteed, and not all students have the means to connect, especially not at the exact time that class is scheduled. Putting together an effective online class requires some rethinking.

In the space of a few days in the beginning of March 2020, 1.6 million faculty members at American universities found themselves transitioning to an all-online format. The overwhelming majority tried to retrofit their syllabus to the new constraints of delivering content remotely to the 22 million affected students. New obstacles immediately presented themselves: the effectiveness of prerecorded videos aside, freed from eye-to-eye in-person contact, many faculty and students clearly felt less accountable to each other, and remote testing in an era where the tools for “beating-the-system” continue to grow and proliferate, are among the more conspicuous.

Fortunately, a lot of people had thought about the challenges of online teaching before the pandemic hit. A nonprofit organization called Quality Matters (*www.qualitymatters.org*) offers many resources. Their rubric for higher education course design is a great way to incorporate evidence-based research into your own class. The rubric ensures you remember to include items such as minimum technology requirements and expected computer literacy skills for the class into your syllabus. The site also serves as a repository of literature about online teaching and offers specific training for faculty members to construct effective online classes.

As with every format for teaching, online teaching has its strengths and weaknesses, so a class that makes the most use of the specific strengths of the online format will lead to less frustration. The instructor cannot be the "sage on a stage" when the stage is gone! But how do you engage a class you cannot even really see? Everyone is reduced to a small box on a screen, and that itself assumes a good internet connection.

We hope the future will be different than the abrupt transition to online learning of Spring 2020. The student cohort is now acclimated to online format (and has also likely seen many of its shortcomings and would welcome improvements). With buy-in from students, videoconferencing platforms offer new opportunities. See also the section on Teaching with Technology.

> "In the case of an introductory algebra-based physics course at the University of Kansas, we will employ a homework, and possibly testing system in which students are given a vague template for a problem. Each student is assigned to a four-person group, and charged with 'filling-in-the-blanks' in the template, and solving the problem they have just created; those solved problems are then posted to an online discussion board (or Slack channel). At a predefined time, six four-person groups meet in breakout rooms on Zoom; the host is an undergraduate TA familiar with the template from a previous semester. The expectation is that, through internal discussion, each four-person group will solve most, if not all, of the questions that may have arisen in the course of working through this exercise. When questions arise that may not be answered by internal discussion, students raise their hands through the software and receive guidance from the TA. At the end of the session, the TA has a recording of each session, as well as an electronic record of the posted problems for each student. This approach (hopefully) sidesteps some of the complications presented by Chegg, (hopefully) optimizes TA time, and also offers an extensive electronic paper trail."
>
> **Dave Besson**

The above is, of course, just one example. It nevertheless highlights the fact that electronic course delivery has some advantages relative to in-person content delivery. If addressed proactively, rather than reactively, the online format can likely be equally effective as in-person formats in terms of student engagement.

Just like in a physical classroom, a synchronous online lesson has to be planned to build in points of engagement like polls, breakout rooms, and live or chat-based discussions. Greater equality between instructors and students can lead to more students feeling comfortable participating with proper instructor guidance. The chat function of the software can allow students who would never ask a question in class to type out their comment or suggestion. Breakout room functions — which can allow random assortment of students into subgroups that can discuss a specific question before coming back together with the entire class — can result in far more interesting discussions than in a classroom where people who know each other already tend to sit together. An electronic poll within an online synchronous learning environment is similar to one set up in a classroom using student response systems/clickers, although much slower than a show of hands so extra time has to be budgeted. When asynchronous instruction is necessary, because students are in many different time zones, for example, it is a good practice to build in additional meeting times that can facilitate instructor-student interactions for structured problem-solving sessions or to go over course content to ensure student understanding.

Perhaps counterintuitively, the online format can also provide an opportunity for personalizing the learning experience. The lecture hall, more often than not, is just that — a cavernous space in which the gesticulations of a semi-robotic figure are punctuated by half-mumbled embolalia. By contrast, delivery of pre-recorded lectures can transcend the limitations of a typical lecture hall — the setting or backdrop can be chosen to maximize engagement (or entertainment): for example, lectures recorded in a kitchen, patio, or a family room can humanize the instructor, therefore affording a degree of individual accessibility otherwise not readily achieved in a typical lecture hall setting.

While some faculty are accustomed to using lecture capture technology, in which the entire class session is recorded, shorter lectures of 5-20 minutes work better for a course designed to be delivered entirely online. For hybrid teaching, some faculty record 10-15 minute lectures that are played live during the class period, followed by discussion and problem solving. This eliminates concerns about technology problems, because students can go back to the videos and review the material at any time, and keeps the videos short enough that each one can cover a single element of content.

> "I've used chalkboard paint to paint the walls in my kitchen so I can write on them. Students liked that experience over Zoom a lot more than using a tablet."
> **Ognjen Miljanic**

> "One of the most painful things about going to remote instruction was losing student contact. In a typical online course, it is important to establish a sense of community, and many do this with an introductory activity, often in a discussion board. Those activities, which sometimes ask students to consider course content and their personal experience, are places to foster a safe learning environment as well as develop community that we have all learned is strained by operating, at best, through a screen. In the transition to remote instruction, I had assumed that a small

class that routinely had discussion would smoothly transition to discussion boards, and I was wrong. Despite the asynchronous delivery, I took a student's suggestion for one virtual meeting per week. The meeting wasn't for content delivery. It was about decompressing the material, talking through what worked and didn't, and what was happening in the crisis. We had some sense of community again. A hybrid-type course was not necessary, though. In a different asynchronous course, the students attentively posted and responded, perhaps that worked because that was a less chatty group in person. It is a good reminder that in person, online, or in a hybrid delivery, community and communication do not occur simply because we say so. For each group of students, we must be sure the conditions are right. If we don't think it is right, seeking students' feedback becomes useful, if we respond to it."

Rory Waterman

With more planning, a lecture about an instrument can take place with the actual instrument. Demonstrations that would not be safe for a lecture hall can be filmed in advance. It is also much easier to bring in guest lecturers even for a few minutes, whether prerecorded or live, and thereby bring more diversity to the class experience. Students for whom English is not a first language or who have other reasons for not being able to follow spoken language can slow down or replay recorded components or reread saved chats. A well-designed online class can be much more accessible to a much larger population than a typical lecture-based class. If you play to the strengths of the online teaching format there is a wide scope for creativity and real learning!

"When we rapidly moved to online teaching in Spring 2020, my class was pretty well situated. We were already using FlipItPhysics for video lecture delivery and using the class period for small group work. FlipItPhysics is a set of video lectures, embedded "checkpoint" questions, and homework questions that the students have to do daily before coming to class. It was created by Cottrell Scholar Mats Selen at UIUC Physics. I use it for both Physics 1 and 2, and it really helped when we went remote because so much of the class material was already there and online.

The class basically proceeded as we had prior to the move to remote learning. Students watched the pre-lecture, did the online questions before class and sent questions for just-in-time lectures I would write for three hours prior to class. The "in class" portion continued to be group work. I was lucky that most of the students were able to connect during class time, allowing for synchronous instruction. I used Zoom and broke the students into the usual in-class groups using breakout rooms. The TA attended all the lectures and was a co-host, so he and I could go between rooms and answer questions.

I would start the meeting 30 minutes before class, so that students could come to ask me questions before. I would play music from my computer to signal that class wasn't on yet and to absorb random noises from my house (I have kids, a spouse, and a dog at home). As in the in-person version of the class, the students start each class with a warm-up (which students get points for and is an attendance marker). These previously were on little slips of paper, but in going remote, I moved them to the online "Blackboard" content delivery system. Several students recommended I do that anyway, and it did make grading easier!

When class started, I went through reminders and announcements and then gave a 15–20 minute lecture. The Zoom meeting was recorded and posted using the video posting service provided by my university (we have Ensemble). I would make a link. During the lecture, the TA would monitor the chat box and pause me to answer any questions that popped up from students. The chat was also used for call-response interactions as I lectured. I would say things like, “Which direction is the magnetic field pointing? Left or right?” and students would type their responses in the chat box.

After the lecture, students would go into breakout rooms and work on their assignment for the day. They would use the whiteboard feature or they had Google docs. I gave them a cheat sheet, so they could use a LaTex editor, but most just wrote out equations if they used the Google doc. Students were generally pleased with this method of delivery. I had one student who traveled back to China. Due to that, all assignments had 24 hours to be turned in — even warm-ups and daily group work. This allowed people who had to be asynchronous to watch the videos and turn in something for points each day.

Exams were a huge issue in general for many physics and chemistry departments in the switch to remote learning. Online outlets such as Chegg.com could give students answers within 20 minutes, and students often shared their login credentials. In order to counteract that tendency, I decided to give the students a test bank to study from, letting them know that the exam questions would be selected from the questions they were given. They had the questions for a week in advance, and they were allowed to get any help they wanted on any problem. The exam selected multiple problems with altered numbers and some additional changes.

Students definitely performed better, but they did not appear to cheat. Their answers were not identical, although a few had the same misconceptions — usually students in the same working group who worked together on the practice problems. No one scored a 100%, but my hard-working students who freak out on high stakes exams did a lot better! I might continue to do something similar to this in the future. It forced students to engage with the material and learn it prior to the exam. They had individual accountability (some students clearly didn’t study and did very poorly). I stress putting in the time for the class in order to get a good grade, and this method worked well for that.”

Jenny Ross

Giving Exams as Part of Online Instruction

One of the biggest areas of challenge for any online course is achieving an effective means of student evaluation. No single approach is ideal, and classes of different sizes and/or student makeup may benefit from different forms of evaluation (such as oral exams, extended projects, challenging problem sets, and/or exams). In this section, we will consider explicitly the use of exams, as they are arguably one of the most difficult forms of evaluation to administer effectively and equitably online.

It is hard for students to cheat on proctored, in person, pen-and-paper exams. Online, however, the temptation to look up answers or collaborate with others can be overwhelming. Although it is possible to monitor students remotely with software, or have exams given at remote testing sites, with large class sizes it is challenging to effectively proctor such numbers of students and privacy issues arise. It is better to use assessment strategies that avoid these issues.

Online exam platforms, which can randomize questions, provide numerical variants of the same question, and otherwise achieve variation in real time, can be an effective means to improve integrity. The challenge is that it requires instructors to dramatically change how they would construct a traditional exam, and some may be less comfortable with such a degree of change. Some instructors have also found that giving extremely long exams (arguably ones that cannot be completed in the time allotted) can obviate any effects of cheating, since in the absence of strong knowledge and mastery of content students would not be able to effectively complete enough of the exam in the time allotted; one potential issue with this model, however, is how it impacts students who are allotted extra time or need any additional accommodations. Others have tried to level the playing field by giving students extended time for exams and/or making their exams open note and open book. In general, this model may not be as successful as one might initially think, particularly for large classes, as extended time allows more opportunity for students to work together in ways that might not be desired (unless such collaboration is allowed). Open note tests also have an unintended potential consequence of students being less prepared than they should be overall, since they might believe that by having notes available for the exam that they will have all the tools they need for success. Rephrased, open note tests across the board seem to lower student engagement with material in a substantive way prior to the examination versus that achieved with a closed note test.

If a more traditional exam is to be given remotely, there are some elements that can lead to greater success. With the potential for poor internet service and/or students being dispersed throughout the world, having pre-generated student response sheets (if an exam was not to be multiple choice) that students can print on their own up to several days in advance of the exam can make initial technical issues much easier to deal with once the physical exam is posted electronically, although not all students will have access to printers. Students may also face challenges submitting their work electronically. In one experiment performed at the start of the COVID-19 shutdowns, one of the authors (SAS) gave such an exam to ~100 students. Fifteen of the students had difficulty returning the exam, with many failing to upload all pages within the 20 minutes of additional time provided. Clear and effective PDF file-generating software and student practice with such programs and uploads is critical. Pleasingly, though, grading of exams in such a format, particularly if template pages are provided, can go smoothly for remote evaluators. It is essential to provide a clear and consistent grading rubric to each of the graders involved.

Overall, there is no single model that works perfectly for examinations in an online format, and it is an area that any instructor will want to consider carefully, since final evaluations are a critical concern for students involved and maintaining integrity and appropriate standards are equally essential. You may find that varying assessments throughout the term, including writing assignments, presentations, homework, etc., in addition to exams and quizzes, addresses many of the concerns noted above. Reaching out to the local teaching and learning center may help to build awareness of campus norms and resources. We also recommend consulting with your campus disability resource center to find out both the regulations around whatever assessments you choose as well as services they offer for student accommodations in online and hybrid teaching.

Part II:
Mentoring Students at Diverse Levels in Research

10

Mentoring Goals

We asked survey respondents about their experiences mentoring personnel in their research laboratories: 100% of survey respondents had experience mentoring graduate students, 98% with postdoctoral scholars, 96% with undergraduate students, 13% with professional students (dental, pharmacy, etc.), 27% with high school teachers, 33% with high school students, and 28% had mentored research technicians. This section provides general advice, followed by more specific information organized by mentee career stage. Excellent resources for learning about effective practices in research mentoring are the National Research Mentoring Network and the Center for the Improvement of Mentored Experiences in Research (Appendix I).

> "Keep students on task. Never pit students against one another. Keep expectations realistic. Be sure to dole out positive reinforcement (don't forget those pats on the back). Make sure that students have at least some idea of why they are doing what they are doing (particularly for highly focused mini-projects of limited scope). Remember that everyone makes mistakes (as the old saying goes, experience is directly proportional to the amount of destroyed equipment). Don't dismiss intra-team disagreements and issues. Particularly for undergraduates, be involved during course selection so that you can help them plan to have swaths of unassigned time during the day/week that can be devoted to lab research (checkerboard course schedules are a disaster). Don't play favorites for projects or students. Treat your students something like your grown children, as they will rely on you (and represent you) forever. That said, like your children, don't try to make them all like yourself (most won't go on to be profs, and that's just fine)."
> **Boyd Goodson**

Your success will depend in large part on how well you manage your laboratory and mentor your personnel, as well as the productivity of your staff. Although you may have had little training in this area, you will need to determine effective strategies quickly. In addition to the specific strategies discussed here, additional resources are listed at the end of this book and in the Bibliography. Ideally, your goals for your mentees and the goals of those you are mentoring will coincide. These goals at a minimum should include becoming a creative, productive, and ethical professional scientist, generating high-quality and high-impact scientific results, and achieving access to one's chosen profession. There are numerous models of effective mentoring, reflecting the wide range of aspects involved.

Always interview new people you are considering taking into your group. As much as you need people in your group, you do not need people who will be difficult or obstructionist. In a newly established group, the first members set the tone for years to come. Request the student résumés and then interview applicants. Ask about prior research and work experience, their goals for the research experience, and their long-term and career goals. This is an opportunity to tell students about your research and gauge their level of interest and overall enthusiasm.

Be sure to maintain an up-to-date and attractive website that explains your research and provides links to publications, talks, etc. This will not only convey the sense that you are organized as a researcher, but also afford inquiring students direct familiarity with your research pursuits.

Keep in mind that grades may be a poor predictor of research success. Drive, motivation, curiosity, and resilience, on the other hand, are important characteristics for research excellence. Although these characteristics are difficult to quantify, an interview with the student can help you assess them on this front and their overall level of motivation.

Some people will advise you to develop a single management style and to be consistent. Although that may seem like a good strategy, appreciate that your style will likely need to change depending on the specific needs and developmental stage of your protégé. Some students may require more of you or specific kinds of mentoring that other students do not.

Setting Expectations

Establish high expectations at the outset. You can communicate your expectations in formal meetings, by sharing written documents in which expectations are clearly delineated, or both. Set expectations for effort (work hours, productivity), data management, notebooks, safety, and progress reports. Be sure to check with your institution about legal requirements around mandating specific hours; it may be best to use less specific language that nonetheless conveys that a substantial time commitment is necessary to make research progress. Always review your students' primary data.

Even mature students can miss important trends, caveats, and controls. Furthermore, by seeing data from all students, you may find instrument problems, bad reagents, or other systematic issues that your students might miss. Data management and archiving is particularly important. For experimental scientists, students should be in the habit of coming to every meeting with you with their current laboratory notebook, a pen, and paper. Some students take notes about progress meetings and group meetings in their laboratory notebooks. Decide if you would like your students to do this and let them know.

All members of the group need to be productive, for their and your careers as well as for their development as scientists. You should decide if you prefer personnel to work set hours or have flexible schedules. Further, will you calibrate your expectations to a student's goals, potential, and circumstances, or apply the same standards for everyone? In general, people appreciate flexibility; keep in mind that this is a major benefit of being a graduate student. Research on managing "knowledge workers" recommends allowing workers the freedom to manage their time as they desire. Some students are unprepared for this freedom and may need guidance on how to organize their work and manage their time. Specific suggestions are found below.

Be reasonably patient, supportive, enthusiastic, and as positive as possible. Try to have realistic expectations of everyone in your group based on their developmental stages. Do not take students into your group whom you do not have time to effectively mentor. Beginning students will make mistakes. Be clear that making progress will involve making mistakes, but one should not make the same mistake a second time, and certainly not a third time. As in teaching, be clear about the reasons for your decisions. This will help students understand the reasons behind your actions and will prepare them for leadership roles as well.

Career Mentoring

Ask your students and postdocs about their career goals when you first meet with them. Remind them that you are available to help them make decisions about their future and that they should let you know how their plans are progressing. This way, when you hear about suitable opportunities, you will be able to pass them along to your students. During the last two years of a graduate student's career, have more formal conversations about their employment goals so that you can help the students acquire needed skills and make helpful contacts. Along the way, make sure your students are acquiring professional and career skills such as project management, communication, negotiation, collaboration skills, and mentoring skills. Individual development plans (IDPs) are useful planning tools for students and several are available free online.

Student Presentations

Graduate students and postdocs must be sent to scientific meetings and should present their work in public as much as possible. Having an undergraduate attend a conference and present their work can be a watershed moment for them, and can be of high value in predoctoral fellowship competitions because this experience is rare. Obtaining positive as well as critical feedback from researchers outside of one's own institution is crucial for scientific development and can also be highly motivating. Group meetings, supergroup meetings, departmental student seminars, and conferences are all opportunities for students to present their work and receive feedback from you and others in the group in advance and from the community at large.

Mentoring Within the Group

Establish an expectation for horizontal and vertical mentoring, which means mentoring between students of similar seniority, and between students at different levels of career progression. Both of these types of peer and near-peer mentoring in your group can be very helpful and can save you time, as long as the information being exchanged is accurate. Regular meetings with your group members can dispel inaccuracies that may have been passed along and can help keep protocol drift or sloppiness in check.

Group Environment

How do you maintain the esprit de corps of the most popular, effective labs? Keep your mission for your research in mind and share it often with your group. Write down the mission statement for your research. Share your enthusiasm for the work and for all the projects in your group. Involve students in decision making and running the laboratory; this can be as simple as soliciting input for major decisions at group meetings or assigning group jobs, or as challenging as letting a student take the lead in managing a collaboration. Encourage student feedback. Do not give students busywork; if mundane tasks need to be done, convey why they need to be done and try to spread that work around the lab evenly, or hire a technician or student worker for such tasks. Involve your group members in the visits of seminar speakers. And have fun! Take your group out for a meal or an event, have cake or a treat at a group meeting, or do a fundraiser together, while being aware of cultural, health, or schedule restrictions as you plan events. For example, a group lunch might be more feasible than a group dinner if members have caretaking responsibilities in the evenings. Recognize student expertise by asking them to train others. Convey to students that the overall success of the laboratory benefits everyone in it. Have a party each time a paper is published to celebrate the group's accomplishments (not necessarily just those who authored the work).

Support your students as much as possible. Honor commitments and keep appointments. If you know you need to reschedule an appointment, do it as soon as you realize it. Give constructive feedback. The most useful feedback is specific; tell students what they have done well and why it was effective and where and how they should focus efforts to improve. Correct any mistakes you make as soon as you realize it and apologize when appropriate. Acknowledging that you made a mistake can help build trust and provides important role modeling for your protégés. Edit fellowship applications, give feedback on presentations, and nominate them for awards, both local and national/international. Take the time to listen to several practice sessions of a talk when necessary, and help them prepare for their oral qualifying exams or individual original research proposal talk to the extent allowed in your department. Help them in their job searches by helping them make connections and use your network to make introductions. Send letters of recommendation promptly, within hours or days. As soon as you know one of your students will be looking for a job, if not before, start working on your reference letter. Keep a record of interactions with and accomplishments of the student that you can incorporate into your letters as illustrative examples. Tell your students when you have sent their letters; it is a simple courtesy but also conveys to them that you understand how important this is to them.

Meetings

In addition to weekly group meetings, many PIs and students find it very valuable to meet one-on-one or by project in smaller groups once a week. Some labs use group meeting time for professional development workshops, such as how to give a talk or write a CV. Group retreats, in which an entire day or significant part of a day is reserved for presentations of projects, current problems, and future plans, can be great bonding experiences. Consider delivering a “State of the Lab” address in which you present the mission of the lab and how each project supports the overall mission.

Diversity

It is human nature to want to help most those who seem most like ourselves. Remember to treat all of your students with respect and as people with valid opinions. Excellent resources for mentoring students and others of diverse backgrounds, some of which are listed in the Appendix, cover issues involved in multiculturalism as well as those for whom English is a second language or who come from family backgrounds unfamiliar with the culture and practices of higher education.

Staying Organized

Many groups find having a lab wiki or other electronic organizer to be very useful. At a minimum, a listserv/email list, calendar, and protocol database are essential for experimental laboratories. Some groups have adopted electronic task managers, electronic project management sites, and electronic notebooks to help workers stay organized.

When to Pull the Plug on Projects?

This is possibly one of the most difficult decisions that a PI or a researcher has to face. None of us got to where we are by giving up easily; thus, it is not in our natures to give up on projects, especially those developed after extensive thought and research investment. It is often next to impossible to determine if a project is not working because of an inherent flaw in the idea or approach, or if the problem is the person working on it. Some suggestions: add another person to the project who can contribute some expertise that might be missing; present the problem in a "supergroup" meeting or other "safe" venue to get a broad range of suggestions; go back to proposals you wrote to put yourself in the mindset of identifying potential problems and alternative approaches. Then consider setting a deadline by which you will make a decision about the fate of the project, and let your coworkers know about that deadline as well to try and push for a final set of useful results to aid in that decision.

Motivation Issues and Other Challenges

If a student is not working out, it is better for all involved to let the student go earlier rather than later. Try to figure out early if problems are intractable; set benchmarks for improvement, be clear about them in writing, and stick to them. Some students may thrive in other research groups, so letting them go earlier in their careers gives them plenty of time to change groups without hurting their progression too much.

A sense of ownership is a potent motivator. If students do not develop a sense of project ownership, they may exhibit a lack of progress or sloppy work. Make sure students understand how their project fits into the big picture and that they are responsible for moving the project forward. Provide encouragement for good ideas and good results. Refer to the project as the student's. Ask what their results mean and what they will do next.

> "One of my first graduate students was really struggling to get results with what I thought were relatively straightforward experiments. Nothing was working and he was frustrated. At one meeting we went through possible problems and nothing obvious seemed to be the likely culprit. He finally angrily said, "Have you ever even done this [experiment] before?!" and essentially accused me of being incompetent. I took a deep breath and asked him to tell me step by step everything he did, from putting on gloves to opening a reagent to storing the samples to analysis. About halfway through the story of carrying out the experiment, I identified the problem; he was making a trivial mistake, and one I was sure I had warned him about. As gently as I could, I pointed out the mistake, told him to try again without the mistake, and that I was sure he could get this to work. He went

> on to be very productive. Upon sharing this experience with my colleagues, others have told me they ask students to make a photographic or video protocol in order to identify errors in carrying out experiments."
>
> **Anonymous**

One of the skills most graduate students need to learn is to balance the competing demands on their time, including classes, teaching, research, and their personal lives. Because the demands of classes and teaching are time-sensitive and immediate, research often falls down the list of priorities in those opening months of their time as graduate students. A discussion about priorities and time management with some practical advice can be helpful and sometimes will get a student back on track. If that fails, you might want to ask the student to come to your office with a list of their commitments and demands on their time, with the offer to help them find time to make progress on their research. Usually this will send the message. If not, you might have to have a conversation with the student about why they are in graduate school.

Sometimes lack of progress, poor performance, or a bad attitude signal deeper issues. Asking open-ended questions and listening to the responses can help you understand what is going on. The student may not actually be able to articulate the issues, though, so be prepared to wait in silence and to ask follow-up questions. Some students deal with fear of the future by sabotaging the present; if career goals have changed or students are very unsure of what they want to do, some students react with paralysis or anger. In particular, students who did not grow up with professionals and suddenly find themselves approaching a lifestyle as a professional that is foreign to them can feel disoriented and out of their element.

Do not ignore conflicts in the lab, letting them simmer until things boil over. Remember that most of your students are relatively inexperienced in dealing with conflicts in a professional setting. It will be best for all involved if you provide them with the tools to resolve conflicts on their own. You can accomplish this in part by modeling the behavior you expect of them, namely, to ask questions to establish the interests and motivations of the involved parties and try to come up with a solution that maximally satisfies everyone involved.

11

Support and Professional Development of Students and Mentees

Recent studies reveal a mental health crisis among graduate students, indicating rates of anxiety and depression far higher than the general population. Although faculty members cannot be responsible for guaranteeing the mental health of students, they do have a responsibility to respond to student problems. In addition, research shows that at least some of the mental health problems plaguing students are related to the advisor-student relationship. First, become acquainted with resources at your institution, such as a Health and Counseling Center, campus police department, and emergency and non-emergency contacts. Other sections within this book also have more specific advice for identifying and addressing student challenges.

A common phenomenon among students is stress and anxiety caused by lack of clarity on career goals or mismatches in career goals with personal or family expectations. Although you may not have extensive experience in career mentoring, you certainly have access to resources and contacts to which you can refer students. A few places to start are the campus career services office and your relevant professional societies, most of which offer career planning services as well as local section meetings for networking. Most students, and especially those students who lack direction or plans, will benefit from completion and implementation of an individual development plan (IDP). The American Association for the Advancement of Science has developed the myIDP for STEM students and the American Chemical Society offers ChemIDP for students in Chemistry and Chemical

Engineering. IDPs typically involve assessment of goals and skills, and then may suggest possible careers and developmental activities to reach one's goals. It is helpful to discuss the results of an IDP with the student, to help connect them to campus and other relevant resources.

12

Postdoctoral Researchers

It can be difficult to attract strong postdocs to your group when you are new, but you can recruit postdocs at conferences and by using your network. Ask other faculty members to recommend their talented graduate students to you, or have your former mentors send you applications that they cannot act positively on themselves. Definitely interview postdoc candidates to assess their scientific competence, communication skills, and ability to work with others. Always check references. One bad reference is not necessarily a deal-breaker; someone providing a reference may have a specific personality conflict or just had a bad day. On the other hand, several bad references or a refusal by the candidate to provide references are red flags.

It is critical to set the tone for the group early on. For your new group, recruit postdoctoral researchers who can provide leadership and set good examples. Postdoctoral researchers can provide much more than technical expertise, especially to a new laboratory, where their perspectives can be invaluable in helping write and review your grant proposals and manuscripts and in training and mentoring students. Be aware, though, that this is a two-way street, in that postdocs should be learning new skills and new science in your group, and that you also want to establish your own group ethos, not that of the former lab where the postdoc worked. Just as earning a Ph.D. is an intense learning experience, so should this be. Postdocs should be encouraged to write fellowship applications for their own funding; even if they are not successful, the process of writing about their projects will be valuable experience.

> "I was given start-up funding for a postdoc that had to be used within the first three years of my position. I had requested funding for a technician because I didn't think I would be able to recruit a good postdoc as an unknown assistant professor, but I was told that a technician was not an option. I worked my network and advertised heavily to identify candidates, and made sure to interview more than one. I engaged senior colleagues in the interview process to make up for my lack of experience. I also waited until I had a functioning lab before the postdoc actually started. I was lucky to find someone who really loved lab research and wasn't too set on a specific project, as well as who took their role as leader of the group seriously. I was able to deploy this person as needed to obtain preliminary data for grant applications or help someone else on their project, and the postdoc was able to pivot quickly and seemed to enjoy learning about other areas of research. It also helped that the postdoc I ended up hiring was not interested in pursuing a professorship, so we didn't need to worry about carving out a project that they could pursue in their own future lab. The whole experience was very positive and really helped launch my research group."
> **Anonymous**

Postdoctoral researchers bring a set of more immediate concerns in terms of their career paths. Although some postdocs pursue these positions as a way of postponing career decisions, postdoctoral appointments are temporary, and this should be kept in mind. Be prepared to help postdoctoral scholars define and refine their career goals and give them the resources, personal contacts, and experiences that will help them achieve their goals. It is reasonable that they may well spend 1-3 months searching for a job, so be aware of that commitment in time up-front.

> "Having worked with many postdoctoral scholars and fellows over the years, one of the main challenges to ensuring appropriate career progression is project selection. While that statement may be obvious, I have found it helpful to always remind myself that postdoctoral fellows arrive with different expertise and goals for what they are seeking to learn, and that learning curve can dictate just how rapidly they can advance on a forefront project. Similarly, whether that project is being started from the ground up, or builds on existing findings, can also have a profound trajectory on research progression as well. Since the overall timeline for postdoctoral fellows is far more compressed than graduate students, I feel that more successful outcomes have resulted when appropriate reflection has been devoted to how best to collaborate with them and what additional mentoring and learning opportunities are best worth their valuable time."
> **Scott Snyder**

13

Graduate Students

When you are a new faculty member, you are an unknown quantity to graduate students. One suggestion for recruiting graduate students is to serve on the graduate admissions committee. Although this can be time-consuming, you can ensure that students who fit your needs and interests will be recruited and admitted, and you will have deep knowledge of the full range of files. Often, the personal contacts you make with students during the recruiting process can lead directly to placement in your group. You can also teach a graduate course or at least guest-lecture in one, which will help demystify you. You can then explicitly tell students that you are looking for new graduate students to join your group. Develop an attractive, informative, exciting web page right away to help raise awareness about your group as soon as you sign your contract, and try to reach out to admitted students so that you can recruit a few immediately if you did not have a chance to be part of the recruitment process.

When students express an interest in doing research with you, give them a manageable project that they could complete within a matter of two weeks or so; for example, "write a short piece of computer code or script," or "complete a literature survey." Some faculty members suggest having a prospective graduate student give a group meeting presentation on a topic of interest to your group. This serves the dual purposes of evaluating the scientific maturity of the student and sending a message to the student that joining a group is a mutual decision to be taken seriously. If your department or program has a lab rotation system, use it to get to know prospective students before committing to them.

Many students find it extremely motivating to have their advisor outline a few dissertation projects (chapters) early on. Even though this may change, and probably will, it sends a message to the students that you are thinking about their primary goal of completing their dissertation.

Give students some flexibility and freedom to explore their own ideas along with ideas that you suggest. If students propose something to do that clearly will not work, rather than letting them waste time on it or shoot it down immediately, both of which could be quite deflating, have a discussion in which you explore the idea or ask them to write up a short proposal about it. Either they will come to the realization on their own that the idea is a poor one, or you can then help them identify the holes in the idea. It is also possible that once the arguments are laid out, the students will have turned out to be right, or at least have a useful kernel in the idea that can be used to drive their research. The latter scenario can be a huge boost to the confidence of a junior scientist and will ineluctably help invest the student in her/his research program. Part of your role is to push students to the edge of their abilities, albeit in a positive and supportive environment, to help them develop as scientists. Even though it is often faster and easier for you to do things for your students, they need to learn on their own and to develop resourcefulness. Resist the temptation to micromanage and do things for them.

It is a good idea to have graduate students and postdocs work on two or three projects that are sufficiently independent that one can be picked up when another is not working or while waiting for something to happen on one project. Although you should never pit students against each other or have them compete on the same project, students with complementary skill sets or interests can form a formidable team. Commitment to the team can help students get past roadblocks and increase the probability that the project will be completed in a reasonable amount of time. In any case, students will graduate, so some overlap will be necessary to maintain continuity of a research project if it will not be finished on the timeline of the main student involved.

Define your expectations for successful project completion. Graduating successful Ph.D.s will help in recruiting the next generation of bright, energetic students to your laboratory. How many papers should a Ph.D. student from your group have? How many of them need to be first-author papers? How many of them should be collaborations? Do they need to be completed before the defense? Who will (primarily) write the papers? Consider giving your group members manuscript templates or samples; very few graduate students know what a submitted manuscript should look like or even how best to tackle its preparation. Furthermore, few students understand the importance of precision in language when describing their work. Many may not be clear about what plagiarism and good citation practices are; you will need to teach them. Many campuses have writing centers that can accommodate graduate students and have organized graduate student or science writing groups. Online writing groups are also available. Have students read their writing aloud to others — other students in the laboratory, or even roommates or significant others. Boss and Eckert (2006) suggest that the "House of Pain" model, in which the student is present and observes while the PI edits the student's work aloud, can help students learn how to write. Students must understand the reason for the requested edits, otherwise they will not improve. Figure generation must be precise. As with text edits, preparing figures for manuscripts or talks is an iterative process. Encourage students to read. Reading excellent writing is the pathway to being a good writer. Also encourage them to present their own work orally and to attend and critically evaluate the effectiveness of seminar speakers.

Mentoring students on how to do peer review of manuscripts that you receive — including the expectations for confidentiality, and with permission of or notification to the editor, etc. — can also clarify expectations for what constitutes a completed project. Online courses for training peer reviewers by professional societies and others are now common and can serve as a starting point for this mentoring practice. You can thereby introduce journal editors to the next generation of scientists that these editors can rely on in the future to carry out fair reviews.

Co-advising students with another faculty mentor is a special case. When this works, it is beautiful; students graduate as well-rounded students with interesting interdisciplinary projects. The students have two advisors who know them well and can provide advice and access to their networks as well as recommendation letters. However, students (and collaborators) can abuse this system. To keep students on track and prevent time-consuming problems, put a system in place from the beginning that clearly identifies a primary mentor. A system of regular meetings with both mentors, progress reports, and thesis committee meetings can be very useful for keeping students on track. As mentioned earlier, the completion and regular updating of individual development plans (IDPs) available online can also help clarify and align student career and professional goals with specific action items for learning and doing.

> "I have had both wonderful and less wonderful experiences co-advising students, having co-advised many students over the years. These are aspects I have found to be important for these relationships to work:
>
> - The collaboration needs to make sense scientifically. Having a well-justified project provides motivation for all parties to move the work forward. I have generally entered into these relationships when the co-advisor and I have complementary expertise and good reasons to work together. In one case that did not work well, the project was started because of the perceived likelihood of grant funding. The

project was not that compelling, the funding never materialized, and the forced nature of it made it a difficult experience for everyone involved. Especially if you are pre-tenure, enter into these relationships with care. A lot hinged on the productivity of each of my students, so doing some work up-front to increase the likelihood of success would have been well worth the time. In my case that did not go well, the department graduate director provided advice and the department chair ultimately got involved to help manage the situation.

- Set expectations with the co-advisor about how projects will be funded and who will be responsible for publications and other aspects of the project, possibly including specific aspects of student advising. This may change over time, of course, but it has been helpful to know at the beginning how effectively the co-advisor and I communicate about these issues.
- Communication is key. There should be regular meetings with both advisors present. When the student is giving a group meeting presentation in one group or the other, both advisors should always be included. Emails should be between all three parties. Scientific priorities can be misinterpreted or might change over time, so regular communication among all parties is important to make sure research effort is directed productively. With all my co-advised students, we make sure students can attend the group meetings of both groups. We also make it the student's responsibility to let both advisors know when the student is giving a presentation.
- Be mindful of the challenges of being a co-advised student. All my co-advised students have been in situations in which they work in two different, active research groups. They need to work with two advising styles as well as two sets of group norms and cultures. In addition, a co-advised student working in one lab but not perceived to be held to the same standards as "full-time" students in my group has sometimes engendered resentment. As soon as it becomes clear a student will be spending substantial time in my lab, not just conducting a few experiments, I add them into the regular group rotations in terms of group presentations, reporting, and lab tasks. I have found it to be helpful to have clear expectations for my research group that apply to all members, keeping in mind that certain expectations might need to be scaled to the amount of time the student spends in my group. For example, safe working practices are essential for everyone, but certain tasks such as equipment maintenance are scaled down for co-advised students.
- It can be necessary sometimes to communicate with the co-advisor without the student present. Issues related to funding or bureaucratic aspects of research may not require the presence of the student. Sometimes a co-advisor and I need to communicate separately to strategize about a project or to present consistency on issues such as graduation timelines, authorship, or student productivity. We sometimes meet separately to make a plan for how this conversation will go with the student, so that the two of us are in agreement or at least have considered the issue thoroughly when the three of us meet. It is important in these conversations to consider the perspective of the student as well and give them plenty of space to talk about the issues and their concerns. In a co-advising situation that did not go well, the student played the co-advisor and me off each other, telling each of us that the student was working hard on the work of the other advisor and didn't have time to work on anything else. In reality, the student was not working much at all. I make sure that I don't agree to anything important without communicating with the other advisor, and always check with the co-advisor if a student tells me something that doesn't seem reasonable.

- At my institution, only one advisor can be listed officially. I am always listed as the official advisor when the project is being driven by me and vice versa. This is important to discuss with a potential co-advisor, especially if advising and graduating Ph.D. students is part of evaluation for tenure and promotion. If the project represents a more equal contribution of expertise of each advisor, we usually have the student choose who they prefer.

  Overall, my co-advising experiences have been extremely rewarding. In the cases where things did not go well, I was able to learn where things went wrong and adjust our working relationships either in those cases or in future interactions. I make sure that expectations are discussed, and although circumstances can change over time, I make sure at least that everyone involved knows the level of communication that is expected to make the relationship successful."

  Anonymous

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Undergraduate Students

Two important reasons for mentoring undergraduates are the opportunity for you to have a major impact on the student, and the enthusiasm and fresh perspectives the student brings to the group. The key to making such relationships work well is to make your expectations clear. Is a one semester, 10 hour per week commitment enough for a student to accomplish something and warrant the training time you and your students will provide? Does your research require longer-term commitments for the student to be productive? Do you expect at least one summer of full-time work from a student, and if so, how will the student be compensated? Some departments have a culture of "lab-hopping," in which students change research groups every semester. You might find this to be detrimental to your productivity — the student leaves just as they are becoming productive. If this is the case for you, make clear your expectations for a long-term commitment from the student. Explain to them that their experience in your group will be far more fulfilling if they can develop a project to completion or near completion. Some PIs even require students to sign agreements committing themselves to one research laboratory until graduation.

> "Most of my undergraduate researchers work directly with Ph.D. students on their day-to-day research. I generally assign students to projects and Ph.D. students based on their schedules. Whenever I have a Ph.D. student taking on an undergraduate for the first time, the Ph.D. student and I have a conversation about their expectations for the student and what the student might expect from them. We discuss technical skills and we have now developed some exercises that new students do to demonstrate proficiency that must be completed satisfactorily before

> the student can dive into research. We also discuss what the Ph.D. student can do to help the student build research skills, including discussing the project and reading and discussing the literature. I always interview undergraduates before accepting them into the group, and sometimes have the Ph.D. student interview them as well. I encourage them to attend all group meetings and relevant project meetings so they feel a part of the group and get practice describing their work."
> **Anonymous**

Having two or three undergraduates work as a team can be a productive arrangement. Undergraduate schedules can be a challenge for conducting research, but setting up a wiki or similar electronic tool for multiple students with different schedules to communicate with each other about progress on the project is one way to deal with complicated schedules. You may also want to help undergraduates with course selection and craft a schedule that maximizes time for research. Having a "pipeline" of undergraduates where the senior ones train the newcomers can work. Pairing undergraduate students with a graduate student or postdoc can be a valuable experience for both mentor and mentee and can be used explicitly as a mentoring experience for the senior member to learn how to manage people and collaborative projects. Be sure to provide oversight and be prepared to intervene if conflict arises. For summer students, try to design a project that can reach an endpoint or on which the student can make substantial progress during that limited summer period. Similarly, supervising an undergraduate thesis requires thoughtful design of a project that can be complete enough to be written up in a thesis within the timeframe allowed. Choosing projects for undergraduates in which either their lack of experience or their recent experience in the classroom is an asset can be particularly fruitful. For example, the robustness and clarity of a new protocol can often be readily revealed by replication attempts by a newcomer. Research in the development of new undergraduate laboratory experiments or teaching techniques can also be aided immensely by the perspective of someone who has recently completed the targeted class.

> "I had a team of more than 10 undergraduates work on a research project for about five years. They trained each other and maintained their data in a shared online document. This worked great because I or a Ph.D. student could check it regularly and address problems with the data right away. When it came time to write the paper, all of the students had graduated, but because the results were collected in a central location, it was not so difficult to put it all together into a coherent story. We had agreed on a format for the data in advance that cross-referenced lab notebooks and instrument readouts, so we could double-check data. All the students who worked on this project were co-authors on the paper that was published."
> **Anonymous**

Be mindful of the critical roles of mentors with undergraduate researchers. Encouragement at this career stage can be life-changing for students, instilling confidence and setting them on career paths not previously imagined; the inverse is also true. Faculty members and other senior mentors also provide access to resources, such as information about graduate and professional school and career options. Be available and prepared for these discussions. Here again, open-ended and “why” questions are useful to assist with career planning. Connections to alumni and a referral to the campus career services office are also important ways to support students.

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High School Students, Teachers and Other Researchers

Hosting high school students or teachers in laboratories can be very rewarding, but it also requires planning, arguably more planning than most any other group of students since the level of experience and knowledge will be the least. You will need to be selective; be sure the people you bring into your group honor their commitments and are mature enough to respect safety guidelines and expectations with respect to data and materials. There are legal considerations with hosting minors; consult with your university well in advance of committing to hosting minors in your laboratory. You might have Young Scholars Programs and Research Experiences for Teachers programs on your campus, or the opportunity to host students through Project SEED with the American Chemical Society, which will make things easier by providing program infrastructure. It works well to have high school teachers or students work in pairs (two students, two teachers, or a teacher and a student) and to pair them with a graduate student or postdoc mentor who has been coached in how to guide the research project. Equally important, plan a real project for them; perhaps not something of critical importance for your overall research program to move forward, but something that will generate tangible results and contribute to your research in a substantial way. Flexibility in the project is important. A well-designed project can lead to co-authorship on publications, which will be incredibly rewarding for all involved. Remember that neither high school students nor teachers are likely to have research experience, so be patient. Convey your excitement about science; this is an opportunity to educate the public about what motivates scientists and how science is done, rather than dwelling on too many subtle details and caveats.

For high school teachers in particular, find out their goals for working in your laboratory. Often their motivation is to develop curricular materials or innovations that will enrich their teaching. Conversations with them will help you improve your own teaching, so listen to their concerns and plans. Teachers can help students in your group clarify their career paths and plans. You may also host community college faculty or faculty on sabbatical; again, have a discussion about their goals and plan the research and other activities in which they will engage accordingly.

With high school students, it is a good idea to have a trial period to make sure the students are mature enough and that the arrangement is a good fit for both the lab and the student. A good way to do this is to set up a "potentially renewable" monthlong trial. A summer research period provides a defined timeline. Consider as well that the high school students need not work five days a week, full-time. Two or three days a week can work really well and will offer the chance for your students doing mentoring to get some other work done while also having the fulfilling and rewarding experience of mentoring a high school student.

High school students can be intimidated by the university environment and by graduate students. Spending some time with them in the laboratory can be helpful to make them feel more comfortable. The choice of a graduate student mentor is also very important, so choose someone who will be supportive. It might also work better to pair a high school student with an undergraduate researcher who would be closer in life experience but would still have more research experience. Consider establishing a team of mentors, where students move between a different mentor each day in lab; this approach requires careful organization, but again it allows for more group participation in mentoring, and divides the labor of this critical activity so no single student is overly impacted in their ability to advance their own major research project.

In addition to high school students working directly in your lab, you might also consider other ways to engage these students by giving short presentations on your work at their schools, inviting them to visit campus for an afternoon to observe your class, or giving them a tour of your labs and demonstrating what your lab does (see section below on effective community engagement). For students at the high school level, even seeing a university environment and modern research laboratory can be a deeply impactful experience.

Other Researchers: Technicians, lab managers, and other staff present unique situations. In some cases, they will be in their positions for many years to come, and in other cases, their current position is a stepping stone to other opportunities. You will need to determine the goals of each of these people and mentor them accordingly.

Part III:
Developing Effective Community Engagement

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Goals of Community Engagement

> "As part of my research program, I engage quite often with local industrial collaborators on projects both small and large. I have been drawn into several regional economic development programs that are seeking to establish a blueprint for reinventing manufacturing through an emphasis on advanced technology with a focus on materials and life sciences. I've been involved with several aspects of this planning process as well as with meeting with large multinational corporations seeking to locate research and manufacturing operations. I look upon economic development and industrial outreach as an integral part of my job both in helping the university engage better with the local community as well as a means to secure the economic future of my graduate and undergraduate students."
> **Anonymous**

Community engagement, or outreach, is intended to broaden and diversify the demographics of scientists, to provide an entrée into research for future scientists, and to communicate science to the broader community. Resources for community engagement can be found on professional society or governmental websites (e.g. *http://www.aps.org/programs/outreach/guide/nsf.cfm and www.nsf.gov/pubs/2002/nsf022/bicexamples.pdf*).

Although time-intensive, community engagement can be deeply rewarding. For most junior faculty members, "outreach" represents an opportunity to communicate their idealism and excitement about their science to the world. New professors may find requests for interviews, public presentations, etc., competing with other job-related time demands. At the beginning especially, prioritize your efforts and activities.

In 1997, outreach ("broader impacts") took on new importance when it was elevated by the NSF to a second major review criterion for all proposals. This emphasis is reflected in the NSF's mission statement: "To promote the progress of science; to advance the national health, prosperity and welfare; to secure the national defense (NSF Act of 1950)." Science conducted in isolation is inconsistent with that mission statement.

> "In general, the most important impact I feel I can have with outreach is not teaching students, but helping their high school or elementary school teachers. The primary and secondary teachers often have lots of questions (some of which they are afraid to ask). As a result they themselves can have a superficial understanding of the science concepts that they are teaching. In general I think the biggest impact we can have with outreach beyond simply inspiring students is to help the teachers."
> **David Vanden Bout**

The most successful faculty members incorporate outreach seamlessly into their day jobs. Outreach helps to educate the public about science and the frontiers of current research, and it might even lead to philanthropy for your university, department, or research program. Of our survey respondents, 67% made presentations in public as part of their outreach activities; 62% visited science classes in their local schools; 12% volunteered on an ongoing basis at either a science museum or children's museum and an additional 10% volunteered in such venues occasionally or as needed. In terms of hosting visiting researchers, 43% hosted high school students and 31% hosted high school teachers in their laboratories. Our respondents hosted open observatory nights, led teacher workshops, prepared materials for teachers, were interviewed for or worked with TV programs, made movies, welcomed students and the public to tour their laboratories, interacted with congressional representatives, worked with faculty and students at community colleges or non-Ph.D.-granting institutions, judged science fairs, and put on science shows and science workshops for students and the public. Clearly, there are nearly as many different outreach programs as there are people doing them.

Faculty members partner with a wide range of people when doing outreach. In our sample, 78% of respondents involved undergraduate or graduate students in their outreach activities, 56% involved staff at their own institution, 47% involved other faculty members, and 25% involved others, including teachers, museum staff, and postdocs. As with teaching resources, there are plenty of excellent resources online, but they are generally not centralized or organized. Several professional societies have education and outreach resources on their websites.

> "I was fortunate enough to have an excellent postdoc who was awarded an NSF American Competitiveness in Chemistry Fellowship — a program that itself includes a broader impact aspect. I was able to team up with the postdoctoral fellow to implement an outreach program that could be sustained over multiple

years, and with longer lasting results. Our program brought a community college student to work in our group for 8-10 weeks in the summer — we have continued this program over three consecutive summers with an excellent record of moving students into the four-year and then Ph.D. STEM pipeline."
Stephen Bradforth

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Developing an Outreach Program

In some cases, "outreach just happens." For example, most institutions maintain a speakers bureau or faculty expertise database; someone in need of a subject matter expert might just call you. Typically, though, a successful outreach program requires planning and effort. Many universities and research centers have their own outreach programs. Partner with them to plan, implement, and launch your outreach program. Grants are available to support outreach. For example, the Cottrell Scholar program of the Research Corporation for Science Advancement, which funded the initiative to produce and distribute this book, is a prime example.

> "Divide & conquer! I was successful in procuring external funding to run "Lasers in Action" workshops during the year of the laser. In the budget, I specifically included funds to hire an instructor to coordinate and run the workshops. We planned them together, but I left the running of them to her and her team of volunteers. I would love to have done this myself but could not spare the time to run two three-hour workshops each week during the school year. They were a great success!
>
> Lasers in Action workshops were targeted at students in grade 8, as this is where optics are first extensively covered in the provincial curriculum (topics such as reflection and refraction). They were designed to introduce students to the properties of light, how it interacts with matter, what makes laser light special, and provide many opportunities for hands-on experiments with light. Students rotated among four different work stations, which they completed in groups of two or three, and which, through hands-on activities, explored the following concepts: (1) Reflection and refraction (through simple experiments); (2) Total internal reflection; (3) Color and dispersion; (4) Reflection and refraction (directing light through an optical obstacle course). By including household items like JELLO™

> in the workshop (e.g. total internal reflection within JELLO™ optical waveguides; observing light transmission through different colors of JELLO™) the workshops were designed to show how Physics concepts are not limited to fancy laboratory equipment. Although the funding opportunity arose from the International Year of the Laser, the success of our initially funded one year of workshops led to the availability of university funds to continue these workshops over the years. They have now introduced thousands of students to lasers and optics, and are an ongoing component of outreach activities in our department."
> **Nancy Forde**

Approach your outreach project as a scientist. Gather information on what is needed and identify effective strategies to address those needs. Find the experts who understand your intended audience and obtain their advice. If you want to go into schools, ask teachers what would be most effective or helpful to them. If you would like to volunteer at a museum, ask an outreach coordinator or curator what is effective, what would be valuable, and for examples of other similar activities. If you want to mentor students, familiarize yourself with the literature on effective mentoring.

Your enthusiasm and obvious love for science will go a long way to making your outreach event a success. Aim your approach to the level of the audience and keep people engaged with hands-on activities. Connect your work to something your audience is already interested in; for example the chemistry of cosmetics, forensic science, physics of candy, etc. Use analogies to help your audience relate to the amazing feats of nature; for example, the length of DNA contained in a cell of a given size or the force exerted by a molecular motor. Ask questions. This will keep your audience engaged and help you adjust the level of your presentation accordingly. Use everyday household or hardware store items to convey to the public that science is all around us and is generally applicable to their lives. Provide materials lists and instructions so that your attendees can replicate your activities at home (with appropriate cautions, of course).

Solicit help. It is rewarding, and can save time and money, to enlist undergraduate or graduate students in your outreach efforts. Your involvement can range from consultant and perhaps provider of some funding, to participant alongside the students. Some students may need encouragement to overcome their timidity about approaching a faculty member; advertising in-class or on a local job board are means of bringing students into the fold. You and your student helpers will benefit from planning the activity and explaining the science behind it. Involve lecture demonstration staff, teaching staff, public engagement offices, community outreach offices, philanthropy groups, and education departments in planning activities and making connections to community members. Many faculty members report that interactions with younger students, ranging from elementary to high school students, or their teachers, are especially rewarding. You will know you have designed a successful outreach activity when your participants record the activities with their phones to share with parents and friends later!

Similarly, personalize your presentations. Science is done by real people. Tell the story of the people behind the work. Tell your own story. How did you get interested in science and your field of research? What have been your biggest challenges and successes? How long did it take you to make your most recent discovery? What are the current unsolved problems that need the next generation of solutions? Your students can share what excites them about their fields. Most people find that members of the public are quite interested in what we do as scientists.

The most successful faculty members retain their initial sense of idealism throughout their careers; for them, community engagement continues to be a welcome opportunity, rather than a perfunctory afterthought on a proposal to satisfy funding agency requirements or university directives.

Effectiveness of Outreach

Was your outreach successful? Having defined goals for your outreach activities will help in assessing whether you are achieving those objectives. Once you have defined realistic goals, plan how you will assess the success of your event. Consider using self-reporting surveys, analyzing repeat attendance, informally assessing enthusiasm and excitement at the activity. When involving students in research, consider tracking publications and other student outcomes, such as college or graduate school attendance, choice of major, and employment. You may also want to enlist a professional, external evaluator for specific projects, who can help design surveys or other evaluation instruments and can assist in interpreting data and designing follow-up surveys or interventions. A university institutional data analysis office or survey design service can be a good place to start.

Part IV:
Thoughts on Becoming an Effective Teacher-Scholar

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Balancing Responsibilities

Remember that time is always your limiting reagent. You must understand the priorities of your institution and allocate your limited time accordingly. Know what is expected for tenure and promotion. Ask questions; you may get conflicting answers, but with increasing sample size, you should be able to determine which opinions are outliers. Take seriously the feedback you receive in annual and other reviews and discuss it with your mentors. Do what you can to address perceived shortcomings.

You may experience interactions that are perplexing, frustrating, or worse. Conserve your mental energy for things that matter. Take what you can from negative interactions to improve yourself, your work, or your outlook, but do not take things too personally. However, if you believe that you are the subject of harassment or discrimination, keep detailed records and consider speaking to a confidential advisor, such as a university ombudsperson.

Many new faculty members, especially those in experimental sciences, get a one- or two-semester teaching release to get their research up and running. Consider saving teaching releases for later, rather than using them during the first year. There are many benefits to teaching early, even in your first semester. First, it is often difficult to make much research progress in your first semester or first year, as you wait for equipment and recruit and train your first students. Instead, you could be gaining teaching experience and recruiting talented research students from your class. In addition, being a beginning faculty member can be lonely. Trying to make progress in an empty laboratory can be a profoundly isolating experience. Teaching will bring you into contact with students as well as staff and other faculty and can help make you feel more a part of the community. This advice is obviously dependent on the field. If field work or data collection opportunities occur on a limited schedule, that may require your attention instead.

Flexibility in your teaching schedule can be very valuable. Some people find it useful to teach a double schedule one semester to have another semester off. Others find it helpful to teach during the summer instead of during the regular semester. It is worth asking your department or division head about this type of arrangement if it would be useful to you. Find out whether you are expected to demonstrate proficiency in teaching a wide range of courses or to focus on one or two different classes. Team teaching may also give you added flexibility as well as additional opportunities for mentorship; in such cases, be sure you can demonstrate your own contributions to the class.

Remember to document your teaching efforts and effectiveness. You may be required to report end-of-semester student evaluations, or they may be automatically imported into your annual-review documents. In addition, keep records of other assessments of your teaching that have been carried out, particularly peer observations of your teaching. Many new technologies, such as ePortfolios, make this sort of record-keeping much easier and are able to support very rich documentation, and other online drives and data storage services can serve this purpose. Save a copy of each of these items as you obtain them to prevent a scramble when you assemble your dossier, or worse, loss of key information due to changes in university systems.

As a new faculty member, obtaining effective mentoring is essential. It is crucial that you find mentors with whom you can work well. Your mentors must be willing to listen to your concerns and be able to provide reasonable, candid feedback. For this reason it is often helpful to have a mentor outside your home department, in addition to a mentor within your own department and discipline. An external mentor can give you a broader perspective on professional expectations, help you prepare for tenure, and provide professional connections and opportunities. You may be able to negotiate funds for expenses, such as travel costs, associated with visiting an external mentor or meeting them at conferences as part of your start-up package.

> "When our external mentoring program was established, my department chair asked me to identify someone I thought would be a good mentor and who is also recognized as a leader in my field. I came up with a short list and ran it by my postdoc advisor. I had switched fields between graduate school and postdoctoral training, so my postdoctoral advisor was the most appropriate person to ask. I hadn't known my external mentor very well before we set up this formal relationship, but it turned out that we had a lot in common and she has been someone I truly enjoyed getting to know. My mentor has given me some extremely valuable professional opportunities as well as advice about difficult situations. The other real value of the program was for me to get an outsider's perspective on my progress as I was nearing tenure."
> **Penny Beuning**

"I found at the start of my career that advice from many people outside my department and supervisors was critical to early success. Whether from people who were just a few years ahead of me (who could tell me some of their recent stories and experiences) to more senior faculty whom I met at conferences and workshops (who had a lifetime of practical experience), seeking assistance and asking advice from these individuals dramatically aided my first few years as faculty. Now, especially when I speak with younger faculty on lecture trips or at conferences, I try and pay that advice back by offering to mentor them as well, whether on grants, papers, teaching, or the faculty experience in general. I also continue to seek advice from those beyond my experience level (including outside my institution) as I have moved up the faculty ranks into additional responsibilities outside of research and teaching."
Scott Snyder

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Mentoring: The Importance of Building a Network

Contributed by Kana Takematsu

As you navigate the challenges of your new faculty career, you may find yourself taking on multiple roles that are personally and professionally defined. At the professional level, you may identify yourself as a researcher, teacher, departmental and institutional citizen, mentor, grant writer, etc. At the personal level, you may identify yourself as a parent, caregiver, partner, friend, etc. These roles will change and evolve over time.

As the tasks and responsibilities of these roles differ, the people who can best support you in these various roles will also differ. It is highly unlikely that there will be one person who can provide guidance for all these roles, and even if you feel that you have identified one such person, you may find yourself asking whether it is equitable for that one person to provide all your professional and emotional support.

The best advice for young faculty members is to build a network of people who can best support you in meeting your goals. Before we discuss identifying such people, please remember that self-care is essential. You will be under professional and personal stress; be kind to yourself and realize that you are balancing many roles. You may excel in one moment in one role and struggle or fail the next moment in another role. This is okay and normal, and we all share this struggle. Both your physical and mental health are valuable, and professionals who can help you maintain good health in both these areas should be included in your network.

Guidance for Shaping Your Network

Identify your goals. As you begin your new faculty career, you may have been encouraged to form a list of short and long-term teaching and research goals. Take a look at your list of goals, but now think about what information or support you may need to reach your goals. The more specific your short-term goals are, the more you can identify areas in which you may need guidance. As you go through this exercise, consider also making a list of goals related to understanding departmental and institutional politics/expectations and balancing work-life goals.

Identify people in your department, institution, and field to be part of your network. Once you have identified what support you may need, there may be immediate people in your department who could provide you with that support. Ask your chair to help identify members within your department for specific areas of concern, ask your colleagues for contacts at the institution, or reach out to institutional support centers. For field-dependent advice, you may have to go outside your institution. There are many avenues to build a network: attend conferences (regional and national), volunteer for grant reviews, invite people of interest to seminars at your institution, join online resource groups, etc. Your colleagues or postdoctoral/graduate advisors may also have connections. Do not be afraid to ask for introductions.

Find your accountability mentors and partners. Although we try our best, we can often get overwhelmed by the many demands of our personal and professional lives. To keep you on track, find mentors or colleagues who can help you hold yourself accountable for reaching specific goals. For example, if you need to write a paper or proposal, consider joining either a physical or virtual writing group or utilizing an online resource in which you report your writing time.

Find your safe space and support. Navigating the early years of your career is fraught with many emotions. Find a safe space for you to celebrate your triumphs, share your challenges, vent your frustrations, and express your concerns. You may have separate or overlapping people that you lean on to share your personal and professional experiences. You may also turn to professional help for self-care. The most important thing is that you feel supported throughout the process and know that you are never without resources.

Appendix I: Resources for Further Reading

Ambrose, Susan, Michael W. Bridges, Michele DiPietro, Marsha C. Lovett, Marie K. Norman 2010 "How Learning Works" Jossey-Bass

Angelo, Thomas A. and K. Patricia Cross 1993 "Classroom Assessment Techniques" Jossey-Bass

Boice, Robert 2000 "Advice for New Faculty Members: Nihil Nimus" Pearson

Boss, Jeremy and Susan Eckert 2006 "Academic Scientists at Work" Springer

Handelsman, Jo, Sarah Miller and Christine Pfund 1997 "Scientific Teaching" W. H. Freeman

Handelsman, Jo, Christine Pfund, Sarah Miller Laufer, and Christine Pribbenow 2005 "Entering Mentoring" Board of Regents of the University of Wisconsin System

Laskow Lahey, Lisa and Robert Kegan 2009 "Immunity to Change" Harvard Business Review Press

Mazur, Eric 1996 "Peer Instruction: A User's Manual" Addison-Wesley

Mintzes, J. J. and W. H. Leonard. 2006 "Handbook of College Science Teaching." NSTA

National Academies Press 1997 "Science Teaching Reconsidered"

National Research Council (NRC) 2012 "Discipline-based education research." National Academy Press.

Nathan, Rebekah 2006 "My Freshman Year" Penguin

Research Corporation for Science Advancement 2015 "Searching for Better Approaches: Effective Evaluation of Teaching and Learning in STEM"

Vandermaas-Peeler, Maureen, Paul C. Miller, Jessie L. Moore 2018 "Excellence in Mentoring Undergraduate Research" Council on Undergraduate Research

Wankat, Philip C. 2001 "The Effective, Efficient Professor" Pearson

Waterman, Rory and Jen Heemstra, Eds., 2018 "Expanding the CURE Model: Course-based Undergraduate Research Experience" Research Corporation for Science Advancement

Wiggins, G. and J. McTighe, 1998 "Understanding by design." Merrill/Prentice Hall

Zinsser, William 2012 "On Writing Well" Harper Perennial

Useful Links

American Chemical Society *http://www.acs.org/*

American Physical Society *http://www.aps.org/*

American Society for Biochemistry and Molecular Biology *http://www.asbmb.org/*

Center for Astronomy Education *https://www.as.arizona.edu/center-astronomy-education*

Council on Undergraduate Research *http://www.cur.org*

Institute for Chemical Education *http://ice.chem.wisc.edu/*

Journal of College Science Teaching *http://www.nsta.org/college/*

National Science Teachers Association *http://www.nsta.org*

Project Kaleidoscope *http://www.aacu.org/pkal/*

Physics and Astronomy Education Communities (Open Source Physics) *http://www.compadre.org/*

Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES, assessment) *http://ccliconference.org/measuring-teaching-practices/*

Mentoring

http://www.nationalpostdoc.org Includes description of core competencies postdocs should develop

http://www.rackham.umich.edu/downloads/publications/Fmentoring.pdf

http://www.rackham.umich.edu/downloads/publications/mentoring.pdf

National Research Mentoring Network *https://nrmnet.net/*

Center for the Improvement of Mentored Experiences in Research *https://cimerproject.org/*

National Center for Faculty Development and Diversity *https://www.facultydiversity.org/*

Best practices in supporting Honours and Coursework Dissertation Supervision *https://www.researchgate.net/publication/286239145_Guide_for_Honours_and_Coursework_Dissertation_Students*

COMPASS *https://www.trinity.edu/sites/compass/resources*
The COMPASS site contains resources for students and faculty related to career mentoring.

Active Learning Repositories and Resources

Science Education Resource Center (SERC) *https://serc.carleton.edu/*
Resources for K-college science educators, organized by education level, topic, and field

CREATE *https://teachcreate.org/*
Resources and examples for using the C.R.E.A.T.E. (Consider, Read, Elucidate the hypotheses, Analyze and interpret the data, and Think of the next Experiment) method to teach with primary literature.

Course-based Undergraduate Research Experience Network (CUREnet) *https://serc.carleton.edu/curenet/index.html*
Site providing a network as well as resources and examples for faculty teaching CUREs.

Quality Matters *https://www.qualitymatters.org/*
Resources and information about validated effective practices for teaching online.

PhET interactive simulations *https://phet.colorado.edu/*
Simulations for teaching science and math to students in K-college. Includes user-produced simulations as well as research on effectiveness.

The Jigsaw Classroom: A Cooperative Learning Technique *http://www.jigsaw.org/*
Overview of the jigsaw teaching technique and tips for implementation, as well as a list of related articles and a history of the technique.

National Center for Case Study Teaching in Science *https://sciencecases.lib.buffalo.edu/*
A collection of case studies for use in STEM teaching as well as resources and workshops for teaching effectively with case studies.

Analytical Science Digital Library (ADSL) *https://home.asdlib.org/*
Curriculum and active learning resources related to analytical chemistry

Virtual Inorganic Pedagogical Electronic Resource (VIPER) *https://www.ionicviper.org/*
Teaching and learning resources for inorganic chemistry

ComPADRE *https://www.compadre.org/*
Resources for teaching physics and astronomy

CourseSource *https://www.coursesource.org/*
Teaching resources for biology and biochemistry undergraduate education, including active learning examples connected to specific learning objectives

Appendix II: Examples of Active Learning Activities

http://ch301.cm.utexas.edu/; http://ch302.cm.utexas.edu/

Unit 5 Day 3 Activity: "Thinking About Solutions"

CH302
Spring 2013
Vanden Bout/LaBrake

Name: ______________________

EID: ______________________

A major goal for this class is for you to learn the concept of macro/micro thinking or "Thinking Like a Chemist." Thinking like a chemist is the ability to look at the macroscopic properties of a static substance or a substance undergoing a change and be able to simultaneously account for those properties on a microscopic (molecular) level. Today we will practice this skill while considering the process of dissolution. Platinum stars will be on the line.

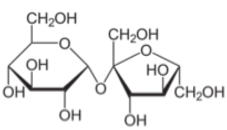
Write your answers on a separate sheet of paper.

Consider the following two crystalline substances, sucrose (table sugar) and sodium chloride (table salt). You should have prior experience at placing each of these substances in water at room temperature.

1. Please draw/explain to the best of your ability a **macroscopic** description of the sugar dissolving in water and the salt dissolving in water:

Given the chemical formulae/structures, consider the microscopic properties.

$C_{12}H_{22}O_{11}$ NaCl



2. What type of solid is each of these substances?

3. What types of intermolecular forces hold these substances together as solids?

4. Draw a microscopic view of the dissolution process for each solid.

Check In: If called on be prepared to share your answers with the rest of the class.

Now we are ready to look at the energy changes associated with the dissolution process.

5. Is the dissolution process an endothermic or exothermic process?
Watch a class demonstration on dissolving different compounds (sodium chloride, sucrose, and ammonium nitrate) in water.

6. In general, is the dissolution process endothermic or exothermic process? *Explain*:

7. Fully describe the change in enthalpy for the dissolution process, that is what parts of the process should require energy and in what parts of the process should energy be given off.

Check In: If called on be prepared to share your answers with the rest of the class.

8. Is the entropy of the system (pure solvent + pure solute) higher or lower after the solute has been added to the solvent and a solution has formed?

9. Is there ever a situation in which the entropy of the solvent and solute would be greater than the entropy of the solution? *Explain:*

10. Is the dissolution process always spontaneous?

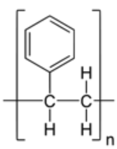
11. What thermodynamic property can predict the spontaneity of the dissolution process?

Check In: If called on be prepared to share your answers with the rest of the class.

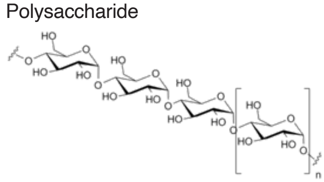
12. Thinking about the Gibb's free energy, what must be true about the enthalpy, entropy, and temperature for dissolution to be spontaneous?

Watch a class demonstration on dissolving different packing peanuts in acetone vs water.

Water (H_2O)
Standard Packing Peanuts
Polystyrene



Acetone (CH_3COCH_3)
Bio-degradable Packing Peanuts
Polysaccharide



Consider the four possible combinations:
A. polystyrene packing peanuts in water
B. polystyrene packing peanuts in acetone
C. bio-degradable peanuts in water
D. bio-degradable peanuts in acetone

13. What do you think the sign is for change in **free energy** of solution for each of these: "+", "-" or about zero?

What do you think the sign is for change in **entropy** of solution for each of these: "+", "-" or about zero?

What do you think the sign is for change in **enthalpy** of solution for each of these: "+", "-" or about zero?

Check In: If called on be prepared to share your answers with the rest of the class.

Unit 4 RAQ

VandenBout/LaBrake
Fall 2012

Name: ____________________

UTEID: ____________________

Consider the following chemical change:

Acetylene (C_2H_2) combusts in oxygen to form carbon dioxide and water.

Single Bond Energies (kJ/mol of bonds)

	H	C	N	O	S	F	Cl
H	436						
C	413	346					
N	391	305	163				
O	463	358	201	146			
S	347	272	–	–	226		
F	565	485	283	190	284	155	
Cl	432	339	192	218	255	253	242

Multiple Bond Energies (kJ/mol of bonds)

C=C 602	C=N 615	C=O 799
C=C 835	C=N 887	C=O 1072
N=N 418	O=O 498	N=N 945

1. Estimate the enthalpy of combustion of acetylene using bond energies data.

2. Calculate the enthalpy of combustion of one mole of C_2H_2 using heats of formation data found on the course website using your personal wireless device.

3. Calculate the change in entropy for this reaction using standard molar entropy data found on the course website.

4. Calculate the change in Gibbs free energy for this reaction.
Is there ever a temperature where this reaction would be non-spontaneous?
If so, what is that temperature? *If not, why*?

5. 40 g of acetylene was combusted in a bomb calorimeter that had a heat capacity of 3.51 kJ/C for the device and contained 2000 g of water (C = 4.184 J/mol C) to absorb the heat as well.
What is the expected temperature change in such a calorimeter given the complete combustion of the 40 g of the fuel?

6. What is the work for this process (combustion of 40 g C_2H_2)?

7. What is the change in internal energy for this process (combustion of 40 g C_2H_2)?

Consider the following physical change:

$N_2\ (liq,\ 77K) \longrightarrow N_2\ (gas,\ 298K)$

and the following **thermodynamic data** for N_2 :

$\Delta H^0_{vaporization}$ = 5.56 kJ mol^{-1}

$C(N_{2\,gas})$ = 29.1 J $K^{-1}mol^{-1}$

1. How much heat is absorbed during this change given 4 moles of N_2?

2. What is the work for this process
(assuming the initial volume of the liquid is zero)?

3. What is the change in internal energy for this process?

4. What is the change in enthalpy for this process?

5. What is the change in entropy of the system for this process?

6. What is the change in entropy of the surrounding for this process?

7. What is the total change in entropy (change in entropy of universe) for this process?

8. Does the thermodynamic calculation predict the observation that this process is spontaneous?

Chemistry Exposed: Molecular Orbitals

Linda Columbus

Objectives

1. Visualize linear combination of atomic orbitals as bonds

2. Understand the atomic interactions that dictate bond formation

3. Compare trends in molecular orbitals and associated energies between molecules

4. Using molecular orbital theory, determine if a molecule can form and if the molecule is diamagnetic or paramagnetic

5. Continue to hypothesize about the correlation(s) of orbital energies and shapes with molecular stability/reactivity

Activities

Be sure to take notes using your notepad here in TopHat so you can answer the Bringing It Together[1] questions and review for exams.

1. Energy and visualization of molecular orbitals of dinitrogen (N_2):

1.1 On the dry erase board, sketch the valence N atomic orbitals and the molecular energy diagram for N_2 diatomic molecule. The sketch should look like those found in your textbook.

1.2 Upload an image of your energy diagram for N_2 to the week four tab of your ePortfolio[2].

Ch04: Expo Q01: Is N_2 stable?
A: Yes B: No

Ch04: Expo Q02 Show Correct Answer Show Responses

What information allowed you to answer the above question?

A	There are more electrons in the antibonding orbitals than the bonding orbitals. Thus, the bond order is greater than zero and the molecule is stable.
B	There are more electrons in the bonding orbitals than the antibonding orbitals. Thus, the bond order is greater than zero and the molecule is stable.
C	The energy of the lowest occupied orbital is below zero. Thus, the total energy for the molecule is negative and the molecule is stable.
D	The energy of the highest occupied orbital is below zero. Thus, the total energy for the molecule is negative and the molecule is stable.
E	The energy of the molecular orbitals that result from the 2s orbitals is lower than the energy of the molecular orbitals that result from the 2p orbitals Thus, the molecule is stable.

[1]BIT; an assignment completed by individuals after the group work activities outlined in this document
[2]A virtual collection of important assignments that a student collects and analyzes on their own

Ch04: Expo Q03: Is N_2 diamagnetic or paramagnetic?
A: diamagnetic B: paramagnetic

CH04: Expo Q04 Show Correct Answer Show Responses

What feature of the molecular orbital diagram allowed you to answer the previous question?

A	All electrons are paired in the molecular orbitals.
B	There are electrons in the antibonding orbitals that are formed for the mixing of the atomic p-orbitals.
C	There are unpaired electrons.
D	The orbitals formed for the mixing of the 2s atomic orbitals are occupied.

Ch04: Expo Q05: What is the bond order of N_2?
A: 3 B: 2 C: 1 D: 0
Ch04: Expo Q06: Based on the bond order what type of bond does N_2 have?
A: No bond, it is unstable B: single C: double D: triple

1.3 Open WebMO: *https://www.webmo.net/*
In WebMO, build N_2. See the TopHat guide for molecular calculations in WebMO for help. Use the information above in terms of the type of bond to build between the two nitrogen atoms.

1.4. To get the molecular orbitals for a molecule in WebMO,
you must run two calculations:
(1) First, a “Geometry Optimization” must be run.
(2) Once the calculated preferred geometry is obtained,
a “Molecular Orbital” calculation can be run.
For both of these calculations, there are two inputs that you need to consider before submitting your calculations for N_2 in WebMO:

Ch04: Expo Q07: What is the charge of N_2?
A: −1 B: −2 C: neutral D: +1 E: +2
The **Charge** field in your calculations should be set to this number.

Ch04: Expo Q08: How many unpaired electrons does N_2 have?
A: none B: 1 C: 2 D: 3
Your N_2 calculations should have the ***Multiplicity*** *field set as “Singlet” if the molecule has zero unpaired electrons, “Doublet” if it has one unpaired electron, “Triplet” if it has two unpaired electrons, etc.*

1.5 Calculate the idealized geometry for N_2. Use “Geometry Optimization” as the **Calculation**, “B3LYP” for the **Theory** (an approximation of the Schrödinger equation), and ‘6-31G(d)” for the **Basis Set** (the orbitals used in the calculation).

1.6 When the geometry calculation is complete, open up the results of the calculation. Using the “Adjust” tool (the icon with the uncurved arrow on the left-hand side of WebMO), check the calculated bond length for N_2 by selecting the two atoms of the molecule. The bond length will be listed in units of Angstroms (Å) on the bottom of the WebMO window. (Angstroms are a non-standard unit of length that have been classically used by chemists because it is on the order of the length of a bond. 1 Å = 1 x 10^{-10} m. Its use is being phased out in place of SI units like picometers, where 1 pm = 1 x 10^{-12} m.)

Ch04:Expo Q09: What is the calculated bond length for N_2 in Å?

Ch04:Expo Q10: What is the experimental bond length for N_2 in Å?

Ch04: Expo Discussion Question 1

Only one person in this group needs to answer this question. Include your group name at the top of your answer. How does your calculated bond length compare to the experimental bond length for N_2? Do you think the calculation is giving a reasonable model for the molecule? Why or why not?

Responses

Reply

Ordered by Newest Responses

8 months ago

The calculated bond length is larger than the experimental bond length for diatomic nitrogen.

Comments 0 1

If your bond length is considerably different than the experimental length, let an instructor or TA know before continuing.

1.7 When viewing the results of your calculation, click the “New Job Using this Geometry” button on the bottom of the window to set up your molecular orbital calculation. Then, click on the bottom right arrow to get to the job configuration screen.
Calculate the MOs for N_2. To do this, you should only have to change the ***Calculation*** *type to “Molecular Orbitals.” The other fields should be correctly set: “B3LYP” for the* ***Theory*** *(an approximation of the Schrödinger equation), and “6-31G(d)” for the* ***Basis Set*** *(the orbitals used in the calculation), and the previously determined values you put for* ***Charge*** *and* ***Multiplicity****.*

1.8 On graph paper, plot the orbital energies N_2 for the valence orbitals of the N_2 molecule. The valence orbitals are the ones that are formed from the n=2 orbitals of the two N atoms. How do you know which are the valence orbitals? You will have to use your chemical knowledge from the reading and class to make that determination.

On your diagram, indicate which orbitals have electrons in them.
Label the HOMO and LUMO for this molecule.

Ch04: Expo Q11 Show Correct Answer Show Responses

Multiple answers: Multiple answers are allowed for this question.

What information do you get out of the orbital calculations for N_2 from WebMO that is not available in the molecular orbital energy diagram from your text (Figure 4.12 from the reading)? Select all that apply.

A	The relative atomic orbital energies for N.
B	The relative molecular orbital energies for N_2.
C	The quantitative atomic orbital energies for N.
D	The quantitative molecular orbital energies for N_2.
E	The specific atomic orbitals that contribute to make up each molecular orbital.

1.9 On the white board sketch out the shape of the orbitals that are the HOMO and LUMO for this molecule. Label them with the descriptor for the orbital (σ, π, σ*, etc.) and their energy. If there are two orbitals that could be HOMO or LUMO, you only need to sketch one.
What atomic orbitals are combined to generate each of these orbitals?
Draw the interaction of the two atomic orbitals that lead to each molecular orbital (the HOMO and LUMO) showing the correct phases for each atomic orbital.

2. Energy and visualization of molecular orbitals of dioxygen (O_2):
2.1 On the dry erase board, sketch the molecular orbitals and energy diagram of O_2. You should be able to use the N_2 MO diagrams and modify based on the difference in electron configuration (e.g. the difference in the number of electrons between N and O) and properties that control atomic orbital mixing.

2.2 Calculate the optimized geometry and molecular orbitals of O_2 with WebMO in the same way you did for N_2 above. Pay particular attention to determining the **Charge** and **Multiplicity** for this molecule. Are either of these different than they were for N_2?

2.3 The results from this calculation are going to look a little different than for the N_2 molecule. Because O_2 has at least one electron that is unpaired, the calculation ends up looking like there is only one electron in each orbital (as shown in the “Occ” or occupancy value when looking at the orbitals).
The other electrons have been calculated, but are given separate “orbitals” in the calculation because they are at slightly different energies. From after this point in the course, we will only be looking at molecules that have paired electrons, as they are more common and more stable, so we will not have to deal with this issue again.
To simplify the treatment of O_2, we only need to consider the first 15 or so orbitals listed in the output. We will use our chemical knowledge (and the energy diagram we already constructed for O_2) to determine which orbitals are valence orbitals, which have two

electrons in them, and which only truly have one electron.

2.4 On graph paper, plot the orbital energies for **just the HOMO and the LUMO**. Indicate how many electrons are in each orbital (not how many WebMO tells you, but how many are actually in the orbital).
Take a picture of your graph paper work to post to your ePortfolio for this week.

2.5 Next to your drawings of N_2 orbitals on the white board, sketch out the shape of the orbitals that are the HOMO and LUMO for this molecule.
Label them with the descriptor for the orbital (σ, π, σ, etc.) and their energy.*
If there are two orbitals that could be HOMO or LUMO, you only need to sketch one.

What atomic orbitals are combined to generate each of these orbitals? Draw the interaction of the two atomic orbitals that lead to each molecular orbital (the HOMO and LUMO) showing the correct phases for each atomic orbital.
Take a picture of the HOMO and LUMO for each molecule to post to your ePortfolio for this week.

Ch04: Expo Q12: What is the bond order for O_2?
A: 0 B:1 C: 2 D: 3

3. Why do we need to breathe oxygen?
At the beginning of Ch 4, it was asked "Why do we breathe O_2 instead of N_2?" Based on your work today, come up with a hypothesis as to why our bodies have evolved to use atmospheric O_2, and not the much more abundant N_2, to function. Your answer should incorporate the information you found using molecular orbital theory.
Be prepared to present your hypothesis and your answer to Discussion Question 3 to the class.

Appendix III:
Use of Songs for Teaching

"Electric Field & Potential," courtesy Nancy Forde
(Sung to the tune of "Alice the Camel" *http://www.youtube.com/watch?feature=player_detailpage&v=GpoqrvTLc8M*. The lyrics are entirely my fault)
— Nancy Forde

The E-field flows from a ... + charge
The E-field flows from a ... + charge
The E-field flows from a ... + charge
... Go Vectors Go!
The E-field points where the ... force goes
The E-field points where the ... force goes
The E-field points where the ... force goes
... on a POSITIVE charge
Potential is positive 'round a ... + charge
Potential is positive 'round a ... + charge
Potential is positive 'round a ... + charge
... and negative 'round a minus

"Right-Hand Rules," courtesy Nancy Forde
(Sung to the tune of the "Hokey-Pokey". The lyrics are entirely my fault)
— Nancy Forde

You put your right hand in,
You point your thumb straight up,
You curl your fingers around.
(Now you've got the wire held.)
The thumb points with the current
And the fingers show the field.
Charge flow produces B. Whee!!
You put your right hand in
You find the I or the v
You point your fingers that way,
Then you turn them to B.*
Your thumb points where the force goes
(if the charge is positive).
Force is qv cross B. Whee!
*This part can be quite tricky!

"Song: SOS"
A song about the bacterial SOS response to DNA damage, sung to ABBA's "SOS"
Sharotka M. Simon, Lauren S. Waters, Daniel F. Jarosz, and Penny J. Beuning
Biochemistry and Molecular Biology Education 37 316 (2009)
dx.doi.org/10.1002/bmb.20305

Appendix IV: Survey Questions

There is currently no single, practical, and personal resource that offers advice for young faculty at research institutions on how to best develop their courses, utilize new pedagogy, develop effective outreach, and mentor students at diverse levels. Indeed, many Cottrell Scholars have identified effective strategies along these lines, but often on their own and often by "reinventing the wheel." The purpose of this survey is to gather the combined experiences and collective wisdom of 240 Cottrell Scholars to develop a book and companion website to provide advice and perspective on these issues. We are most interested in hearing about your personal experiences in developing effective teaching and mentoring practices. The text boxes below most questions will accommodate fairly lengthy answers.

This survey is anonymous and should take about 30-45 min of your time. You will have the option at the end to identify yourself as someone willing to be contacted for follow-up discussions, in which case we may be able to link your answers to your identity. If you agree to a follow-up interview, you will still have the option to remove your identifying information from public presentations of the survey data.

1. Before you taught your first class, where did you find the most useful advice?

    Book, specify:
    Web, specify:
    Faculty mentor
    Other faculty
    Teaching workshop, specify:
    No advice or mentoring received, I was just expected to perform the first time around

2. What was the most useful advice you received before teaching your first class, or what advice might you now offer, in retrospect, to a first-time instructor?

3. After you taught your first class, what would you have wanted to change?

4. What factors are key to using technology in your classes?

    Staff support
    Technical support
    Departmental or university culture
    Other (please specify) or comments

5. What factors are hindrances to using technology in your classes?
   Lack of staff support
   Lack of technical support
   Departmental or university culture
   Other (please specify) or comments

6. What have you done or what advice do you have to overcome resistance by colleagues, teaching assistants, and/or students to adopting new teaching practices?

7. What practices do you think are most effective for motivating students to learn?

8. What advice do you have for engaging students in large lecture classes?

9. What helped you most in preparing to teach specifically a large lecture class for the first time?

10. What are examples of innovative and/or especially effective practices you have adopted in your teaching?
    Clickers/Student Response Systems
    Other non-electronic response systems (for example, cards)
    Least clear/most clear end-of-class survey
    Think-pair-share
    POGIL (Process Oriented Guided Inquiry Learning)
    Peer-Led Team Learning (PLTL)
    Creative assignments (for example, student-produced videos)
    Research experiences in teaching laboratories
    Student Assessment of their Learning Gains (SALG)
    Please describe these or other innovations you have adopted

11. What prompted you to adopt those practices?
    Desire to improve learning
    Desire to add variety to teaching
    Expectations or peer pressure
    Requirements of course or department
    Feedback from students
    Feedback from faculty or department
    Other (please specify) or comments

12. How were those innovations received by your students?
    Very enthusiastic
    Positive
    Neutral
    Negative
    Very resistant
    Comments

13. What was the biggest misconception you had to overcome in terms of teaching, campus resources on education, or anything else of significance?

14. What resources saved you tremendous time in lecture preparation, changing your pedagogy, or that you found useful more generally?

15. What, if any, impediments prevent you from implementing new teaching tools or technologies in your curriculum?
   Time demands of research
   Time demands of service
   Teaching load
   Family or other external commitments
   Lack of reward or recognition for doing so
   Other (please specify) or comments

16. What personnel have you mentored in your research laboratory?
   Postdoctoral scholars
   Research technician
   Graduate students
   Professional students
   Undergraduate students
   High school teachers
   High school students
   Other (please specify)

17. If you have had high school teachers or students, what advice do you have for effective mentoring?

18. Please share any advice you have for mentoring students in your research.

19. What outreach activities are you, or have you been, engaged in?
   Hosting high school students as laboratory researchers
   Hosting high school teachers as laboratory researchers
   Visiting science classes in local schools
   Volunteering on an ongoing basis in science museum or children's museum
   Volunteering as needed in science museum or children's museum
   Presentations in public

20. What practices have you found to be most effective in outreach activities?

21. How did you determine the effectiveness of your outreach efforts?

22. What resources have you utilized or are you aware that increase effectiveness and/or save you time in planning and carrying out outreach activities?

Graduate or undergraduate students
Staff at own institution
Other faculty
Other professionals (teachers, museum staff, etc.)
Websites
Books
Other

Please describe examples of above:

23. What practices have you found to be most rewarding to you in outreach activities?

24. Please include a 1-2 paragraph description of what you consider your most successful teaching and/or mentoring experiences.

25. Are you willing to be contacted for further discussions?
This information is optional.

If you consent to be contacted, you may still request that your name or other identifying characteristics be removed.

Name:
Institution:
Email Address:

Annotated Bibliography

Contents

General

Alden, E. (2017) "ConfChem Conference on Select 2016 BCCE Presentations: Changing Roles for Changing Times — Social Media and the Evolution of the Supplemental Instructor." *Journal of Chemical Education* 94(12): 2007-2009. DOI: 10.1021/acs.jchemed.6b01012

This paper describes the need for updating classroom roles as the types of classrooms and pedagogies change. The authors focused on the supplemental instructor (SI) role in hybrid and blended classrooms. The SI is a point of contact the students can interact with and, in traditional classrooms, holds question/problem solving sessions. The authors use a two-semester general chemistry course as a case study explaining the connections and community that were built using a combination of online and in person interactions with the SI. Each semester used a slightly different format to explore how varying levels of activity affect student outcomes. It was found that a more active learning environment that allowed the SI to interact with students during the class created a better sense of community among the students and made them more likely to reach out to the SI.

Allen, D. and K. Tanner (2005) "Infusing Active Learning into the Large-enrollment Biology Class: Seven Strategies, from the Simple to Complex." *Cell Biology Education* 4(4): 262-268. DOI: 10.1187/cbe.05-08-0113

The authors give overviews of several active learning strategies that can be implemented in large enrollment classes without radical change. This paper provides a good overview of these strategies for instructors seeking active learning techniques and provides plenty of references for further reading. Strategies range from the short and simple, such as using discussion-prompting questions during lecture, to more involved approaches, such as problem-based learning and Workshop Biology.

Arthurs, L. A. and B. Z. Kreager (2017) "An integrative review of in-class activities that enable active learning in college science classroom settings." *International Journal of Science Education* 39(15): 2073-2091. DOI: 10.1080/09500693.2017.1363925

This analysis of 127 articles published between 1994-2014 found in the Education Resources Information Database (ERIC) pertaining to college science classrooms reviews the use of active learning practices. The authors found an increase in use of active learning activities across four dominant science disciplines. After looking for patterns they constructed the active learning strategy (ALS) model that divides active learning strategies based on social interdependence and peer interaction. They also propose the instructional decisions to enable active learning (IDEAL) theory for instructional decisionmaking. The ALS model and the IDEAL theory can be used to conceptualize many active learning possibilities and help instructors who might be overwhelmed to begin implementing active learning strategies in their classrooms.

Berk, R. A. (2005) "Survey of 12 Strategies to Measure Teaching Effectiveness." *International Journal of Teaching and Learning in Higher Education* 17(1): 48-62. *http://www.isetl.org/ijtlhe/pdf/IJTLHE8.pdf*

Berk surveys literature to determine the effectiveness of twelve strategies for evaluating teacher effectiveness. With a bit of humor, he describes peer ratings, self-evaluation, videos, student interviews, alumni ratings, employer ratings, administrator ratings, teaching scholarship, teaching awards, learning outcome measures, and teaching portfolios. Beck then summarizes each strategy with a "bottom line" recommendation on whether the strategy should be used (one he says should be used "with extreme caution"). Additionally, he discusses whether each strategy is appropriate for formative or summative evaluations.

Bhattacharyya, G. (2013) "From Source to Sink: Mechanistic Reasoning Using the Electron-Pushing Formalism." *Journal of Chemical Education* 90(10): 1282-1289. DOI: 10.1021/ed300765k

The author of the paper conducted a three-phase study to further understand mechanistic reasoning and use of electron-pushing formalism (EPF) in organic chemistry classrooms. The paper covers the process used to create a nationwide survey of organic chemistry faculty to better understand the definition of mechanistic reasoning and the skills necessary to develop it. Utilitarian skills were found to be the most important for this type of

thinking, some of which are taught after the introduction of EPF. Based on the type of skills found to be important for mechanistic thinking the authors question when mechanisms should be taught in organic chemistry classes.

Burke, C. J. and T. J. Atherton (2017) "Developing a project-based computational physics course grounded in expert practice." *American Journal of Physics* 85: 301-310. DOI: 10.1119/1.4975381

The authors present their first attempt at implementing a project-based course designed to develop computational skills in physics. Interviews with experts in the field and course syllabi were used to help determine the competencies expected of the students. Using the information gathered in the research the authors created a rubric and a project list to be used in class. The authors also tailored the course based on prior knowledge of the students in physics and computer science as well as in programming. They describe how they implemented these projects and adapted the class throughout the semester, as well as how they used student feedback to alter the class during the semester, for example by adjusting student group size. The authors also shared projects with the consulted experts in the field for feedback, which revealed that the students acquired aspects of expert practice. Overall the course showed many of the desired outcomes, but questions remain about the most effective ways to teach computation, whether through a dedicated course such as this, material distributed throughout the curriculum, or a combination.

Chasteen, S. V., K. K. Perkins, P. D. Beale, S. J. Pollock and C. E. Wieman (2011) "A Thoughtful Approach to Instruction: Course transformation for the rest of us." *Journal of College Science Teaching* 40(4): 24-30. *https://www.jstor.org/stable/42992874*

The University of Colorado (CU) and University of British Columbia Science Education Initiative have worked together to develop a model of research-based course transformation. The paper focuses on the use of education research to make updates in an upper-level science course at CU. The paper discusses the creation of learning goals and the use of student feedback to create change in the classroom. To determine if the changes made were effective, they used student surveys and attendance records for the class and additional group sessions. Maintaining a transformed classroom can be done through team teaching, finding faculty that support the transformation to continue teaching the class, archiving materials so other faculty have access, and having departmental support. The authors also offer advice for faculty who may feel overwhelmed by the process of course transformation.

Chasteen, S. V., S. J. Pollock, R. E. Pepper and K. K. Perkins (2012) "Thinking like a physicist: A multi-semester case study of junior-level electricity and magnetism." *American Journal of Physics* 80(10): 923-930. DOI: 10.1119/1.4732528

The authors describe the implementation of several nontraditional instructional techniques into an upper-level physics course. With input from

faculty and alumni, learning goals were developed for the redesigned course: mathematical sophistication, problem-solving expertise, and developing as a physicist. In addition to regular lectures, clicker questions, homework assignments, optional help sessions, and optional tutorials were added to the course. The redesigned course did not impact student performance on traditional exams compared with the traditional course. However, performance on a conceptual assessment was much improved with the redesigned course. This improved conceptual understanding suggests that the course redesign was successful in addressing the learning goals.

Cooper, K. M., V. R. Downing and S. E. Brownell (2018) "The influence of active learning practices on student anxiety in large-enrollment college science classrooms." *International Journal of STEM Education* 5(1): 23. DOI: 10.1186/s40594-018-0123-6

Science classes are rigorous, difficult, competitive, and often large, and science faculty have been described as unapproachable by the students. These elements can lead to greater prevalence of stress and anxiety. While some studies indicate low levels of anxiety can increase mental focus and performance, high anxiety leads to low grades and poor study skills. Active learning has been shown to be a more effective way to teach but there is little research into how these practices affect student anxiety. This study looks at clicker questions, group work, and cold calling and how these affect student anxiety. They found clicker questions and group work can increase anxiety when the students are concerned about what other students think about them or if they need to think too quickly. However, there are ways to use these activities in a more productive manner. Cold calling or random calling on students to answer questions in class was found only to increase student anxiety. Overall, many students have a fear of negative evaluation and that can make active learning environments stressful but if used in a way that takes this into account these practices can be beneficial to students.

Cooper, M. M. and R. L. Stowe (2018) "Chemistry Education Research-From Personal Empiricism to Evidence, Theory, and Informed Practice." *Chemical Reviews* 118(12): 6053-6087. DOI: 10.1021/acs.chemrev.8b00020

This article is a review of the development of chemical education research. The authors give a brief background on chemistry education and the development of learning theories. They discuss different learning theories and the unique challenges that come with teaching and learning science. Using learning theories and results from recent science education research they suggest students need help making connections between concepts and seeing how these relate to broader topics. They suggest designing new assessments that focus on deep understanding by students rather than repeating facts and using algorithms and that the results from these assessments should be used to redesign curriculum periodically to deepen understanding. The authors end by saying there is still much research to be done into which techniques work best and why.

DeHaan, R. L. (2005) "The Impending Revolution in Undergraduate Science Education." *Journal of Science Education and Technology* 14(2): 253-269. DOI: 10.1007/s10956-005-4425-3

In this review, the author briefly describes current research in several fields related to science education, addressing student learning, the role of undergraduate research in learning, the benefits of information technology, and institutional changes necessary to improve science teaching. The author covers a broad range of topics but does not address them in depth. This article should serve as a starting point for those wishing to broaden their knowledge regarding science learning by seeking the references described in this work.

DeHaan, R. L. (2011) "Teaching Creative Science Thinking." *Science* 334: 1499-1500. DOI: 10.1126/science.1207918

Science has many ill-structured problems that may have more than one solution or pathway to a solution, but not a lot of time has been spent on creative thinking for science students. Creativity can be developed through individual thinking and peer-peer interactions. The author suggests several short activities that could easily be worked into science classrooms that could help foster more creative and higher-order thinking. The author suggests more research be conducted on the relationship between creative thinking and problem solving in the sciences, but the activities suggested could be a convenient place to start.

Feinstein, N. W., S. Allen and E. Jenkins (2013) "Outside the Pipeline: Reimagining Science Education for Nonscientists." *Science* 340(6130): 314-317. DOI: 10.1126/science.1230855

This article focuses on how science educators can best serve students who will not go on to science careers — by teaching them to be "competent outsiders," or nonscientists who can thoughtfully interact with science that is relevant to their lives and communities. Important to the "competent outsider" is the ability to recognize important science, judge the validity of scientific claims, and find additional resources to understand unfamiliar concepts. These skills can be encouraged using techniques such as problem-based learning (PBL), Socio-Scientific Issue Discussions (SSID), and interest-driven student exploration. These methodologies are discussed, focusing on how each helps develop certain traits of the "competent outsider."

Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth (2014) "Active learning increases student performance in science, engineering, and mathematics" *Proceedings of the National Academy of Sciences, USA* 111(23): 8410-8415. DOI: 10.1073/pnas.1319030111

This meta-analysis of 225 studies on STEM teaching revealed that students taught with active learning performed better on exams and concept inventory tests than students taught only with traditional lecturing. Students taught with active learning also had an overall 12% decrease in failure rate in STEM courses. These effects held across course level, STEM discipline, majors vs. non-majors courses, and class size, although classes with fewer than 50 students showed the largest effects. The authors suggest that the increases in student performance and decreases in failure rates associated with active learning could increase student retention in STEM fields.

Granger, E. M., T. H. Bevis, Y. Saka, S. A. Southerland, V. Sampson and R. L. Tate (2012) “The Efficacy of Student-Centered Instruction in Supporting Science Learning.” *Science* 338(6103): 105-108. DOI: 10.1126/science.1223709

The paper reports on a large-scale comparison of student-centered and teacher-centered approaches to learning about space science in elementary school and found that the student-centered approach produced better learning outcomes.

Grove, N. P., M. M. Cooper, and E. L. Cox (2012) “Does Mechanistic Thinking Improve Student Success in Organic Chemistry?” *Journal of Chemical Education* 89(7): 850-853. DOI: 10.1021/ed200394d

The authors of this paper look at the use of mechanisms, specifically curved arrows, by second semester organic chemistry students. Students were given six reactions and asked to provide mechanisms and predict the product. Of these reactions four were the same as or like reactions they had seen in their courses. The last two required the students to apply knowledge to an unknown reaction. It was found that for the four reactions with which students were familiar, the use of a mechanism didn’t alter their ability to successfully predict a product. However, for the two reactions with which the students were unfamiliar, those that used a mechanism were more successful at predicting the product. This paper shows that mechanisms are most helpful for students when they need to use mechanistic thinking, like predicting an outcome for an unknown reaction, and that many students are not learning this type of thinking with the methods currently being used.

Haak, D. C., J. HilleRisLambers, E. Pitre and S. Freeman (2011) “Increased structure and active learning reduce the achievement gap in introductory biology.” *Science* 332(6034): 1213-1216. DOI: 10.1126/science.1204820

The authors investigated whether a highly structured course involving frequent practice with higher-order cognitive skills had a differential impact between disadvantaged and non-disadvantaged students. Previous work showed that using daily clicker questions, weekly practice exams, and a lecture-free format increased overall performance of students. Here, the authors compared biology students in a program for educationally or economically disadvantaged students to the general population of biology students and found that all students benefited from active learning, and disadvantaged students benefitted even more than the general population. Further, because the change to active learning increased the difficulty level of exam questions, based on Bloom's taxonomy, the better performance shows that students are actually learning more.

Halme, D. G., J. Khodor, R. Mitchell and G. C. Walker (2006) "A Small-Scale Concept-based Laboratory Component: The Best of Both Worlds." *CBE-Life Sciences Education* 5(1): 41-51. DOI: 10.1187/cbe.05-02-0065

This paper describes a voluntary, small-scale laboratory component to accompany introductory biology at MIT following the Biology Concept Framework (BCF) (Khodor, Cell Biology Education, 2004). Several goals were articulated for the laboratory, such as making abstract concepts tangible and highlighting connections between different topics in the course. To achieve these goals, a combination of hands-on and minds-on activities were developed. The students who volunteered reported high expectations of the laboratory, but that these expectations were met or exceeded. Additionally, the laboratory improved student learning and retention of concepts.

Handelsman, J., D. Ebert-May, R. Beichner, P. Bruns, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Stewart, S. M. Tilghman and W. B. Wood (2004) "Scientific Teaching." *Science* 304(5670): 521-522. DOI: 10.1126/science.1096022

This Policy Forum piece presents an overview of ideas for implementing and supporting scientific, research-based active learning strategies, with several successful courses and programs briefly described. Methods are introduced that can improve or even replace lectures, including the use of computer systems and inquiry-based activities. Additionally, several strategies are discussed to encourage scientists to become better teachers, such as restructuring reward systems, providing funds for new faculty to attend education workshops, and incorporating education about teaching into graduate programs. The supplemental materials, available online, provide many references for additional reading, as well as lists of online teaching resources and scientific teaching methods.

Henderson, C., M. Dancy and M. Niewiadomska-Bugaj (2012) "Use of research-based instructional strategies in introductory physics: Where do faculty leave the innovation-decision process?" *Physical Review Special Topics - Physics Education Research* 8(2): 020104. DOI: 10.1103/PhysRevSTPER.8.020104

This paper describes the results of an online survey of physics faculty members regarding their use of research-based instructional strategies (RBIS). Respondents were asked their level of familiarity with various forms of instruction such as Peer Instruction, Workshop Physics, and Interactive Lecture Demonstrations. The study shows that 23% of faculty have used RBIS previously but no longer do so; this figure represents 1/3 of faculty who have tried RBIS. Additionally, respondents reported on twenty factors the study authors believed might influence the decision to use or continue to use RBIS, such as professional development workshops, class size, and instructor age. The study authors found that new faculty workshops were successful in introducing faculty to RBIS, but do not help the faculty continue to use RBIS. The report emphasizes that it is important to find ways to help faculty to continue using RBIS.

Henderson, C., R.Khan, and M. Dancy (2018) "Will my student evaluations decrease if I adopt an active learning instructional strategy?" *American Journal of Physics* 86(12): 934-942. DOI: 10.1119/1.5065907

Many instructors fear their student evaluations will go down if they implement active learning strategies in the classroom. This is a concern since student evaluations are often used as a measure of teaching quality. The authors surveyed physics instructors who had attended a new faculty workshop (NFW) and had taught an introductory quantitative physics course. The authors focused on the NFW as it was used to introduce new faculty to the idea and practices of active learning. The survey results indicate that most evaluations stayed the same or increased and most students did not complain about the new methods. The authors also found that there was a correlation between the amount of time lecturing and student satisfaction. The authors point out there is still much to study on this point as the survey used here relied on self-reporting and did not show change in evaluations over time. The authors report most students enjoy the active learning style but those who are nervous should start with moderate changes and to be attentive to student feedback and response.

Jenkinson, J. (2018) "Molecular Biology Meets the Learning Sciences: Visualizations in Education and Outreach." *Journal of Molecular Biology* 430: 4013-4027. DOI: 10.1016/j.jmb.2018.08.020

Visualization is used in a variety of ways to assist in the understanding of molecular biology. The molecules and mechanisms studied in this class are on a small scale and can be difficult for students to conceptualize. The authors of this paper discuss the use of 3D graphics, pictures, cartoons, animations, interactive simulations and games to better understand the processes studied. While these are great tools each different representation has its own limitations, some of which are discussed in this article. There are also not always systems in place for checking the validity of these visualizations. The best practice is for teachers to use a variety of visualizations and to consider the limitations of the chosen options when discussing them with the students.

Khodor, J., D. G. Halme and G. C. Walker (2004) "A Hierarchical Biology Concept Framework: A Tool for Course Design." *Cell Biology Education* 3(2): 111-121. DOI: 10.1187/cbe.03-10-0014

The authors describe the development of the Biology Concept Framework

(BCF) to organize the course material from introductory biology. The BCF is hierarchical, with concepts organized by order of importance under “top-level” concepts. Additionally, concepts are cross-referenced, which is helpful for ideas that come up in multiple contexts. The article discusses motivation for and development of the BCF as well as its application.

Kind, V. (2004) Beyond Appearances: students’ misconceptions about basic chemical ideas (2nd ed.). *School of Education*. Durham, UK, Durham University. *https://edu.rsc.org/resources/beyond-appearances/2202.article*

This report addresses common misconceptions about chemistry. Though it focuses on students aged 11-18, these misconceptions may carry over to undergraduates taking chemistry for the first time. The author discusses misconceptions, speculates on their origins, and presents strategies for teaching to correct these misconceptions.

Mazur, E. (2009) “Farewell, Lecture?” *Science* 323(5910): 50-51. DOI: 10.1126/science.1168927

Wonderfully written short piece on why we should lecture less and instead guide students as they learn on their own.

Michael, J. (2006) “Where’s the evidence that active learning works?” *Advances in Physiology Education* 30(4): 159-167. DOI: 10.1152/advan.00053.2006

A review of literature on active learning techniques that includes helpful references and a list of relevant journals.

Modell, H. I. and J. A. Michael (1993) “Promoting Active Learning in the Life Science Classroom: Defining the Issues.” *Annals of the New York Academy of Sciences* 701: 1-7. DOI: 10.1111/j.1749-6632.1993.tb19770.x

This paper discusses several important ideas for active learning. The authors note that active learning is important for the development of problem-solving skills and appreciation of science. The role of student and teacher is different in an active learning classroom from a traditional lecture classroom, where the rationale behind each step in each activity is important. Students must be present and actively participate. The teacher must help the student learn, rather than simply disseminating information. Another important aspect of active learning is ongoing assessment to make sure students are properly prepared in addition to determining what they are learning. The authors also discuss educational objectives, learning resources, and learning environments for an active learning classroom.

Olmsted, J. (1999) “The Mid-Lecture Break: When Less Is More.” *Journal of Chemical Education* 76(4): 525-527. DOI: 10.1021/ed076p525

The use of “mid-lecture breaks” is described, a quick 2-3 minute break in lecture meant to increase student attention. These breaks allow students to recharge their brains, but also encourage student involvement. The breaks can be used for in-class assessment of material, the instructor, instructional

techniques, or many other aspects of the course. Students consistently rate the mid-lecture break as their favorite aspect of the course. This method represents a simple and quick method to increase student involvement.

Olsson, K. A., M. M. Balgopal and N. E. Levinger (2015) "How Did We Get Here? Teaching Chemistry with a Historical Perspective." *Journal of Chemical Education* 92(11): 1773-1776. DOI: 10.1021/ed5005239

Students could better understand the nature of science and scientific practices involved in research if they learned about the history of science. It is important to learn how discoveries were made; not just what discoveries were made. The authors of this paper suggest a course for science educators on the history of science. The article outlines recommended topics, assessments, and pedagogical strategies for this course. The authors believe their recommendations will create a class for educators to learn a more in-depth history of science. They also suggest teachers add history of science components to their class to help students better understand science.

Riffell, S. and D. Sibley (2005) "Using web-based instruction to improve large undergraduate biology courses: An evaluation of a hybrid course format." *Computers & Education* 44(3): 217-235. DOI: 10.1016/j.compedu.2004.01.005

A hybrid format course is compared to a traditional course. In the hybrid course, two class meetings of three each week were substituted with online homework assignments; the third class session consisted of active lectures. The hybrid course was compared to a traditionally taught course with two passive and one active lecture per week taught concurrently. The students in the hybrid course performed better than students in the traditional course. Additionally, students in the hybrid course used their textbooks much more frequently, with 80% of students reporting that they used the textbook twice a week or more.

Schearer, W. R. (1988) "Beyond the traditional lecture system of teaching chemistry: organic chemistry." *Journal of Chemical Education* 65(2): 133-136. DOI: 10.1021/ed065p133

The paper describes how study sheets are used to improve organic chemistry lectures. The study sheets are one-page outlines of each major topic, including the major types of questions students should be able to answer and textbook problems to check understanding of the topics. Before the relevant lecture, students are expected to go through the study sheet systematically. This allows them to better understand the lecture and ask more questions. The author does not include analysis of effectiveness or student satisfaction with the study sheets, however.

Smith, A. L. and S. L. Keller (2006) "Advice for New Faculty Teaching Undergraduate Science." *Journal of Chemical Education* 83(3): 401-406. DOI: 10.1021/ed083p401

The authors compiled advice received regarding managing time as a first-year faculty member. Included are tips on choosing what courses to teach, managing time outside of the classroom, effectively creating and using a syllabus and course website, creating and grading exams and homework, and getting help from students, TAs, and colleagues.

Spelt, E. J. H., H. J. A. Biemans, H. Tobi, P. A. Luning and M. Mulder (2009) "Teaching and Learning in Interdisciplinary Higher Education: A Systematic Review." *Educational Psychology Review* 21(4): 365-378. DOI: 10.1007/s10648-009-9113-z

The problems being faced in the world today are complex in nature and boundary crossing, suggesting a shift away from narrowly focused education. Due to this there has been an increased call for interdisciplinary higher education. The authors conducted a literature search using four databases to find the most recent articles on interdisciplinary thinking. They focused their search on articles that contained empirical evidence and studies conducted in a higher education setting. They conducted a critical review of the articles through the lens of the theory of Biggs (2003). This theory had them focusing on the four components of teaching and learning: student, learning environment, learning process, and learning outcomes. The authors used the critical review to determine the characteristics of each component that was important for higher-order learning. They discuss these characteristics in the article.

Stains, M., J. Harshman, M. K. Barker, S. V. Chasteen, R. Cole, S. E. DeChenne-Peters, M. K. Eagan, Jr., J. M. Esson, J. K. Knight, F. A. Laski, M. Levis-Fitzgerald, C. J. Lee, S. M. Lo, L. M. McDonnell, T. A. McKay, N. Michelotti, A. Musgrove, M. S. Palmer, K. M. Plank, T. M. Rodela, E. R. Sanders, N. G. Schimpf, P. M. Schulte, M. K. Smith, M. Stetzer, B. Van Valkenburgh, E. Vinson, L. K. Weir, P. J. Wendel, L. B. Wheeler and A. M. Young (2018) "Anatomy of STEM teaching in North American Universities." *Science* 359(6383): 1498-1470. DOI: 10.1126/science.aap8892

It has been shown that interactive learning is more beneficial to students. There is a push to incorporate more interactive learning into STEM classrooms but the research currently available for teaching relies heavily on self-reporting surveys. The paper presents a study of 2000 classes taught by 50 different faculty at 25 institutions. Classroom Observation Protocol for Undergraduate STEM (COPUS) was used to assess the different classes. The COPUS focuses on documenting teacher and student behaviors in the classroom. The authors looked at eight specific behaviors and used these to cluster the observations into seven instructional profiles. These clusters allowed the authors to look at prevalence, trends, and examine if and how different factors, like classroom setup or course level, affected teaching style. There was no correlation between teaching style and course level. Instructors vary their teaching styles from day to day so at least four visits are required for an accurate picture. There are no indications that classroom layout or class size affect the ability to use interactive learning practices. To encourage more instructors to use student-centered methods there should be a change in promotion criteria and more research should be conducted to get a bigger picture of teaching strategies.

Stains, M. and T. Vickrey (2017) "Fidelity of Implementation: An Overlooked Yet Critical Construct to Establish Effectiveness of Evidence-Based Instructional Practices." *CBE Life Sciences Education* 16(1). DOI: 10.1187/cbe.16-03-0113

There has been an increase in research to enhance how STEM subjects are taught to students. The result of these studies has been an increase in evidence-based instructional practices (EBIP). However, assessing the efficacy of these practices is still difficult. This article introduces a framework that can be used to measure the fidelity of implementation (FOI) of a new instructional practice. The authors suggest determining the critical components of the EBIP and varying levels of implementation of these critical components. The authors break down the critical components into structural and procedural components. The materials and activities necessary for a practice were considered structural components. The expected student behaviors and the expected instructor behaviors were considered procedural. This information can be used to develop a tool specific to each EBIP to understand outcomes. The authors apply the FOI tool to peer instruction, a commonly used EBIP, as an example and test case.

Stassun, K. G., S. Sturm, K. Holley-Bockelmann, A. Burger, D. J. Ernst and D. Webb (2011) "The Fisk-Vanderbilt Master's-to-Ph.D. Bridge Program: Recognizing, enlisting, and cultivating unrealized or unrecognized potential in underrepresented minority students." *American Journal of Physics* 79(4): 374-379. DOI: 10.1119/1.3546069

The authors describe a master's program designed to increase underrepresented minority (URM) students in Ph.D. programs. The program serves as a pipeline, but not a direct entry point for physics Ph.D. programs and focuses on preparing URM students for success at the Ph.D.-level. The paper describes the admission process, which focuses on student potential by such metrics as passion, motivation, drive, and leadership. Additionally, the paper describes the refinement of potential in these students through mentoring, research and presentation opportunities, and holistic skills such as time management.

Tanner, K. D. (2013) "Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity." *CBE Life Sciences Education* 12(3): 322-331. DOI: 10.1187/cbe.13-06-0115

The author offers 21 teaching strategies to help promote equity in the classroom. The teaching strategies are organized into five categories or goals to help the reader choose the activity to help most with their intended outcome. Each goal has a short explanation of the importance for the students and several suggested strategies that align with the goal. A small explanation of how the strategy can help the students and a few examples are included for each strategy. The suggested strategies range from increasing wait time after a question is asked to using active learning strategies, to learning all the students' names. A self-assessment is included to help the reader determine which strategies might be most useful to them. The author encourages the reader to use these examples as a starting point but to continue to look for or create the ideal strategy for each individual classroom.

Thiry, H., S. L. Laursen and A.-B. Hunter (2016) "What Experiences Help Students Become Scientists? A Comparative Study of Research and other Sources of Personal and Professional Gains for STEM Undergraduates." *The Journal of Higher Education* 82(4): 357-388. DOI: 10.1080/00221546.2011.11777209

The authors conducted interviews with 26 undergraduate STEM students at four colleges that offer undergraduate research opportunities on campus. Of the students interviewed 42% had participated in some research experience or extracurricular activity and the rest had only classroom experiences. The students self-reported how their experience had affected them in areas like becoming a scientist, gaining confidence, and education/career path. The authors found that research experiences outside the classroom were most beneficial to students developing into scientists. Other activities outside the classroom were beneficial but they did not have the same effects as research opportunities. The authors also noted that the quality of the research experience affected student reported outcomes as well.

Tinto, V. (2016) "Classrooms as Communities: Exploring the Educational Character of Student Persistence." *The Journal of Higher Education* 68(6): 599-623. DOI: 10.2307/2959965

Students learn better and more fully when the classroom becomes a community. The author compares students taking a coordinated studies program (CSP) with students taking standard stand-alone classes at a local community college. The CSP rolls several classes representing multiple disciplines, usually spanning the Humanities Division but occasionally expanding into other divisions, into one class that meets several times a week with the same students in every meeting. The author describes how these consistent meetings create a community atmosphere encouraging deep conversations about science both in and out of the classroom. The author interviewed students from the CSP and found they felt they learned better, more deeply, and persisted in their fields when compared to students in standard classes. The author used interviews with the CSP students, students in traditional classes, and student records to collect information. Student learning, feelings of community, and persistence in the field were the focus of the study. The author notes that programs like this can be an option for many schools to help increase persistence. This program was helpful in a commuter-heavy situation like a community college and is likely to be helpful in many other programs with high rates of on-campus housing where communities are easier to form.

Trahanovsky, W. S. (1968) “A nontraditional approach to teaching organic chemistry: The “note-test” system.” *Journal of Chemical Education* 45(8): 536. DOI: 10.1021/ed045p536

The author describes a “note-test” teaching method. In this method, students receive lecture notes prior to the start of the three-day cycle. In the first day of the cycle, the instructor covers highlights from the notes, and then opens the class for questions. The question session is continued on the second day. The third day consists of a 30-minute exam covering the material from the lecture notes, followed by discussion of the exam. Students are given hourlong lectures every three to four cycles. This method takes minimally more time than preparing lectures and covers the same amount of material, but the responsibility for learning is more clearly placed on the student.

White, H. (2011) “How to Construct a Concept Map.” Retrieved July 9, 2013, from *http://www.udel.edu/chem/white/teaching/ConceptMap.html.*

This website gives a brief overview of concept maps and helpful steps for creating concept maps. Additionally, the page has several helpful links for more information on concept maps.

Wood, W. B. and K. D. Tanner (2012) “The Role of the Lecturer as Tutor: Doing What Effective Tutors Do in a Large Lecture Class.” *CBE-Life Sciences Education* 11(1): 3-9. DOI: 10.1187/cbe.11-12-0110

The authors examine the differences between learning by one-on-one tutoring or in a large lecture class. Characteristics of effective tutors are discussed, as well as implementation strategies for these characteristics. Most important, the author describes many ways for the lecturer of a large-enrollment class to translate these strategies to their classrooms.

How Can You Incorporate Active Learning into Your Classroom? *https://twut.nd.edu/PDF/ActiveLearningContinuum.pdf* Retrieved December 29, 2019, and see Paulson, D.R., and J.L. Faust Active and cooperative learning. Retrieved December 29, 2019, from California State University, L.A. Web site: *http://www.calstatela.edu/dept/chem/chem2/Active/*

A list of several active learning techniques with short explanations of each technique. The techniques are listed from simplest to incorporate to more time-consuming practices. This is only a small list of some of the many options but a good place to start. The Paulson and Faust site provides a longer list as well as more detailed descriptions for implementation.

Assessment of Student Learning

Brandriet, A. R. and S. L. Bretz (2014) “The Development of the Redox Concept Inventory as a Measure of Students’ Symbolic and Particulate Redox Understandings and Confidence.” *Journal of Chemical Education* 91(8): 1132-1144. DOI: 10.1021/ed500051n

The authors discuss the design and validation of a concept inventory to test understanding of redox chemistry. The authors used a qualitative study to design the concept inventory which was subjected to validation interviews and a few revisions to ensure the inventory was not ambiguous or misleading. The final draft of the inventory was used in a study of general chemistry 1 and 2 students at a liberal arts college. It was found, through the use of statistical analysis, the inventory could measure student understanding in a reliable and valid manner. The inventory is useful for students to gauge understanding and for instructors to measure the effectiveness of their classroom pedagogy.

Buck, L. B., S. L. Bretz and M. Towns (2008) “Characterizing the Level of Inquiry in the Undergraduate Laboratory.” *Journal of College Science Teaching* 38(1): 52-58. *www.jstor.org/stable/42993237*

Many researchers have called for an increase in inquiry-based learning in science classrooms. However, there is no clear definition or understanding of what inquiry means. This makes it difficult for researchers to understand the effect this style of learning has on student success because it can be used to describe a variety of teaching styles and methods. The authors of this paper create a rubric they hope will eliminate some of the discrepancies by focusing on common catch phrases associated with inquiry. The rubric uses discrete levels of student independence across six characteristics, problem/questions, theory/background, design, analysis of the results, communication of results, and conclusions. The levels of student independence range from highly structured, or confirmation labs, to highly unstructured, or authentic inquiry. To validate the rubric so it could be used successfully across multiple disciplines, the rubric was used to assess 386 lab activities from a variety of science disciplines. The rubric was found to be a good resource to evaluate the inquiry level of different laboratory classes.

Corwin, L. A., C. Runyon, A. Robinson and E. L. Dolan (2015) “The Laboratory Course Assessment Survey: A Tool to Measure Three Dimensions of Research-Course Design.” *CBE-Life Sciences Education* 14(4): ar37. DOI: 10.1187/cbe.15-03-0073

Course-based undergraduate research experiences (CUREs) allow undergraduate research experiences to be scaled-up by turning laboratory classes into group research projects. The use of CUREs has been widespread but more information on the features that make them successful needs to be obtained. The authors created a survey to investigate lab course design that focuses on features commonly associated with CUREs. The features that were the focus of the survey are collaboration, discovery, relevance, and iteration. The survey was validated by administration to biology students in both traditional laboratory courses and CUREs. The survey found differences between students in the two lab types in the iteration and discovery and relevance features but not in collaboration. The authors hypothesize that lab environments generally encourage collaboration but would like to further investigate the types of collaborations and knowledge sharing that occur in each laboratory type. The authors suggest this survey could be used by instructors to assess their labs and compare outcomes between different types of courses being offered.

Crowe, A., C. Dirks, and M. P. Wenderoth (2008) "Biology in Bloom: Implementing Bloom's Taxonomy to Enhance Student Learning in Biology." *CBE-Life Sciences Education* 7(4): 368-381. DOI: 10.1187/cbe.08-05-0024

The authors present the Blooming Biology Tool (BBT) based on Bloom's Taxonomy to better assess biology students. The paper includes a brief overview of Bloom's Taxonomy, and then introduces the tool for use as a general guide for instructors and students. Additionally, the Bloom's-based Learning Activities for Students (BLASt) is introduced, which describes study activities geared toward each level of Bloom's Taxonomy. The authors also include three examples of very different implementations of the BBT into biology courses. In a laboratory course, students were expected to develop an NIH-style research proposal, which was graded using specific aims based on the BBT. Here, initial work on the research proposal, including collection of preliminary data, was done in groups while individual students wrote the final proposal. In a large lecture course, students were taught Bloom's Taxonomy and were expected to rank in-class questions by their Bloom's level. After exams, the instructor presented how the class performed at each level of Bloom's assessed by the exam. Additionally, students could access their individual Bloom's scores. Students were directed to BLASt to help improve their performance at each level of Bloom's. A third course using the BBT was a workshop course, where students were trained in Bloom's, then developed, answered, and critiqued their own questions at various levels of Bloom's Taxonomy.

Elmgren, M., F. Ho, E. Åkesson, S. Schmid and M. Towns (2014) "Comparison and Evaluation of Learning Outcomes from an International Perspective: Development of a Best-Practice Process." *Journal of Chemical Education* 92(3): 427-432. DOI: 10.1021/ed500542b

The use of learning outcomes has become common practice in chemistry programs. They help shift the focus of learning from the teacher to the student, therefore encouraging student-centered education. They can also stifle creativity of both the student and the teacher if they are written too narrowly. To create useful learning outcomes there needs to be discussion about what skills and knowledge a student should have. Many places have written learning outcomes, but it is difficult to compare them within the different levels of a university to see if the ideas are consistent. It is also difficult to compare the learning outcomes at the same level across universities around the world. IUPAC created a tool for comparison and discussion of learning outcomes. A matrix was created that can be used to compare various documents and facilitate discussions that would be used to increase the quality of learning outcomes but not force conformity. To test their matrix the IUPAC brought together chemistry educators and education researchers from the USA, Sweden, Germany, Australia, Finland, France, and The Netherlands to compare the documented learning outcomes within their universities and across nations. It was found the matrix, when coupled with deep discussions, can be helpful to determine necessary learning outcomes, how to focus lessons to meet learning outcomes, and how to assess the learning outcomes.

Harris, C. J., J. S. Krajcik, J. W. Pellegrino and K. W. McElhaney (2016) "Constructing Assessment Tasks that Blend Disciplinary Core Ideas, Crosscutting Concepts, and Science Practices for Classroom Formative Applications." Menlo Park, CA: *SRI International*. *https://www.sri.com/publication/constructing-assessment-tasks-that-blend-disciplinary-core-ideas-crosscutting-concepts-and-science-practices-for-classroom-formative-applications/*

The article presents an approach to designing new assessments of science proficiency. The authors use evidence-based design principles to develop methods to measure knowledge-in-use. Knowledge-in-use is described as using science knowledge to solve a problem or develop a theory, and it is a central component of the U.S. Next Generation Science Standards (NGSS). The NGSS suggests performance expectations that combine practice, ideas, and crosscutting concepts into one statement to be used in place of separate learning goals for ideas and abilities. To illustrate their idea the authors describe how to break down a performance expectation into the three concepts and break down the concepts into the essential elements. These essential elements are used to design the assessments. The authors present two assessment examples for the performance expectation discussed in the article. Since these performance expectations can be crafted for any class at any level, this process can be used to create assessments for any level.

Jacobs, L. C. (December 14, 2004) "How to Write Better Tests: A Handbook for Improving Test Construction Skills." Retrieved July 5, 2020, from *http://institutionalmemory.iu.edu/aim/bitstream/handle/10333/9104/CTLA_BetterTests_2004.pdf*

This handbook offers practical advice, suggestions, and arguments for writing tests to more accurately assess students on educational objectives. Included are tips for planning the test, such as preparing a table of contents and objectives (such as Bloom's levels). The bulk of the handbook is devoted to test formats, starting with how to consider what is being measured, class size, and time available when choosing test formats. Several test formats are discussed in detail — essay, multiple choice, true-false, matching, and completion. Strengths and weaknesses of several formats are discussed, as well as strategies for writing and scoring these formats. Additionally, strategies for writing essay and multiple choice questions at different Bloom's levels are presented with some examples.

Klionsky, D. J. (2001) "Constructing Knowledge in the Lecture Hall." Journal of College Science Teaching 31(4): 246. *http://www.nsta.org/store/product_detail.aspx?id=10.2505/4/jcst01_031_04_246*

The author describes a strategy to encourage students to read and study consistently outside of class. Lecture notes are given in advance of the class in lieu of textbook reading assignments. These notes include an outline as well as "guideline questions," which are questions on key concepts from the reading that students should be able to answer. Additionally, some lecture time was replaced with problem-solving sessions. No exams or finals were given; instead, students were graded on daily reading and concept quizzes only. This approach has many advantages, such as increased participation and frequent feedback. Weaknesses are also addressed, such as the amount of time necessary to implement the strategy. The author also makes a comparison to lecture-only courses and found that students rated the course higher when this strategy was used. Students also performed better than in a lecture-only version of the course.

Lemons, P. P. and J. D. Lemons (2013) "Questions for Assessing Higher-Order Cognitive Skills: It's Not Just Bloom's." *CBE-Life Sciences Education* 12(1): 47-58. DOI: 10.1187/cbe.12-03-0024

The authors observed discussions regarding the use of Bloom's Taxonomy in biology to write higher-order cognition questions. While Bloom's language was often used, other ideas were used to classify questions as higher order or lower order. Difficulty, including the time required to answer the question and student experience with the question type, was often used in classifying a question. By studying biologists' views of higher-order cognition questions, the authors suggest additional research that can be done regarding these questions.

Luxford, C. J. and S. L. Bretz (2014) "Development of the Bonding Representations Inventory to Identify Student Misconceptions about Covalent and Ionic Bonding Representations." *Journal of Chemical Education* 91(3): 312-320. DOI: 10.1021/ed400700q

Concept inventories have been shown to be useful methods to assess student understanding. Inventories have been created for ionic/covalent bond learning assessment but there have not been any created to assess student understanding of the many different methods of depicting bonding

in chemistry. This article presents the development of a concept inventory to identify misconceptions of bonding and bonding theory by general chemistry undergraduate, AP, and high school students. The authors used interviews with general chemistry students to develop the questions and answers used in the concept inventory. These interviews allowed the authors to focus on the most common misconceptions. The finalized concept inventory was administered to students across the three levels of chemistry education of interest in this study. Using statistical analysis, it was found that the concept inventory was an appropriate difficulty level for all three student classifications, and was valid and reliable. The concept inventory used in this article was a quick, easy, and efficient tool for instructors to test understanding of bond theory.

Luxford, C. J. and T. A. Holme (2015) "What Do Conceptual Holes in Assessment Say about the Topics We Teach in General Chemistry?" *Journal of Chemical Education* 92(6): 993-1002. DOI: 10.1021/ed500889j

To investigate topic coverage holes in general chemistry courses, the authors compiled a database of 2000 questions used on the past American Chemical Society (ACS) general chemistry exams. ACS general chemistry exams are created by committees of chemistry experts and therefore are considered be good representations of the topics covered in general chemistry courses. An anchoring concepts content map (ACCM) was created for general chemistry topics. The map starts with big topics called anchoring concepts and breaks them down into detailed content statements. The question topics from the exams were put into each of the categories on the ACCM to look for trends and holes in topics covered. Several holes were found in the content knowledge covered on the exams, indicating there is likely a content hole in the topics covered in general chemistry courses. The authors suggest these areas can be used as guidance for instructors who are trying to broaden the coverage of their chemistry courses.

Narloch, R., C. P. Garbin, and K. D. Turnage (2006) "Benefits of Prelecture Quizzes." *Teaching of Psychology* 33(2): 109-112. DOI: 10.1207/s15328023top3302_6

Graded, in-class quizzes at the beginning of each new chapter were assessed as a tool to encourage class preparedness. Quizzes were at the knowledge level of Bloom's Taxonomy, while cumulative exams were at higher levels. Results showed that the quiz sections performed better on exams, spent more time preparing for class, less time preparing for exams, and asked higher order questions in class than sections without quizzes.

Raker, J. R. and M. H. Towns (2012) "Designing undergraduate-level organic chemistry instructional problems: Seven ideas from a problem-solving study of practicing synthetic organic chemists." *Chemistry Education Research and Practice* 13(3): 277-285. DOI: 10.1039/C1RP90073K

It has been suggested that making studying science more like doing science would help increase student retention in the science fields. The authors examined many problems discussed in sophomore organic chemistry courses. Then, working with many skilled organic chemistry practitioners, they developed new organic chemistry problems. The authors suggest seven ideas that could be used to develop problems that are more like those faced by practicing chemists to coincide with the movement of making learning science more like doing science. The authors used these ideas to develop a few questions and asked students to solve them. The authors suggest more research should be done to determine how more questions like this could be used and how they affect student learning and skill development.

Semsar, K., J. K. Knight, G. Birol and M. K. Smith (2011) "The Colorado Learning Attitudes about Science Survey (CLASS) for use in Biology." *CBE Life Sciences Education* 10(3): 268-278. DOI: 10.1187/cbe.10-10-0133

The article describes the adaptation of the CLASS-physics survey for use in biology. The survey compares student perceptions to that of experts in the field. The survey comprises questions from the physics and chemistry surveys and questions developed specifically for this survey. The survey was examined by students and experts in the field for clarity and expert opinion and then administered for validation. The survey showed students in upper-level biology classes came in with more expert-like thinking than students in general biology courses and maintained their scores after finishing their classes. Students in general biology courses had more novice-like thinking after taking the course than when entering. This was found to be similar to results from the other CLASS surveys. The information from this survey can be used to better understand the perceptions of the students entering and persisting in the biology courses as well as measures of pedagogical reform on student perceptions.

Shea, K. M., D. J. Gorin and M. E. Buck (2016) "Literature-Based Problems for Introductory Organic Chemistry Quizzes and Exams." *Journal of Chemical Education* 93(5): 886-890. DOI: 10.1021/acs.jchemed.5b00937

The authors present their use of literature in two organic chemistry courses. In organic chemistry I the students are presented an organic synthesis paper relating to a recently discussed topic. The students have time to study the article and work with their classmates to understand it before they are given a take-home quiz. In organic chemistry II the students are given a recent paper that relates to topics that have been previously covered during the semester. The students have time to study the article and are encouraged to work with their peers. The students are given an exam that contains questions relating to the article. The authors have found giving the students quizzes and exams relating to the papers encourages them to think more deeply and spend more time on the articles than other types of assessments. The students in the classes have had positive feedback regarding the assignments and have given positive reviews for the course.

Stull, J. C., D. M. Majerich, M. L. Bernacki, S. J. Varnum and J. P. Ducette (2011) "The effects of formative assessment pre-lecture online chapter quizzes and student-initiated inquiries to the instructor on academic achievement." *Education Research and Evaluation: An International Journal on Theory and Practice* 17(4): 253-262. DOI: 10.1080/13803611.2011.621756

The authors examine the effect of formative assessment in the form of online quizzes and contact with the instructor outside of class on student performance. Two sections were compared: one was taught traditionally, whereas the experimental section used formative assessment. Online quizzes were available for each chapter; students were given immediate feedback after completing the quizzes. Additionally, student contact by email and in-person with the instructor was logged and categorized as an "administrative" or "content" based contact. Analysis of performance revealed that quiz completion correlated positively with course performance.

Williams, A. E., N. M. Aguilar-Roca, M. Tsai, M. Wong, M. M. Beaupre and D. K. O'Dowd (2011) "Assessment of Learning Gains Associated with Independent Exam Analysis in Introductory Biology." *CBE-Life Sciences Education* 10(4): 346-356. DOI: 10.1187/cbe.11-03-0025

This paper describes a study on the effectiveness of a "learn from exam" homework activity, in which students examine a midterm question answered incorrectly by a large portion of the class. Prior to the homework activity, students are given a brief lecture on how to analyze a question. To evaluate this activity, students were assigned to evaluate two of four questions from a midterm exam; these questions were then paired with final exam questions which were identical, had a similar emphasis, or had a different emphasis. The authors observed significantly better performance on final exam questions when the students had analyzed the matched midterm question for some of the questions used. Further analysis revealed that when the emphasis of the question was the same, students answered the matched question correctly half of the time. The authors also found that if the emphasis of the final exam question was changed, the effect of the activity was diminished. Overall, this activity improves student performance in subsequent exams on similar topics. Additionally, the activity teaches students important self-regulated learning skills that can be applied to future courses.

Classroom Demonstrations

Bowen, C. W. and A. J. Phelps (1997) "Demonstration-Based Cooperative Testing in General Chemistry: A Broader Assessment-of-Learning Technique." *Journal of Chemical Education* 74(6): 715-719. DOI: 10.1021/ed074p715

The paper discusses using classroom demonstrations as a means of assessing students. Several demonstration-based assessment activities are discussed: separate demonstration-based quizzes, and exams containing demonstrations. For exams, the demonstration can be given during the exam period, and questions related to the demonstration are included in the exam. Alternatively, the demonstration can be given in advance of the exam, and students are given questions about the demonstration to work on in groups outside of class. The authors present several examples of chemistry demonstrations and questions that can be used for assessment. In a small study, the authors compared two sections of general chemistry where one section had demonstration-based questions as part of exams. The students tested using demonstrations showed better performance on concept-based questions on the concepts illustrated by demonstrations, showing that demonstration-based assessment can increase conceptual understanding.

Crouch, C., A. P. Fagen, J. P. Callan and E. Mazur (2004) "Classroom demonstrations: Learning tools or entertainment?" *American Journal of Physics* 72(6): 835-838. DOI: 10.1119/1.1707018

The authors examined three different modes of presenting demonstrations in an introductory physics course: the demonstration followed by instructor explanation (observe), the demonstration following a chance for students to predict the outcome of the demonstration from several options (predict), or the demonstration with a chance to predict and discuss the outcome prior to the demonstration (discuss). At the end of the semester, the observe group displayed no greater understanding of the concepts presented in demonstrations compared to a control group (no demonstration). Both predict and discuss groups understood the concepts better than the control group, with only a slight improvement with the addition of the discuss component. By giving students the opportunity to predict outcomes of demonstrations, which only take an additional two minutes, students are able to better understand and retain information from demonstrations.

Communication

Cirino, L. A., Z. Emberts, P. N. Joseph, P. E. Allen, D. Lopatto and C. W. Miller (2017) "Broadening the voice of science: Promoting scientific communication in the undergraduate classroom." *Ecology and Evolution* 7(23): 10124-10130. DOI: 10.1002/ece3.3501

It is important for scientists to learn how to communicate their science effectively across multiple platforms. Unfortunately, there are often few chances for undergraduate students to learn the skills necessary to communicate their science. The goal of this paper is to highlight the possibility of students in a research laboratory conducting research and learning how to communicate that research at the same time. The students in this study were involved in research both in and out of the classroom and had at least one semester of previous research experience. They met weekly and were asked to complete a research talk, a one-minute research monologue, and a research poster. Student learning was investigated using the CURE survey (Lopatto 2008). The answers from the students in the study were compared to answers from over 9000 previous student responses. Students felt the activities in this course increased their confidence in talking to multiple audiences and increased their understanding of how complicated science messages can be ignored. The graduate students who worked with the undergraduate students in this study reported that the students they worked with helped move their research further, the interactions helped improve their communications skills, and they had gained valuable skills for the academic job market.

Dowd, J. E., T. Duncan and J. A. Reynolds (2015) "Concept Maps for Improved Science Reasoning and Writing: Complexity Isn't Everything." *CBE Life Sciences Education* 14(4): ar39. DOI: 10.1187/cbe.15-06-0138

Concept maps can be a useful tool for students learning science. Currently there is little evidence of how the change in complexity between drafts of these maps relates to understanding and thinking. The authors studied writing and concept maps created by senior undergraduate students in a writing-focused biology course. The students develop a concept map to explain their research and then submit additional drafts during the semester. During this time, they also write a research thesis. The authors compared the complexity of the maps throughout the semester. They also rated the students' theses to determine the dimensions of the writing. They compared the writing dimensions and the concept map complexity and found there is no correlation between student understanding and a change in complexity. They say that concept maps are still helpful tools, but their complexity is not an indication of understanding.

Gallagher, G. J. and D. L. Adams (2002) "Introduction to the Use of Primary Organic Chemistry Literature in an Honors Sophomore-Level Organic Chemistry Course." *Journal of Chemical Education* 79(11): 1368-1371. DOI: 10.1021/ed079p1368

There is interest in more literature review and writing opportunities for students in the sciences. In this article the authors discuss a research journal assignment to introduce students to the literature resources available and to expose them to the content available in the literature. The students were asked to find an article relating to topics covered in their organic chemistry course. The students needed to submit a summary of the article to the TA for approval and, once approved, to write a summary, analysis, and evaluation of the article by the end of the semester. The students were given surveys throughout the semester and participated in a focus group near the end of the semester to evaluate the success of the project. The students indicated while it did not increase their knowledge of organic chemistry, it did increase their confidence in using literature and their ability to understand the literature. Students had more discussions outside of class with their peers and professors and were impressed by their own ability to understand the material in the papers.

Smith, D. K. (2014) "iTube, YouTube, WeTube: Social Media Videos in Chemistry Education and Outreach." *Journal of Chemical Education* 91(10): 1594-1599. DOI: 10.1021/ed400715s

Videos can be used to share information and present it in a different fashion for chemistry students and can also be used to share science with the general public. The author created a YouTube channel to share contextual organic chemistry concepts with students. The channel grew and the author started creating videos for the general public to explain organic chemistry topics that were in the news. Realizing the importance of science communication, the author decided to create a final project during the polymer chemistry unit. The students had the option of creating a short video or submitting an essay. He found the students enjoyed making the videos, felt they had developed important skills, and felt more positively about the class than the students who did not choose to make a video. While the students did not use the videos to learn content, they felt they could be helpful for others. Many students who did not choose to make a video wished they had as they thought it would have been a better experience than writing the article.

Stewart, A. F., A. L. Williams, J. E. Lofgreen, L. J. G. Edgar, L. B. Hoch and A. P. Dicks (2015) "Chemistry Writing Instruction and Training: Implementing a Comprehensive Approach to Improving Student Communication Skills." *Journal of Chemical Education* 93(1): 86-92. DOI: 10.1021/acs.jchemed.5b00373

Students need more help with writing and communicating science. Incorporating more writing activities and feedback into the course curriculum can help the students improve their writing. The University of Toronto Faculty of Arts and Science created the Writing Instruction and Training (WIT) program designed to improve discipline-specific undergraduate writing. The WIT program involves both faculty and TAs to introduce more writing in the curriculum and feedback for the students. There is a specific structure that helps the faculty to include more writing instruction and trains the TAs on effective feedback and assessment of student writing. The WIT program was incorporated in five science courses designed for third-year students. Feedback on a draft report, using journal styles to submit lab reports, and increased feedback on every report were some of the changes made to the courses. When third year, fourth year, and graduate level students were polled all students agreed that the increased writing curriculum was helpful and better enabled them to communicate their science.

Cooperative Learning

Aronson, E. and S. Patnoe (2011) *Cooperation in the Classroom*: The Jigsaw Method. London, Pinter & Martin Ltd. ISBN: 1905177224

Written by the inventor of the technique (Aronson), this book describes the jigsaw technique. Jigsaw activities divide learning materials between students; each student learns his or her portion of the material and then teaches the rest of the group.

Bowen, C. W. (2000) "A Quantitative Literature Review of Cooperative Learning Effects on High School and College Chemistry Achievement." *Journal of Chemical Education* 77(1): 116-119. DOI: 10.1021/ed077p116

The author performs a meta-analysis to quantitatively examine the effects of cooperative learning on high school and college chemistry outcomes. The meta-analysis allows data from studies with different designs to be summarized together, broadening the sample size and allowing for better estimates of outcomes. Summarizing 15 studies of more than 1,500 students, the meta-analysis shows an overall increase in student performance when cooperative learning techniques are used. While the broad category of cooperative learning techniques glosses over the many techniques available, the meta-analysis provides strong evidence of a positive effect of these techniques, especially in light of the often (statistically) small effects seen in individual studies.

Burrowes, P. A. (2003) "A Student-Centered Approach to Teaching General Biology That Really Works: Lord's Constructivist Model Put to a Test." *The American Biology Teacher* 65(7): 491-502. DOI: 10.2307/4451548

The author compared two sections of a college biology course. A control section was taught with traditional lectures. The experimental section was taught with short, 10- to 15-minute lectures followed by group exercises. After each group exercise, a few groups present their results to the class. This allows the professor to elaborate on the results and explain any misconceptions. This process was repeated several times during the class period, and the class period ended with a quiz. Of note, student interest in biology increased considerably more in the experimental section than in the control section. Additionally, students in the experimental section performed better on exams, particularly on questions requiring interpreting data, applying concepts, and connecting concepts. The author also discusses strategies used to keep the groups organized.

Caprio, M. W. (1993) "Cooperative Learning–The Jewel among Motivational-Teaching Techniques." *Journal of College Science Teaching* 22(5): 279-281. *https://www.jstor.org/stable/42985811*

The paper discusses various aspects of group learning, suggesting how each aspect can help motivate students. Included are sections on forming study groups, the benefits of group projects, and group presentations of material in class.

Carroll, D. W. (1986) "Use of the Jigsaw Technique in Laboratory and Discussion Classes." *Teaching of Psychology* 13(4): 208-210. DOI: 10.1207/s15328023top1304_9

The author describes the use of the jigsaw technique in a psychology research design laboratory course. Students undertake two research experiments: a sample experiment replicating a published study and an independent experiment. The tasks for each study are divided between members of a group. For the independent study, each group member presents an idea, then the group can choose to undertake an experiment together or each member can perform their own experiment. Overall, the course was well-received by students, and rates of course completion increased with implementation of the jigsaw method.

Carroll, F. A. and J. I. Seeman (2001) "Placing Science into Its Human Context: Using Scientific Autobiography to Teach Chemistry." *Journal of Chemical Education* 78(12): 1618-1622. DOI: 10.1021/ed078p1618

This paper describes the use of autobiography in an undergraduate advanced organic chemistry course. The autobiography, coupled with several papers from different periods of the author's scientific career, allows students to learn chemistry concepts in depth and in context of the human experience. After covering relevant material in class, students are assigned a paper and asked to present a summary of the paper to the class. Following the presentation, the class reviews the chemistry from the paper and discusses the context of the paper in the author's career. In end-of-semester evaluations, students reported positive reactions to the method, enjoying the greater responsibility for their own learning and being able to better humanize scientific research. Though geared toward advanced undergraduate and graduate students, this method provides an opportunity for students to learn complex topics independently.

Cooper, J. L. and P. Robinson (2000) "Getting Started: Informal Small-Group Strategies in Large Classes." *New Directions for Teaching and Learning* 2000(81): 17-24. DOI: 10.1002/tl.8102

This paper describes a variety of informal small-group learning activities and their advantages. Strategies such as think-pair-share, minute paper, quick-thinks, and concept maps are briefly described. The authors also discuss when and how small-group activities can be implemented into the classroom.

Cooper, M. M. (1995) "Cooperative Learning: An Approach for Large Enrollment Courses." *Journal of Chemical Education* 72(2): 162-164. DOI: 10.1021/ed072p162

The author discusses the use of cooperative learning techniques in large-enrollment classes. With the use of cooperative learning, students become more responsible for and involved in their own learning and can better develop higher-order thinking skills. Cooperative learning techniques have also been

shown to improve student attitudes and retention rates. Practically, the author discusses forming groups and the balance of accountability between groups and individuals. Additionally, the author discusses how to introduce group work and choose group assignments. The author also addresses two common problems with cooperative learning: not covering enough material, and resentment among "good" students for helping other students along.

Crouch, C. H. (1998) "Peer Instruction: An Interactive Approach for Large Lecture Classes." *Optics and Photonics News* 9(9): 37-41. *http://www.osa-opn.org/home/articles/volume_9/issue_9/features/peer_instruction_an_interactive_approach_for_larg/*

An early paper on peer instruction, this paper presents a brief overview of the technique, including data on students taught using peer instruction compared with traditionally taught students.

Crouch, C. H. and E. Mazur (2001) "Peer Instruction: Ten years of experience and results." *American Journal of Physics* 69(9): 970-977. DOI: 10.1119/1.1374249

The authors describe the evolution of Peer Instruction (PI) used in introductory physics courses at Harvard University. Over ten years of use in introductory physics, the authors saw consistently higher learning gains as measured by the Force Concept Inventory. Additionally, despite the de-emphasis on problem-solving in lecture, students showed increased problem-solving skills. The authors also describe several modifications made to PI. Web-based reading assignments replaced reading quizzes as incentive for students to read the text before class. Structured cooperative activities were added to discussion sections as well. Strategies for teaching problem solving are also discussed. The authors describe how to better motivate students through grading and class tone. ConceptTest selection is also discussed, including ideas for incorporating open-ended and quantitative problems. The authors also describe strategies for streamlining lectures to save time and ideas for motivating TAs.

Deslauriers, L., E. Schelew and C. Wieman (2011) "Improved Learning in a Large-Enrollment Physics Class." *Science* 332(6031): 862-864. DOI: 10.1126/science.1201783

This report describes a one-week study in a large-enrollment introductory physics course. During the study, two sections were compared: the control section was taught by an experienced professor using traditional lecture techniques and clicker questions. The experimental section was taught by a postdoctoral fellow with little teaching experience. The experimental section was designed to give students practice thinking scientifically and used clicker questions, small-group active learning tasks, and targeted instructor feedback. Both sections covered the same topics, though the experimental section covered slightly less material in all. In a test following the study, the experimental section performed significantly better (effect size of 2.5 standard deviations) than the control section. Additionally, students were more engaged in the experimental section.

Dinan, F. J. and V. A. Frydrychowski (1995) "A Team Learning Method for Organic Chemistry." *Journal of Chemical Education* 72(5): 429-431. DOI: 10.1021/ed072p429

This paper introduces a structured approach to using small groups in organic chemistry. In this approach, groups are designed to be maximally heterogeneous regarding academic ability, race, and gender. In advance of each class, students are given learning guides, consisting of a reading assignment, problems, and a list of specific tasks students should be able to do; each guide covers material for one class period. At the beginning of each class, groups are given a chance to briefly discuss the learning guide, and then are tested on the material, both individually and as a group. Instructors were able to cover more material with this approach than with a traditional lecture approach. Students responded well to the approach, and final exam grades were improved, although the improvement was not statistically significant.

Dougherty, R. C. (1997) "Grade/Performance Contracts, Enhanced Communication, Cooperative Learning and Student Performance in Undergraduate Organic Chemistry." *Journal of Chemical Education* 74(6): 722-726. DOI: 10.1021/ed074p722

The author describes several strategies implemented in an undergraduate organic chemistry course. The most notable of these strategies is the use of grade/study performance contracts. These contracts, which students may opt to sign or not, guarantee the student a grade of C or better in the course if certain study requirements are met, including reading the text and attending class and recitation, transcribing notes, and studying for the course for nine hours per week. Crucial to the contract is the clause requiring the student to visit the instructor after an exam in which the student receives below a grade of 70%. In these visits, the instructor examines the contract documents, and suggests alternate study strategies that may be implemented. Compared to a traditionally taught lecture course, retention rate in the contract course was substantially higher. Additionally, students in the contract section performed better on average on the standardized ACS exam than students in the traditional section.

Dougherty, R. C., C. W. Bowen, T. Berger, W. Rees, E. K. Mellon and E. Pulliam (1995) "Cooperative Learning and Enhanced Communication: Effects on Student Performance, Retention, and Attitudes in General Chemistry." *Journal of Chemical Education* 72(9): 793-797. DOI: 10.1021/ed072p793

This work compares cooperative learning methods using three large sections of introductory chemistry. One section used a simple but structured cooperative learning method, with communication enhanced by email. A second section used an unstructured cooperative learning method, with enhanced communication via a modified "one-minute paper." The third section served as the control and was taught as a traditional lecture course. The structured-cooperative section showed significantly higher performance and retention rates than the other two sections. The unstructured cooperative section had higher retention than the control, but lower than the structured cooperative section. This shows that even a simple cooperative learning model has significant impact on student retention and performance.

Fagen, A. P., C. H. Crouch and E. Mazur (2002) "Peer Instruction: Results from a Range of Classrooms." *The Physics Teacher* 40(4): 206-209. DOI: 10.1119/1.1474140

Authors report on a survey of instructors using Peer Instruction (PI) or similar collaborative learning strategies. Instructors using PI reported higher gains on the Force Concept Inventory (FCI) than instructors teaching traditionally. The paper also addresses common challenges to peer instruction, and several solutions to each challenge. A number of survey respondents were concerned with the time investment required to develop good ConceptTests for use in PI; the authors recommend using the abundant ConceptTests available online, such as Project Galileo at Harvard. With the implementation of ConceptTests, some respondents reported difficulty covering enough material; the authors recommend encouraging students to learn some of the material on their own using methods such as Just-In-Time Teaching. The authors also address student and faculty resistance to new teaching methods.

Felder, R. M. (1996) "Active-Inductive-Cooperative Learning: An Instructional Model for Chemistry?" *Journal of Chemical Education* 73(9): 832-836. DOI: 10.1021/ed073p832

The author describes the details of a radical redesign of five sequential chemical engineering courses to focus on cooperative learning including in-class group exercises and group homework assignments. By using cooperative learning techniques in sequential courses, students gain additional benefits in performance, attitude, and self-confidence. Though this model would require some reworking to be successful in other disciplines, the basic elements and ideas described can apply.

Freeman, S., E. O'Connor, J. W. Parks, M. Cunningham, D. Hurley, D. Haak, C. Dirks and M. P. Wenderoth (2007) "Prescribed Active Learning Increases Performance in Introductory Biology." *CBE-Life Sciences Education* 6(2): 132-139. DOI: 10.1187/cbe.06-09-0194

The authors examined several active-learning methods in an effort to reduce failure rates in an introductory biology course. Peer-instruction techniques were used during lecture, where the use of clickers or cards was compared, and students took practice exams, either online or in study groups. In a second term, clicker questions were either graded for correctness or for participation. Overall, failure rates were reduced and exam grades were higher than in a prior class taught without peer-instruction. No statistically significant difference was observed in exam scores between cards and clickers, graded or ungraded. However, when clicker questions were graded, students performed better on the questions. Overall, this paper shows that peer-instruction can increase student performance, though the format is not as important.

Gosser, D., V. Roth, L. Gafney, J. Kampmeier, V. Strozak, P. Varma-Nelson, S. Radel and M. Weiner (1996) "Workshop Chemistry: Overcoming the Barriers to Student Success." *Chemical Educator* 1(1): 1-17. DOI: 10.1333/s00897960002a

This article presents the details of Workshop Chemistry and includes descriptions of the first workshop courses offered, sample workshop problems, and interviews, surveys, and logs of students, undergraduate workshop leaders, and faculty involved. The Workshop Chemistry model replaces some lecture time with two-hour problem-solving sessions consisting of a group of six to eight students and an undergraduate peer leader. One hallmark of Workshop Chemistry is the peer leaders, who are undergraduates who have recently completed the course successfully. These leaders are better able to connect with the students because of their status as peers and, thus, in addition to guiding the problem-solving sessions, can become mentors for the students.

Gosser, D. K., J. A. Kampmeier and P. Varma-Nelson (2010) "Peer-Led Team Learning: 2008 James Flack Norris Award Address." *Journal of Chemical Education* 87(4): 374-380. DOI: 10.1021/ed800132w

This paper provides an overview of Peer-Led Team Learning (PLTL). It includes descriptions of how the authors came to develop and use PLTL as well as how the strategy was disseminated to other institutions and instructors. A brief overview of the technique describes several critical components: Workshops as an integral part of the course, careful training of peer leaders, and appropriate problems for the Workshop. A brief literature review describes successes with PLTL. In addition, the benefits of the technique for peer leaders, faculty, and institutions are described.

Gosser, D. K. and V. Roth (1998) "The Workshop Chemistry Project: Peer-Led Team-Learning." *Journal of Chemical Education* 75(2): 185-187. DOI: 10.1021/ed075p185

This is the initial report on peer-led team learning (PLTL). In PLTL, a recitation section or a small amount of lecture is replaced with a 2-hour student-led workshop. These workshops are composed of groups of six to eight students and an undergraduate peer leader, a recent successful student of the same course. Discussion of selection and training of peer leaders is included, as are various strategies for designing the workshop problems. The method has been piloted at several diverse colleges and universities, and a significant improvement in grades, retention, and student satisfaction levels were seen.

Groccia, J. E. and J. E. Miller (1996) “Collegiality in the Classroom: The Use of Peer Learning Assistants in Cooperative Learning in Introductory Biology.” *Innovative Higher Education* 21(2): 87-100. DOI: 10.1007/BF01243700

This paper describes an adjustment to a previously described (Goodwin, Miller and Cheetham, 1991, Miller and Cheetham 1990, Miller, Wilkes, Cheetham and Goodwin 1993) cooperative learning method. In an intensive cooperative learning method described in previous papers, instructors found themselves overtaxed with a class of 70 students. This paper describes the addition of Peer Learning Assistant (PLAs) undergraduates, managed by the instructor, who guide small group work during and outside of class. PLAs were meant to facilitate group problem solving and help manage group dynamics. This modification was successful in reducing the instructor’s workload, while simultaneously improving student performance. Additionally, students with PLAs reported higher levels of satisfaction with their group experience.

Hagen, J. P. (2000) “Cooperative Learning in Organic II. Increased Retention on a Commuter Campus.” *Journal of Chemical Education* 77(11): 1441-1444. DOI: 10.1021/ed077p1441

The author discusses implementation of several strategies to increase retention in an organic chemistry course. The author incorporates several techniques to this goal including group quizzes, testing cycles, “muddiest point” essays, and think-write-compare (TWC). The combination of strategies resulted in an increase in retention rate by 20% without a subsequent drop in average scores on the standardized ACS exam.

Hamby Towns, M. and E. R. Grant (1997) ““I believe I will go out of this class actually knowing something”: Cooperative learning activities in physical chemistry.” *Journal of Research in Science Teaching* 34(8): 819-835. DOI: 10.1002/(sici)1098-2736(199710)34:8<819::aid-tea5>3.0.co;2-y

Authors describe a discussion session in a graduate-level thermodynamics course where cooperative learning activities were implemented. In small groups, students discussed questions (given in advance) for the beginning of class, then each group presented the solution to the class. Student attitudes to this format are discussed in detail and are, for the most part, positive. Students reported that the discussion sessions increased their conceptual understanding of physical chemistry. Also, the group nature of the sessions helped the students develop better interpersonal and communication skills. Additionally, some suggestions are made for improving participation of every group member, such as assigning roles to group members and using untimed activities.

Holme, T. A. (1998) “Using Interactive Anonymous Quizzes in Large Lecture General Chemistry Courses.” *Journal of Chemical Education* 75(5): 574-576. DOI: 10.1021/ed075p574

This is a precursor of sorts to clicker questions, using “interactive anonymous quizzes" (IAQs) where the class is given time to respond to a question posed by the instructor and rate their confidence in their answer. Peer discussion follows where students are instructed to convince their classmates that their answer is correct. A second chance to answer the question follows discussion. Overwhelmingly, students respond positively to this activity, with over 95% positive outcomes for questions (which are counted as a switch to a correct answer or an increase in confidence on the second attempt to answer).

King, A. (1993) "From Sage on the Stage to Guide on the Side." *College Teaching* 41(1): 30-35. *http://www.jstor.org/stable/27558571*

The author describes how to gradually transition from teaching by simply transmitting knowledge, as with classical lecturing, to a more constructivist mode of learning. In the constructivist view of learning, students must construct knowledge themselves by making connections with things they already know. The author presents some activities that can be incorporated easily and without taking much time away from lecture, such as think-pair-share and concept mapping. Then the author describes more formal and involved models of cooperative learning including "Guided Reciprocal Peer Questioning" and Jigsaw.

Knight, J. K. and W. B. Wood (2005) "Teaching More by Lecturing Less." *Cell Biology Education* 4(4): 298-310. DOI: 10.1187/05-06-0082

The authors describe a redesigned biology course to incorporate more interactive teaching methods and compare the outcomes of the redesigned course with the previous, traditionally taught course. In the redesigned course, cooperative group problem solving and in-class questions (ICQs, similar to questions used in peer instruction) were interspersed throughout the class time. Additionally, undergraduate learning assistants (LAs) were used to facilitate group work. A comparison of normalized learning gains was made, based on a pretest and a posttest administered to students in both the traditional and the redesigned course. This comparison revealed that A and B students made higher learning gains in the redesigned course, while C students fared as well in either course. Student reception to the course redesign was suspicious at first, with students disliking the interactive nature of the class. However, most students reported that the course helped their learning.

Kogut, L. S. (1997) "Using Cooperative Learning to Enhance Performance in General." *Journal of Chemical Education* 74(6): 720-722. DOI: 10.1021/ed074p720

This describes a fairly simple use of cooperative learning, where students are required to form groups that meet outside class. A comparison is made to a similar course (same material but fewer lecture hours), showing that the students performed better on similar exams when compelled to meet in groups. Positive and negative comments on the method are presented.

Lasry, N. (2008) "Clickers or Flashcards: Is There Really a Difference?" *The Physics Teacher* 46(4): 242-244. DOI: 10.1119/1.2895678

This paper reports on a study comparing the use of clickers and flashcards in Peer Instruction (PI). No significant difference in conceptual learning gains or exam scores was found between sections using clickers or flashcards. Other differences are noted between the two systems. Using flashcards requires instructors to tabulate or estimate responses, costing class time. Clickers tabulate automatically and allow student responses to be archived. Archived responses present an opportunity to refine questions to be more effective.

Lewis, S. E. and J. E. Lewis (2005) "Departing from Lectures: An Evaluation of a Peer-Led Guided Inquiry Alternative." *Journal of Chemical Education* 82(1): 135-139. DOI: 10.1021/ed082p135

This paper describes a combination of Peer-Led Team Learning (PLTL) and guided inquiry into a new method, Peer-Led Guided Inquiry (PLGI). Students in the experimental section attended two regular 50-minute lectures and one 50-minute PLGI session each week, while students in the control section attended three 50-minute lectures each week. Exam results indicate that the experimental section consistently outperformed the control section on exams. Additionally, attendance at PLGI sessions was correlated with better performance.

Libby, R. D. (1995) "Piaget and Organic Chemistry: Teaching Introductory Organic Chemistry through Learning Cycles." *Journal of Chemical Education* 72(7): 626-631. DOI: 10.1021/ed072p626

The author discusses implementation of learning cycles into an organic chemistry course. Learning cycles rely very little on lecture. Rather, students discover concepts themselves through the process. Prior to class, students explore a set of data using example problems then students and the instructor work together to develop a hypothesis to fit the data. Finally, students supply the hypothesis to new situations outside of class. Detailed instructions are given on developing this method for use in other classrooms. Though no data is presented, the author observes that students performed as well on standardized exams when taught by learning cycles as they did when taught using traditional lecture methods, but with better attitudes. Learning cycles provide students experience with the scientific thought processes, an additional benefit over traditional lecture

Paulson, D. R. (1999) "Active Learning and Cooperative Learning in the Organic Chemistry Lecture Class." *Journal of Chemical Education* 76(8): 1136-1140. DOI: 10.1021/ed076p1136

The author describes his experiences incorporating several active and cooperative learning techniques into a three-term organic chemistry sequence in order to decrease attrition rates. The author formed cooperative learning groups who worked together on activities both during and outside of class

time. Students were also given one-minute quizzes on assigned readings at the beginning of each class to encourage pre-class preparation. Finger signals (similar to the flashcard or clicker techniques) were used to answer in-class questions. Additionally, the "minute paper" was implemented, as were guided class discussions. While the author continued to lecture as the main means of transmitting information, breaks and pauses were incorporated into lectures to increase understanding. One year of the sequence was analyzed using either a standard lecture format or the cooperative and active learning techniques. This analysis showed that the average retention rate for the full sequence increased from 38% to 75% upon incorporation of the new techniques. Though only one year of each method was compared, the results are striking. The personal nature of the report is helpful for those seeking to incorporate newer teaching methods into their lecture-based courses.

Perkins, D. V. and R. N. Saris (2001) "A "Jigsaw Classroom" Technique for Undergraduate Statistics Courses." *Teaching of Psychology* 28(2): 111-113. DOI: 10.1207/s15328023top2802_09

The authors report on the use of the "jigsaw classroom" technique in an undergraduate statistics course. In this case, the technique was implemented in an activity using worksheets. Each activity was divided into two to four parts necessary for the final solution, and each part was distributed on a separate worksheet to a group of students. The students worked on their worksheet as a group, and then split up to find other students with different worksheets. Together, these students completed a final worksheet. In general, students responded positively to the activity, with 84% enjoying the time savings of working together on the worksheets and 88% finding the activity a positive alternative to lecture.

Poole, M. J. and R. E. Glaser (1999) "Organic Chemistry Online: Building Collaborative Learning Communities through Electronic Communication Tools." *Journal of Chemical Education* 76(5): 699-703. DOI: 10.1021/ed076p699

This paper describes a group research project used in an undergraduate organic chemistry course. This project was implemented to develop small learning communities within the larger lecture course. The research project required students to draw heavily from internet resources, and the finished projects were published online. Students participating in this project achieved higher exam grades than students in previous years before the group project was implemented.

Ross, M. R. and R. B. Fulton (1994) "Active Learning Strategies in the Analytical Chemistry Classroom." *Journal of Chemical Education* 71(2): 141-143. DOI: 10.1021/ed071p141

The authors present a redesigned course focusing on cooperative learning. Course material is broken down into three-day cycles, each covering approximately one chapter in the textbook. Students are given homework

problems, due the first day of each cycle. The first day of the cycle, students work in groups on the homework problems. Over the following two class days, groups present the solutions to the problems and important concepts contained within the problem. Here, the instructor facilitates discussion and provides mini-lectures to complement the problems. Additionally, the course includes quizzes after every two cycles, and an orally administered final exam that allows the instructor to probe student understanding more fully. Students perform as well or better than students taught in the traditional manner, and the same amount of material is covered.

Sandi-Urena, S., M. Cooper and R. Stevens (2012) "Effect of Cooperative Problem-Based Lab Instruction on Metacognition and Problem-Solving Skills." *Journal of Chemical Education* 89(6): 700-706. DOI: 10.1021/ed1011844

Laboratory sections are an important part of introductory science courses, but there is little evidence that the way these labs are currently being taught supports student learning and understanding. Metacognition is described as awareness of one's own thought process and is believed to be an important part of developing problem-solving skills. This study examined the effect of cooperative, project-based labs on general chemistry I students' metacognition. The study was conducted at a university that had established cooperative-based labs. They used IMMEX software to track students' problem-solving strategies and performance. The software offers students a problem-set to solve, in this case substance identification. Since the problems used are not well-defined there are many ways to approach the problem and allow the students a chance to use their own strategies to solve the problem. The study finds using cooperative, project-based lab environments appears to influence students' metacognition.

Sandi-Urena, S., M. M. Cooper, T. A. Gatlin and G. Bhattacharyya (2011) "Students' experience in a general chemistry cooperative problem based laboratory." *Chemistry Education Research and Practice* 12(4): 434-442. DOI: 10.1039/C1RP90047A

This article focuses on the process taking place in the classroom to understand better why there is an increase in the use of metacognition in project-based labs. The quantitative results showing the difference in metacognition is reported in the article discussed above. The authors found students go through a series of dimensions. First, the students must accept that the learning environment in the lab will be different than many others they have taken. The students will then start to understand the reason for designing the lab this way and how it will help them. Finally, the students start developing the skills needed to complete the task. The authors indicate these dimensions initially occur linearly, but over time will occur in conjunction with each other. They say all these dimensions are explained by students taking control of their learning. The authors note that these findings indicate that a purposeful social interaction combined with an environment that promotes metacognitive thinking are fundamental to this type of learning, and those ideas can be applied to a variety of laboratory courses.

Smith, M. K., W. B. Wood, W. K. Adams, C. Wieman, J. K. Knight, N. Guild and T. T. Su (2009) "Why Peer Discussion Improves Student Performance on In-Class Concept Questions." *Science* 323(5910): 122-124. DOI: 10.1126/science.1165919

The authors show that students improve on clicker questions after discussion with peers, even when the question following discussion is modified (but still on the same concept) from the discussed question, showing that peer discussion increases student understanding.

Snyder, J. J., J. D. Sloane, R. D. Dunk and J. R. Wiles (2016) "Peer-Led Team Learning Helps Minority Students Succeed." *PLoS Biol* 14(3): e1002398. DOI: 10.1371/journal.pbio.1002398

This article discusses the use of peer-led team learning (PLTL) alongside an introductory biology lecture course. Due to a recent change in curriculum, the lab course that corresponded with this lecture was made voluntary. The initial data showed students who chose not to participate in the lab were not scoring as well as students who were taking the lab, whereas students who enrolled in PLTL but opted out of the lab performed as well as students in the lab. PLTL is a well-studied active learning strategy that focuses on small groups of students working together to learn. The authors found that students who opted to engage in PLTL were less likely to fail or drop the course and showed a decrease in the number of underrepresented minorities (URM) who were dropping or failing.

Tien, L. T., V. Roth and J. A. Kampmeier (2002) "Implementation of a peer-led team learning instructional approach in an undergraduate organic chemistry course." *Journal of Research in Science Teaching* 39(7): 606-632. DOI: 10.1002/tea.10038

The paper describes interviews with peer leaders, who have perspective as both a student and a peer leader. The excerpts from the interviews are mainly about how exciting the teaching was and the strategies they used.

Towns, M. H. (1998) "How Do I Get My Students to Work Together? Getting Cooperative Learning Started." *Journal of Chemical Education* 75(1): 67-69. DOI: 10.1021/ed075p67

The author presents strategies for improving quality of group dynamics when using cooperative learning techniques. In order for group activities to work, groups must know how to work together and be willing to work together. The author describes how she encourages groups to work together in her classes. Students are told why they are working in groups and how the groups are being formed. "Group Covenants" are created, describing the responsibilities of each member of the group and of the group as a whole.

This is an excellent resource for facilitating cooperative learning and teaching students how to work together in teams.

Watson, S. B. and J. E. Marshall (1995) "Effects of cooperative incentives and heterogeneous arrangement on achievement and interaction of cooperative learning groups in a college life science course." *Journal of Research in Science Teaching* 32(3): 291-299. DOI: 10.1002/tea.3660320308

This paper looks at the effect of heterogeneous grouping and cooperative incentives in cooperative learning. Groups were created based on achievement on a pre-test — students were either assigned to homogeneous groups with students who performed similarly on the pretest or to heterogeneous groups, with students of different performance levels. Then, the homogeneous and heterogeneous groups were assigned either cooperative and individual incentives or only individual incentives. After a post-test, no significant difference was seen between any of the groups in terms of achievement. However, heterogeneous groups were found to interact more than homogeneous groups. The authors note that these groups were assigned based on their knowledge of the current subject matter. A more comprehensive way to assign groups might include a metric of learning ability or performance, such as grades in prerequisite classes, overall GPA, or standardized test scores.

Wilson, S. B. and P. Varma-Nelson (2016) "Small Groups, Significant Impact: A Review of Peer-Led Team Learning Research with Implications for STEM Education Researchers and Faculty." *Journal of Chemical Education* 93(10): 1686-1702. DOI: 10.1021/acs.jchemed.5b00862

This article discusses recent reviews of peer-led team learning (PLTL) outcomes and experimental design. Reviews of the effect of PLTL on student's learning as examined by test scores and self-reports, on the effect of PLTL on the peer leaders, and variants of the PLTL model are all included The authors also outline areas of possible future research around PLTL approaches and possible experimental designs to cover current gaps in the knowledge. The article shows that size and duration of the PLTL group is not as important as the content discussed and the consistency with which the groups meet. The peer leaders are good role models for the other students, especially when students of different backgrounds, gender, and ethnicity are chosen, and the position can help students make career choices. Overall PLTL programs can be good tools in the classroom but there is still some research to be conducted.

CUREs

Ballen, C. J., S. K. Thompson, J. E. Blum, N. P. Newstrom and S. Cotner (2018) "Discovery and Broad Relevance May Be Insignificant Components of Course-Based Undergraduate Research Experiences (CUREs) for Non-Biology Majors." *Journal of Microbiology and Biology Education* 19(2): 19.2.63. DOI: 10.1128/jmbe.v19i2.1515

Course-based undergraduate research experiences (CUREs) offer an opportunity for the entire population of students to get research experience, not just those who choose to seek out additional research opportunities. CUREs contain five aspects: investigative experiments followed by data analysis, collaboration with other students, using scientific practices, discovery or information as they work on novel questions, and production of data that someone cares about. This paper investigates the importance of the last two components for efficacy and student outcomes. The authors investigated three classes of introductory biology students, each with multiple lab sections. One class had an experience with all five CURE components, one class used only the first four CURE components, and the final used only the first three CURE components. Laboratory grades, self-reported science efficacy, and self-reported project ownership were analyzed. Students in all three groups performed similarly in the course and reported similar feelings of science efficacy. The authors suggest more work be conducted examining other components of CUREs, looking at differences between majors and non-majors, and graduate students and undergraduate students.

Bangera, G. and S. E. Brownell (2014) "Course-based undergraduate research experiences can make scientific research more inclusive." *CBE Life Sciences Education* 13(4): 602-606. DOI: 10.1187/cbe.14-06-0099

It can be difficult for some students to get positions in research labs. Some students don't know how to find open positions, aren't aware of how beneficial these experiences can be, aren't sure how to interact with the professors who run labs, or can't volunteer their time due to financial obligations. Other barriers to overcome can be the faculty themselves, as some choose to focus on students that they already know perform well or are known to have worked in other labs, further creating a divide in the types of students participating in research experiences. The authors of this article discuss these barriers and how the use of CUREs can overcome many of them. Making these classes mandatory gives all students access and eliminates the need for students to volunteer their time. CUREs are a great way to give all students a chance to get research experiences and therefore an important step in creating a more diverse field.

See also: Corwin, Assessment section

Denofrio, L. A., B. Russell, D. Lopatto and Y. Lu (2007) "Linking Student Interests to Science Curricula." *Science* 318(5858): 1872-1873. DOI: 10.1126/science.1150788

This paper presents an example of the use of the Classroom Undergraduate Research Experience (CURE) survey. The survey was used to evaluate the "Chemistry and Biology of Everyday Life" course, where students are matched with courses and research groups based on their background and interests. The CURE survey was used to show that students benefited from the program by progressing in several areas important for scientific research.

Danowitz, A. M., R. C. Brown, C. D. Jones, A. Diegelman-Parente and C. E. Taylor (2015) "A Combination Course and Lab-Based Approach To Teaching Research Skills to Undergraduates." *Journal of Chemical Education* 93(3): 434-438. DOI: 10.1021/acs.jchemed.5b00390

The directors of the science programs at Mercyhurst University decided to reevaluate their research programs after feedback from the faculty and staff. The directors created a list of goals for the research program to use as a guideline while developing the new plan. They wanted the students to be exposed to safety and ethical considerations, develop literacy skills, write research proposals, and work closely with a faculty member to conduct research. They found neither UREs or CUREs fully fit their goals and decided to make their own combination course. The courses, Research I and Research I Lab, would be taught simultaneously over three weeks. Research I would include coursework like literature searches, giving presentations, research practice, and writing research proposals. Research I Lab focused on lab work and had the students matched up with faculty giving students the ability to work in a lab setting. This program seemed to work well as the students obtained good marks in the class and the faculty agreed they saw an improvement from prior years. It seems the hybrid class that allows students to learn about research and experience research at the same time can be helpful. It should be noted however, this was a small school with only three to nine majors/year and a special semester called J-term that was three weeks long, during which the students and faculty only took or taught one class. The authors believe similar results could be obtained in larger schools or during other semesters.

Lopatto, D. "CURE Survey - Assessment Instruments." Retrieved February 13, 2021, from *https://www.grinnell.edu/academics/resources/ctla/assessment/cure-survey*

The website for the Classroom Undergraduate Research Experience (CURE) survey contains a brief introduction to the survey, which is designed to measure the experiences of students in research-centric courses. In addition to containing links for the pre- and post-test, the page lists several published uses of the CURE survey.

Rodenbusch, S. E., P. R. Hernandez, S. L. Simmons and E. L. Dolan (2016) "Early Engagement in Course-Based Research Increases Graduation Rates and Completion of Science, Engineering, and Mathematics Degrees." *CBE Life Sciences Education* 15(2). ar20. DOI: 10.1187/cbe.16-03-0117

This article compares the completion of science degrees between STEM undergraduate students who participated in a CURE experience with STEM undergraduates who did not. The authors focused on a program at the University of Texas at Austin called Freshman Research Initiative. This program requires the students to complete three research laboratory courses in three consecutive semesters starting in the fall of their freshman year.

The three semesters build on each other, the students start with a research methods course and build up to independent research. This study found that students who participated in all three semesters of the program had higher graduation rates and were more likely to persist in their STEM degree than the students who did not participate. There were also differences between students who only completed one or two of the courses. The article points out that this is a very specific program and more research should be done on which parts of the program are most important to obtaining the higher graduation rates.

Shaffer, C. D., C. J. Alvarez, A. E. Bednarski, D. Dunbar, A. L. Goodman, C. Reinke, A. G. Rosenwald, M. J. Wolyniak, C. Bailey, D. Barnard, C. Bazinet, D. L. Beach, J. E. Bedard, S. Bhalla, J. Braverman, M. Burg, V. Chandrasekaran, H. M. Chung, K. Clase, R. J. Dejong, J. R. Diangelo, C. Du, T. T. Eckdahl, H. Eisler, J. A. Emerson, A. Frary, D. Frohlich, Y. Gosser, S. Govind, A. Haberman, A. T. Hark, C. Hauser, A. Hoogewerf, L. L. Hoopes, C. E. Howell, D. Johnson, C. J. Jones, L. Kadlec, M. Kaehler, S. C. Silver Key, A. Kleinschmit, N. P. Kokan, O. Kopp, G. Kuleck, J. Leatherman, J. Lopilato, C. Mackinnon, J. C. Martinez-Cruzado, G. McNeil, S. Mel, H. Mistry, A. Nagengast, P. Overvoorde, D. W. Paetkau, S. Parrish, C. N. Peterson, M. Preuss, L. K. Reed, D. Revie, S. Robic, J. Roecklein-Canfield, M. R. Rubin, K. Saville, S. Schroeder, K. Sharif, M. Shaw, G. Skuse, C. D. Smith, M. A. Smith, S. T. Smith, E. Spana, M. Spratt, A. Sreenivasan, J. Stamm, P. Szauter, J. S. Thompson, M. Wawersik, J. Youngblom, L. Zhou, E. R. Mardis, J. Buhler, W. Leung, D. Lopatto and S. C. Elgin (2014) “A course-based research experience: how benefits change with increased investment in instructional time.” *CBE Life Sciences Education* 13(1): 111-130. DOI: 10.1187/cbe-13-08-0152

Research has shown that research experiences for undergraduate students are important, particularly for minorities, for retention in the sciences. There have been recommendations by many to replace the current teaching laboratory structure with discovery-based research courses to provide more students access to research experiences. The Genomics Education Project (GEP) is designed to allow students to participate in genomics research while learning about bioinformatics tools. The program has expanded to about 100 universities of various sizes and has been used in a variety of ways in these universities. This wide range of uses and factors can contribute to the knowledge gains and the understanding of the field by the participants in these labs. The article found that the amount of time spent in the research experience has the biggest impact on learning outcomes and understanding. The size of the university, mission of the university, and culture generally do not make a difference in the outcomes. Another important aspect is project ownership, the more ownership a student feels they have the more they feel they get from the project. The authors note that the large amount of computation work involved in genomics lends this class to research projects for students since lab time and materials are not a large concern. They also note that a low student-to-advisor ratio is needed to prevent frustration as the students learn new techniques.

Shortlidge, E. E. and S. E. Brownell (2016) “How to Assess Your CURE: A Practical Guide for Instructors of Course-Based Undergraduate Research Experiences.” *Journal of Microbiology and Biology Education* 17(3): 399-408. DOI: 10.1128/jmbe.v17i3.1103

Many instructors are trying to make the transition to using CUREs. The best ways to carry out and evaluate a CURE are still being determined. The paper outlines a method for instructors to assess the CURE being used. They suggest the instructor start by deciding the learning outcomes they hope are achieved during the course. With the learning outcomes in mind, find or develop an assessment that will provide information about the desired course outcomes. Finally, the authors say that instructors need to be cautious in the interpretation of their assessments and understand the limitations of the assessments used. The authors provide a table of currently available assessments that can be used as a starting point for instructors.

Diversity and Inclusion

See also Bangera, CUREs; Carpi, Research and Mentorship; Estrada, Research and Mentorship; Fisher, Graduate Student Professional Development and Mental Health; Gibbs, Graduate Student Professional Development and Mental Health; Stassun, General; Tanner, General

Dewsbury, B. and C. J. Brame (2019) “Inclusive Teaching” *CBE-Life Sciences Education* 18(fe2): 1-2. DOI: 10.1187/cbe.19-01-0021

In order to address the attrition gap in STEM fields between underrepresented minority and white students, the authors describe an online teaching guide that contains evidence-based practices to help STEM faculty incorporate inclusive teaching practices in their classes. Topics addressed include helping faculty develop self-awareness and empathy and encouraging positive classroom climates. Additional sections address pedagogical approaches that can improve the sense of belonging and self-efficacy in science classes to lead to student development of science identity. Finally, leveraging campus networks is addressed with suggestions to incorporate campus inclusive practices and specific services related to inclusivity in STEM classrooms.

Dimitrov, N. and A. Haque (2016) “Intercultural teaching competence: a multi-disciplinary model for instructor reflection.” *Intercultural Education* 27(5): 437-456. DOI: 10.1080/14675986.2016.1240502

It is important for instructors to be able to communicate with all their students, even those who may be different from themselves. This article offers a model for instructors to further develop skills in communicating across cultures called the intercultural teaching competencies (ITC) model. The authors note this article was intended for instructors who are already using student-centered teaching and are trying to increase their intercultural competencies. They provide 20 teaching strategies that they divided into functional, facilitation, and curriculum competencies. These three categories encompass the instructors' awareness of their own abilities, the instructors' ability to create an inclusive space, and increasing diversity within the curriculum. Examples and descriptions of each teaching strategy are provided. The authors make note that this is not a rigid formula but a guide to be used for introspection, group discussion, and peer observation.

Estrada, M., M. Burnett, A. G. Campbell, P. B. Campbell, W. F. Denetclaw, C. G. Gutierrez, S. Hurtado, G. H. John, J. Matsui, R. McGee, C. M. Okpodu, T. J. Robinson, M. F. Summers, M. Werner-Washburne and M. Zavala (2016) "Improving Underrepresented Minority Student Persistence in STEM." *CBE Life Sciences Education* 15(3): es5. DOI: 10.1187/cbe.16-01-0038

The authors present recommendations to improve underrepresented minorities (URMs) persistence in STEM. In order to increase the diversity in STEM fields investigation is needed into the barriers preventing URMs from succeeding. The authors of the article are members of the joint working group on improving URM persistence in STEM assembled by the National Institute of General Medical Sciences and Howard Hughes Medical Institute to address the lack of diversity in STEM fields. The authors use Kevin Lewin's three-step model to make suggestions to improve URM retention in STEM fields. The first step in Lewin's model suggests obtaining accurate and quality information to encourage change. The information should come from institutions tracking student performance, degree candidates and earners and should include demographic information. This information is important for establishing and supporting a need for change and to track the effectiveness of programs that are developed. The second step is moving to a more effective system. For this the authors suggest creating partnerships between institutions with strong programs for URMs and those trying to develop programs, using active learning and new curriculum developments, addressing the differences in students' resources, and using curricula that spark creativity and connection to keep students engaged. Committing to these five suggestions can help institutions move toward increasing URM persistence in the sciences. Once increased persistence is achieved, the third step is maintaining the new system in place to continue seeing the positive outcomes.

Furge, L. L. (2015) "Social ecology of the classroom: issues of inclusivity." *Biochemistry and Molecular Biology Education* 43(1): 1-2. DOI: 10.1002/bmb.20832

It has been shown that collaborative active-learning environments, even in small amounts, have an impact on exam grades. However, stratification and marginalization of underrepresented groups can happen even when the professors are unaware. Student-centered classrooms give the professor the chance to create cooperative learning environments where all students are included. Team-based learning has been shown to give students exposure to different learning strategies, different ways to solve a problem, and to see how similar their questions are to others in the classroom. These learning practices have been shown to have a positive impact on students, with underrepresented groups seeing the biggest impact. These are easy, more cost-effective ways of creating communities and relationships than activities outside of the classroom and have a similar effect.

Garrison, H. (2013) “Underrepresentation by race-ethnicity across stages of U.S. science and engineering education.” *CBE Life Sciences Education* 12(3): 357-363. DOI: 10.1187/cbe.12-12-0207

There are many racial and ethnic groups that are underrepresented in STEM, and thus there has been a movement to increase diversity in science. To design the most influential, cost effective, and targeted programs there must first be research conducted to determine which education levels to target. The article investigates when race-ethnic disparities in STEM begin to arise. To investigate this the authors examined cross-sectional data focusing on the point when individuals move from one education level to the next. This doesn’t follow one group over time as these data were unavailable for this article. The authors found the biggest disparities occur at the time of graduation from undergraduate and graduate programs. While differences were seen at other levels the largest change occurred at these times. The authors suggest that to make the biggest difference there should be a focus on programs that lower attrition rates.

Handelsman, J. and E. Fine (2005) “Benefits and Challenges of Diversity” from Handelsman, J., C. Pfund, S. Miller Lauffer, and C.M. Pribenow *Entering Mentoring: A Seminar to Train a New Generation of Scientists*, Madison, WI: University of Wisconsin Press

An excellent summary of the benefits of diversity, including a summary of research showing that diverse working groups develop higher quality ideas and analysis, as well as that showing that students who interact with more diverse peers have greater intellectual engagement and active thinking. Challenges of diversity include lower job satisfaction among women and minority faculty members, and feelings of isolation and exclusion among minority faculty and students, as well as among women particularly in male-dominated fields. Stereotype threat and unconscious associations and biases are also discussed as challenges of diversity. Recommendations include developing awareness of and strategies to minimize the effects of unconscious bias, as well as focusing on individuals rather than relying on group associations. In addition, strategies for developing and promoting positive, inclusive communities are given, as well as suggestions to avoid activating stereotype threat, including giving specific, positive supportive feedback and specific, constructive criticism.

Haak, D. C., J. HilleRisLambers, E. Pitre and S. Freeman (2011) "Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology." *Science* 332: 1213-1216. DOI: 10.1126/science.1204820

There has been a goal to increase the number of underrepresented minorities (URMs) in STEM fields. Many programs have been used to increase the representation of URMs but many of these are expensive and once the funding is used the programs tend to end. The authors suggest that increasing structure and active learning activities in the classroom can reduce the achievement gap in the sciences. Reducing the achievement gap has been shown to be an important component of increasing URM representation in STEM. The authors compared introductory biology classes with minimal active learning, classes with some active learning activities, and classes where the lecture was replaced with outside reading and only active learning activities were used in the classroom. It was found that all students benefited the most from the latter class, but there was some improvement seen with the students in the classes with some active learning. Further analysis showed that underrepresented minorities benefited most from the increase in active learning, thus decreasing the achievement gap. The authors suggest that adding structured active learning into classes is a low-cost way to decrease the achievement gap.

Hurtado, S., N. L. Cabrera, M. H. Lin, L. Arellano and L. L. Espinosa (2009) "Diversifying Science: Underrepresented Student Experiences in Structured Research Programs." *Research in Higher Education* 50(2): 189-214. DOI: 10.1007/s11162-008-9114-7

Many undergraduate research programs have been developed at colleges and universities to increase science student retention. Many reasons have been given for why these experiences are so important and in this paper the authors investigate student experiences in these research programs. The authors interview underrepresented minority (URM) students from four universities with structured research programs. The goal of these interviews was to develop an understanding of the experience students had, if these programs helped develop their science interests, and any difficulties they faced. The interviews were organized into seven broad categories but the authors only discuss three in the paper: social stigma, navigating the culture of science, and becoming a scientist. The students discussed topics such as their early interests in science, how research affected their career plans, support from their programs, stigma they faced from other students and from outside sources, competitiveness of the programs and academic intimidation and how these topics affected them. In order to increase support of URM students in STEM fields it is important to understand the barriers that are faced and how to create inclusive learning environments that overcome these barriers.

Johnson, A. C. (2007) "Unintended consequences: How science professors discourage women of color." *Science Education* 91(5): 805-821. DOI: 10.1002/sce.20208

Women are a minority in science and engineering, and women of color make up an even smaller percentage of PhDs in science. There is little information about the experiences of women of color in science classrooms. This study focuses on 16 women of color in an enrichment program for the sciences at a large university. Classroom observations and student interviews were used to obtain information. The study found that the large class sizes left the students feeling alone and anonymous. In-class participation allowed confident students to stand out; however, many women of color have been trained to avoid bringing attention to themselves and didn't feel comfortable participating. Instead of strong mentoring relationships and communities, many women felt isolated in their research labs. These students often felt the professors had a narrow focus, which made it difficult to see how the research and class topics related to the larger picture that they were interested in. Finally, the lack of discussion of race, ethnicity, and gender in science made some students feel awkward about it. Some of these concerns can be addressed, such as realizing science has a culture and starting to adopt some practices that allow more students to succeed. Some small changes like clicker questions, professors establishing rapport with students, showing how research relates to bigger pictures, and incorporating discussions of ethnicity and race when appropriate could help overcome the established culture.

Miyake, A., L. E. Kost-Smith, N. D. Finkelstein, S. J. Pollock, G. L. Cohen and T. A. Ito (2010) "Reducing the Gender Achievement Gap in College Science: A Classroom Study of Values Affirmation." *Science* 330(6008): 1234-1237. DOI: 10.1126/science.1195996

This paper reports on a study evaluating the use of a values affirmation activity at reducing the gender achievement gap in an introductory physics course. For the brief, 15-minute activity, each student chose from a list a value that is most important (affirmation group) or least important (control group) to the student. The student then wrote about why that value was important to them (affirmation group) or to other people (control group). The study found that the values affirmation significantly reduced the gender gap on both exam scores and conceptual understanding of physics. The study also addressed the effect of the values affirmation on those who endorse the stereotype that "men perform better than women in physics." For women, endorsement of this stereotype was negatively correlated with performance. However, this correlation was eliminated for women who completed the values affirmation. Together these results suggest that the values affirmation can address the gender gap in physics.

Whittaker, J. A. and B. L. Montgomery (2012) "Cultivating Diversity and Competency in STEM: Challenges and Remedies for Removing Virtual Barriers to Constructing Diverse Higher Education Communities of Success." *Journal of Undergraduate Neuroscience Education* 11(1): A44-A51.

There is a call to increase the number of STEM graduates, particularly those who are underrepresented minorities (URMs). The authors discuss some institutionally developed programs that offer support to URMs, institutional partnerships that were created to assist in graduate school transitions, and some of the national programs that have been developed to aid students at many institutions. In order to continue to develop programs to aid URMs, the barriers to their success need to be studied. Historically Black Colleges and Universities and Minority Serving Institutions tend to have high success rates of producing URM STEM doctoral degrees, even with more limited resources than predominantly white institutions (PWIs). This suggests it isn't just funding that needs to be addressed but that environmental differences lead to barriers for the URM at PWIs. The authors suggest PWIs investigate the specific barriers their environments might have for URM students and address these on an institutional level. Creating effective support systems for URMs by means of environment and culture are important ways to increase their success.

Graduate Student Professional Development and Mental Health

DeChenne, S.E., N. Koziol, M. Needham and L. Enochs (2015) "Modeling sources of teaching self-efficacy for science, technology, engineering, and mathematics graduate teaching assistants" *CBE-Life Sciences Education* 14:1-14. DOI: 10.1187/cbe.14-09-0153

Teaching self-efficacy, which is the belief in one's ability to carry out a task effectively, has been shown to correlate with student achievement in K-12 teachers, as shown in work cited by the authors. This analysis examined factors that contribute to teaching self-efficacy among graduate teaching assistants (TAs). Hours spent in TA professional development, being in a facilitating environment, K-12 teaching experience, and the quality of TA professional development programs were shown to influence TA teaching self-efficacy. A facilitating environment is considered one that supports teaching through its culture and practices. Examples of such practices include providing high-quality, ongoing TA professional development, taking TA suggestions seriously, and providing feedback to TAs on their teaching performance through mechanisms beyond student course evaluations.

Feig, A. L., L. Robinson, S. Yan, M. Byrd and A. Mathur (2016) "Using Longitudinal Data on Career Outcomes to Promote Improvements and Diversity in Graduate Education" *Change* 48(6): 42-49. DOI: 10.1080/00091383.2016.1247582

The Student Lifecycle Project was undertaken to determine outcomes of doctoral graduate education at Wayne State University. In Phase I, departments and individual faculty were surveyed to acquire information about their alumni, which covered about 20% of alumni. Phase 2 involved searching for alumni online. Phase 3 involved a survey of a subset of alumni to validate the information gathered in Phases 1 and 2 as well as additional information about career trajectory and their experiences as PhD students. These data can then be used in combination with information about campus and professional activities in which students engaged to develop professional development workshops to help students build transferable skills. The data are also useful in graduate recruiting. In addition, the article lists several examples of data dashboards that can be useful for institutions considering carrying out a similar analysis and for students, faculty, and administrators interested in career outcomes.

Fisher, A. J., R. Mendoza-Denton, C. Patt, I. Young, A. Eppig, R. L. Garrell, D. C. Rees, T. W. Nelson and M. A. Richards (2019) "Structure and belonging: Pathways to success for underrepresented minority and women PhD students in STEM fields" *PLoS ONE* 14(1): e0209279. DOI: 10.1371/journal.pone.0209279

A survey of nearly 500 STEM graduate students, excluding the biological sciences, was conducted to identify factors contributing to the success of PhD students, with the goal of diversifying STEM leadership positions. Student feelings of belonging, the extent of structure within doctoral programs, feelings of well-being, sense of preparedness for doctoral study, and publication rates were measured and subject to path analysis. Women and underrepresented minorities reported feeling less prepared than their peers for graduate work and women reported feeling insignificant in their graduate programs. Accounting for differences in perceived readiness for graduate work, sense of belonging, and student perceptions of graduate program structure eliminated differences in the likelihood of publishing by race. Reported well-being was increased by feeling accepted in STEM, perceived success, and positive perceptions of graduate program structure. Graduate program structure includes clear expectations and performance standards and is found here to influence feelings of acceptance, belonging, and well-being, which in turn affect student success; thus, clarifying expectations and standards can help address several factors that lead to student stress.

Gibbs K.D. Jr., J. McGready, J.C. Bennett and K. Griffin (2014) "Biomedical Science Ph.D. Career Interest Patterns by Race/Ethnicity and Gender." *PLoS ONE* 9(12): e114736. DOI: 10.1371/journal.pone.0114736

This survey of 1,500 recent biomedical sciences PhDs found a significant decline in interest in faculty careers and increased interest in non-research careers over the timespan of the PhD. Analyzing women and underrepresented minority PhDs separately revealed that men from well-represented backgrounds had higher interest in faculty careers at research universities than all other groups. Male and female underrepresented minority students showed the largest decrease in interest in faculty positions at research universities followed by well-represented women and well-represented men, whereas overall interest in faculty careers at teaching institutions and in non-academic research positions remained relatively unchanged. Underrepresented minority women had the highest interest in non-research careers at PhD completion. This work also examined potential predictors of career interest and found that higher research self-efficacy was associated with interest in faculty positions at research universities and non-academic research careers. First-author publication rate was associated with interest in faculty careers at research universities, but not with interest in teaching-intensive faculty careers or non-academic research careers. Attending a top-50 research university was negatively associated with interest in faculty careers at research universities but advisor interest in one's career and high levels of departmental career support for academic or non-academic careers were associated with interest in faculty careers at research universities. It is noted that these are associations and do not imply causality.

Gilmore, J., D. M. G. Lewis, D. Feldon, M. Maher and B. E. Timmerman (2015) "Feeding two birds with one scone: The relationship between teaching and research for graduate students across the disciplines." *International Journal of Teaching and Learning in Higher Education* 27(1): 25-41. *https://www.isetl.org/ijtlhe/pdf/IJTLHE1874.pdf*

The authors focus on graduate student perception of the link between teaching and research, the skill set required by both teaching and research, and the integration of both teaching and research. The authors were also curious if there was any difference in perception across disciplines. The study used a survey of 308 graduate students to obtain their opinions on the relationship between teaching and research and their views on this relationship. The students who participated in the study have backgrounds in many fields including sciences and humanities. The results showed most students felt there was a link between research and teaching but how the relationship was viewed varied by student and within disciplines. A small percentage of students felt there was either no relationship or that teaching had a negative effect on research. The authors suggest further investigation into how integrating teaching and research could affect skills and how student-faculty interactions could affect views on teaching-research relationships.

Hish, A. J., G.A. Nagy, C. M. Fang, L. Kelley, C. V. Nicchitta, K. Dzirasa and M. Z. Rosenthal (2019) "Applying the Stress-Burnout and Stress-Depression Relationships in Biomedical Doctoral Students: A Cross-Sectional Pilot Study." *CBE-Life Sciences Education* 18(4): ar51, 1-11. DOI: 10.1187/cbe.19-03-0060

This work follows up on previous reports of high incidence of mental health problems in doctoral students to identify sources and mediators of stress, burnout, and depression in doctoral students. Mastery, the feeling that someone is in control of their circumstances related to self-efficacy, social support, and the relationship with one's advisor were examined. Sources of academic stress, namely mastery and the advising relationship, were positively correlated with burnout. Family and monetary stress were positively correlated with depression. In agreement with other studies, the authors found that academic support has a larger impact on doctoral student satisfaction than the social support of peers and family members. Thus, it is suggested that programs that increase a student's sense of mastery as well as improve the doctoral program environment and improve advising relationships are likely to improve doctoral student mental health.

Hobin, J. A., P. S. Clifford, B. M. Dunn, S. Rich and L. B. Justement (2014) "Putting PhDs to Work: Career planning for Today's Scientist." *CBE-Life Sciences Education* 13(1):49-53. DOI: 10.1187/cbe-13-04-0085

The focus of this study is on understanding the use of individual development plans (IDPs) in career planning. In general, awareness of IDPs and their use was low among postdoctoral researchers and mentors. Those using IDPs reported that the IDP helped them assess their skills and identify additional skills needed for their careers. The use of IDPs also facilitated communication between postdocs and mentors. The study highlighted a disconnect between the stated willingness of mentors to discuss career planning with trainees and the reluctance of postdocs to discuss their career goals with their mentors. Recommendations for postdocs include taking responsibility for their own career planning and discussing their career planning with their advisors, other mentors, and support staff. Faculty mentors are advised to take the initiative in discussing career planning with trainees and learn about institutional and other resources for career planning.

Kearns, H., M. Gardiner and K. Marshall (2008) "Innovation in PhD completion: the hardy shall succeed (and be happy!)" *Higher Education Research & Development* 27: 77-89 DOI: 10.1080/07294360701658781

This article examines self-sabotaging behaviors in PhD students that inhibit success. Such behaviors include overcommitting, procrastination, and perfectionism, and indications that students were not making progress include avoiding interactions with their advisor, isolating themselves, and not seeking feedback on their work. A program is described that uses cognitive behavioral therapy-based coaching to develop cognitive and emotional skills in students to overcome these problems. A series of workshops were delivered to help students identify these behaviors, understand the underlying bases leading to these behaviors, and develop skills to address them. Student impressions of the effectiveness of the course were generally correlated with self-reports of lower stress and the ability to complete their dissertations in a timely manner. In addition, students reported stress reduction that correlated with how often they met with their advisors. While this approach seems broadly applicable, there are a few issues in the article that are specific to the higher education system in Australia.

Kurdziel, J. P. J. A. Turner, J. A. Luft and G. H. Roehrig (2003) "Graduate Teaching Assistants and Inquiry-Based Instruction: Implications for Graduate Teaching Assistant Training." *Journal of Chemical Education* 80(10): 1206-1210. DOI: 10.1021/ed080p1206

This paper indicates that graduate teaching assistants (GTAs) need more extensive training if they are going to teach inquiry-based labs. Many undergraduate labs are taught by GTAs with very little training in general and even less experience in inquiry-based labs. Some GTAs have prior experience with inquiry-based labs and their previous experience, whether good or bad, often determines their ability to teach in these labs. This study focused on six GTAs who were asked to teach an inquiry-based lab after receiving two days of general training and four days of chemistry-specific training. These GTAs also met weekly for meetings and sat in on each other's courses to get feedback. The researchers interviewed the GTAs at the beginning of the semester, observed several classes, and debriefed them at the end of each period. It was found most GTAs do not understand how students learn and this made it difficult to teach. Many of the GTAs were unsure how to interact with the students and instead of asking questions would just give the students the answers or show them how to do things. The researchers recommend classes where the GTAs are introduced to learning theory, careful placement of GTAs into inquiry-based lab environments, and introducing role models who can show expected behavior in inquiry-based labs.

Lovitts, B. E. (2008) "The Transition to Independent Research: Who Makes It, Who Doesn't, and Why" *The Journal of Higher Education* 79: 296-325. DOI: 10.1353/jhe.0.0006

Focus group discussions with faculty who have supervised a relatively large number of PhD dissertations were used to determine the factors that lead students to produce high-quality scholarship vs. passable dissertations vs. leaving the program without completing a dissertation. The qualities leading students to produce high-quality scholarship include practical intelligence, which is the ability to solve problems, be resourceful, and react appropriately to criticism. Informal knowledge about research and the academy were also important for success, and it was noted that students who come from colleges without active research cultures were generally at a disadvantage. Some personality traits were also noted as correlating with success, including self-discipline, intellectual curiosity, persistence, initiative, and patience. Students who had a fear of failure or difficulty coping with ambiguity generally struggled. Intrinsic motivation and a supportive environment including high-quality advising and mentoring were also important for graduate

student success. The author concludes that there is not one single predictor of success in a PhD program and that above a certain threshold of academic performance, admissions committees should consider assessing skills or predictors of success identified in this research.

Mousavi, M. P. S., Z. Sohrabpour, E. L. Anderson, A. Stemig-Vindedahl, D. Golden, G. Christenson, K. Lust and P. Bühlmann (2018) "Stress and Mental Health in Graduate School: How Student Empowerment Creates Lasting Change" *Journal of Chemical Education* 95(11): 1939-1946. DOI: 10.1021/acs.jchemed.8b00188

This paper reports a collaboration between a chemistry department and a university health service to increase student awareness of mental health issues among students and to make students aware of campus resources. The health service surveyed graduate students to assess their mental health needs, which revealed the importance of social support in decreasing stress. In response to the survey results, the department introduced more opportunities for students to receive feedback and learn professional, non-technical skills, and more social events for students, as well as a fourth-year meeting with the likely dissertation defense committee to report on progress and address concerns.

Rice, K. G., H. Suh, X. Yang, E. Choe and D. E. Davis (2016) "The Advising Alliance for International and Domestic Graduate Students: Measurement Invariance and Implications for Academic Stress" *Journal of Counseling Psychology* 63(3): 331-342. DOI: 10.1037/cou0000141

A previously validated instrument, the "Advisory Working Alliance Inventory" was used to compare the advising experiences of international and domestic graduate students. The Inventory assesses the perceptions of students of their working alliance with their advisors, reflecting the connection between them as a result of their working together toward their common goals. Previous work identified a correlation between the advising alliance and feelings of research self-efficacy among students. This study found no overall difference between international and domestic students in alliance or academic stress and makes the recommendation that students be trained in considerations of alliance as well as that advisors intentionally examine their rapport with advisees.

Shortlidge, E. E. and S. L. Eddy (2018) "The trade-off between graduate student research and teaching: A myth?" *PLoS One* 13(6): e0199576. DOI: 10.1371/journal.pone.0199576

There has been a national push toward student-centered teaching practices or evidence-based teaching (EBT). However, many faculty members have not made the change toward EBT practices and many barriers to these practices have been found. One way that has been suggested to help overcome some of the barriers is to train future faculty in these areas before they become faculty. Some institutions offer short trainings, but research

has shown that more long-term training is more effective. There is a widely held belief that graduate students should spend as much time as possible conducting research and long-term teaching training programs would take the focus away from this. However, research is limited in regard to EBT training programs and how they would affect student preparedness for a research career. This article focuses on second year and above PhD students in life sciences who opted to take an online survey about their time and preparedness for a research career. To determine preparedness the researchers looked at how confident students were that their PhD prepared them for future research, how confident they were in communicating their science, and the number of publications a student had. The evidence showed that the students who participated in EBT training courses felt just as prepared for a career in research as those who did not.

Silva, E. A., A. B. Mejia and E. S. Watkins (2019) "Where Do Our Graduates Go? A Tool Kit for Tracking Career Outcomes of Biomedical PhD Students and Postdoctoral Scholars" *CBE-Life Sciences Education* 18(4):le3.1-6. DOI: 10.1187/cbe.19-08-0150

In support of efforts to disseminate information about careers of PhDs, 48 institutions formed the Coalition for Next Generation Life Sciences to collect career information on graduate students and postdoctoral scholars. This paper reports the data collection and classification of careers that went into developing an online tool to make the data available. Data were collected for the past 15 years using mainly surveys and LinkedIn. This is a model for other institutions to collect and share these data to improve transparency about career outcomes. More information is at nglscoalition.org.

Sinche, M., R. L. Layton, P. D. Brandt, A. B. O'Connell, J. D. Hall, A. M. Freeman, J. R. Harrell, J. Gowen Cook and P. J. Brennwald (2017) "An evidence-based evaluation of transferrable skills and job satisfaction for science PhDs" *PLoS One* 12(9): e0185023. DOI: 10.1371/journal.pone.0185023

An analysis of 15 skills indicates that doctoral training develops these transferable skills and that the majority of skills were applicable to both research-intensive and non-research-intensive careers. In addition to discipline-specific knowledge, skills that were examined include the ability to gather, interpret, and analyze data and information; communication skills; project management skills; creativity; goal setting; time management; teamwork; management skills; ability to work with external clients, and career planning skills. The largest skill gaps were identified for time management, teamwork, managing others, ability to work with external clients, and career planning and awareness skills, although even these gaps were relatively small, indicating that skill acquisition and development during doctoral training is generally appropriate for future careers. Job satisfaction was reported to be high and did not differ significantly between the those in research-intensive or non-research-intensive careers. In general, doctoral training provides trainees with transferrable skills for a range of careers, but several areas of improvement were noted as those skills with identified gaps, especially career planning and awareness skills. It is noted that skill gaps may indicate a lack of confidence rather than an actual deficiency in a given skill. Recommendations for graduate programs include helping trainees build these skills as well as helping trainees identify transferrable skills. Additionally, dedicated career planning services and career training and coaching are recommended.

Sverdlik, A. and N. C. Hall (2020) "Not just a phase: Exploring the role of program stage on well-being and motivation in doctoral students" *Journal of Adult and Continuing Education* 26(1): 97-124. DOI: 10.1177/1477971419842887

Graduate student well-being and motivation are important factors for degree completion and satisfaction. This paper examines student well-being over time and finds that generally the less structured aspects of the PhD cause the greatest impact on motivation. Motivation lags and well-being decreases in less structured parts of a PhD such as qualifying exams and dissertation research due to lack of feedback and the solitary nature of the work. A discussion of previous work reveals that motivation in graduate students is linked to their sense of competency and self-efficacy in their professional activities, perception of support from supervisors, and a sense of personal choice and self-determination. This study found that stress levels were highest during the qualifying or comprehensive examination and lowest during the coursework phase, while satisfaction with the program and motivation were lowest during the dissertation research phase; self-efficacy was highest during the dissertation research stage. The authors call for more social support and mental health resources, particularly during the more unstructured dissertation stage.

Wheeler, L. B., J. L. Maeng and B. A. Whitworth (2016) "Characterizing Teaching Assistants' Knowledge and Beliefs Following Professional Development Activities within an Inquiry-Based General Chemistry Context." *Journal of Chemical Education* 94(1): 19-28. DOI: 10.1021/acs.jchemed.6b00373

There has been an increase in the amount of teaching being conducted by teaching assistants (TAs) in recent years. The TAs, their content knowledge, and their beliefs determine how they teach and interact with students during the semester. Furthermore, TAs have little to no background in teaching and professional development (PD) programs are important to help them now and in their futures. The purpose of this study was to investigate how PD and teaching can influence a TA's context knowledge and beliefs pertaining to an inquiry-based general chemistry lab. There were 13 students involved in the study, eight graduate TAs (GTA) and five undergraduate TAs (UTA). The TAs all participated in a pre-test and survey to determine prior content knowledge and personal views on teaching. Before the semester the TAs participated in a one-week PD course and were given another test and survey. The TAs taught inquiry-based labs over the semester and attended weekly PD meetings through the semester and took tests and surveys at the completion of the course. The study indicates PD helped improve the content knowledge of the TAs and changed the TAs' teaching beliefs in the context of an inquiry-based lab. The UTAs seemed to enter with lower content knowledge than the GTAs and seemed to benefit more from the PD than the GTAs, as seen with higher scores on the post tests.

Homework and Flipped Classes

Allain, R. and T. Williams (2006) "The Effectiveness of Online Homework in an Introductory Science Class." *Journal of College Science Teaching* 35(6): 28-30. *https://www.jstor.org/stable/42991854*

The paper examines the use of online homework assignments on student learning. Sections with graded online homework or assigned but ungraded homework were compared. No significant difference in conceptual understanding of the material was seen between sections, despite students with graded homework reporting more time spent studying outside of class.

Bonham, S., R. Beichner and D. Deardorff (2001) "Online Homework: Does It Make a Difference?" *Physics Teacher* 39(5): 293-296. DOI: 10.1119/1.1375468

The authors examined the effect of online homework compared with written homework in introductory physics courses. Back-to-back sections were taught by the same teacher with the same content, but varied homework format. Exam grades for the sections were not significantly different. Web-based homework was well-received, even though students with web-based homework reported spending more time on homework. Despite there being no apparent benefit to student performance, web-based homework has several advantages. Teaching assistants are not needed for grading, freeing them for other aspects of the course. In classes where homework is not given or not graded, web-based homework might afford significant benefits.

Collard, D. M., S. P. Girardot and H. M. Deutsch (2002) "From the Textbook to the Lecture: Improving Prelecture Preparation in Organic Chemistry." *Journal of Chemical Education* 79(4): 520-523. DOI: 10.1021/ed079p520

A technique for encouraging students to read the textbook and study the material before class is described. This method is complementary to traditional lecturing methods, providing a way to use new teaching pedagogies to make the lectures more meaningful and productive. Prelecture assignments, called HWebs, are given on textbook reading assignments relevant to the next class lecture; these assignments are composed of three multiple-choice questions ranging from simple recognition problems to more complex synthesis problems. Assignments are submitted and graded online, and answers are discussed in the next class period. Students reported often reading the textbook before coming to class and that this use of the textbook increased their understanding of the material. Though no correlation was found between grade and attitude regarding the assignments, students who did better on the assignments did better in other areas of the course.

Cormier, C. and B. Voisard (2018) "Flipped Classroom in Organic Chemistry Has Significant Effect on Students' Grades." *Frontiers in ICT 4*: article 30. DOI: 10.3389/fict.2017.00030

The authors investigate the outcome of a flipped classroom for an organic chemistry course. This article explains the methods and practices used by authors in the class. The students were asked to watch approximately 30 minutes of videos each week. There were areas of the video where the instructors asked students to pause and attempt to solve a problem related to the topic at hand. The beginning of every class was used for the students to ask any questions they had from the assigned videos and the remainder was used to solve a portfolio problem due at the end of class. During the problem solving the students could ask questions and seek help from the professor. It was found that there was an increase in the average grade compared to previous years. Most students said they enjoyed the class, but several complained about the amount of outside work. The authors say it is expected that students spend about three hours of time outside the classroom on each class and the work in this class was about three hours. It is believed it made students who would normally spend less time on each class spend more time and therefore felt like a larger workload. The authors think it might be these students who benefit the most from flipped classrooms.

Day, L. J. (2018) "A gross anatomy flipped classroom effects performance, retention, and higher-level thinking in lower performing students." *Anatomical Sciences Education* 11(6): 565-574. DOI: 10.1002/ase.1772

Flipped classrooms use class time to apply the knowledge learned outside the classroom. The students are asked to watch video lectures before class and use in-class activities to apply the knowledge gained from the pre-class videos. This paper discusses the effects of a flipped classroom on a graduate level gross anatomy class. This study focused on depth of understanding and long-term retention of the material to look past grades as the only marker of effectiveness. The authors discuss the design of the class and the types of activities used in the class. The types and timing of the assessments used to determine if the students were retaining the information are described. The test creators used low-level multiple-choice questions to test ability to remember and understand the material and high-level questions to test application and analysis. Using the exam questions and final grades of the students in both classes it was shown that students in the flipped class had better retention of material, had higher grades, and were able to perform better on higher-level questions.

Day, J. A. and J. D. Foley (2006) "Evaluating a Web Lecture Intervention in a Human-Computer Interaction Course." *IEEE Transactions on Education* 49(4): 420-431. DOI: 10.1109/TE.2006.879792

This paper describes the use of web lectures viewed prior to class as a means of freeing up class time for active-learning activities. Lectures were prepared using widely available software and were kept to 15 to 25 minutes while covering approximately the same amount of material as a typical 30 to 50 minute classroom lecture. Lecture homework assignments (LHWs) were used to motivate students to view the web lecture in advance of class time. To test the format, two sections of a course were compared, one using the web lectures and frequent in-class activities, the other in a traditional lecture format. Several controls were implemented, including decreasing the class meeting for the experimental section to account for the out-of-class time students spent viewing the web lectures. Results showed that students in the experimental section scored better, though not statistically significantly, in all aspects of the course, and received overall higher grades (statistically significant). Additionally, student attitudes were assessed four times throughout the semester, revealing that students viewed the web lectures and the experimental course format positively. Both sections viewed the LHWs as helpful in focusing studying and learning the material.

Dobson, J. L. (2008) "The use of formative online quizzes to enhance class preparation and scores on summative exams." *Advances in Physiology Education* 32(4): 297-302. DOI: 10.1152/advan.90162.2008

The author examines the use of formative online quizzes in an undergraduate exercise physiology course. Approximately weekly online quizzes were given to encourage students to complete and critically think about the reading for the class meetings. Quizzes were made available for 48 hours, typically the 48 hours before the first class meeting of the week. Students were allowed exactly 15 minutes to complete each quiz. Since the quizzes are meant to be a tool of formative assessment, they were worth 1% of the course grade, a small percentage meant to encourage students to participate and take it seriously, but without being threatening or stressful. Compared with previous sections of the course, where no online quizzes were given, students given online quizzes performed significantly better.

Klionsky, D. J. (2001) "Constructing Knowledge in the Lecture Hall." *Journal of College Science Teaching* 31(4): 246-251. *https://www.jstor.org/stable/42991369*
See Assessment of Student Learning section

Moravec, M., A. Williams, N. Aguilar-Roca and D. K. O'Dowd (2010) "Learn before Lecture: A Strategy That Improves Learning Outcomes in a Large Introductory Biology Class." *CBE-Life Sciences Education* 9(4): 473-481. DOI: 10.1187/cbe.10-04-0063

The authors examined the effect of introducing new material before class with required pre-class assignments. Three types of learn before lecture (LBL) assignments were examined: a narrated PowerPoint video with required notetaking, a one-page worksheet based on textbook reading, and a hands-on cutout project (construction of a plasmid DNA molecule). Final exam questions specifically addressing the material covered by these assignments were compared over three years with LBLs introduced in the third year. Two sections in the third year were compared to examine the effect of the different LBL methods. Results show that students in the LBL year scored higher on multiple-choice questions than in the previous years, though no difference was observed in the short answer questions. The three LBL methods examined were shown to be equally effective. Student attitudes toward the LBLs were overall positive. The LBL method is shown to be an effective way to increase student understanding of topics. Since the LBLs can be introduced for just one or two topics at a time, instructors can gradually modify their classes.

Inquiry-Based Learning Techniques

Bailey, C. P., V. Minderhout and J. Loertscher (2012) "Learning transferable skills in large lecture halls: Implementing a POGIL approach in biochemistry." *Biochemistry and Molecular Biology Education* 40(1): 1-7. DOI: 10.1002/bmb.20556

A case study in implementing POGIL (process oriented, guided-inquiry learning), this paper describes active learning activities in a large biochemistry class. The class of ~180 students met in a large lecture hall with fixed seating, so student groups were formed of three or four, the largest number that could easily communicate with each other. Each 75-minute class began with a 10-15 minute mini-lecture followed by a POGIL activity. After the activity, the remaining time was used for a second mini-lecture or POGIL activity, clicker questions, or think-pair-share, depending on how the class responded to the initial activity. The authors also describe the analogy to practicing sports used to get students to "buy-in" to this new way of learning. Students made significant conceptual gains with the new class

Barrows, H. S. (1996) "Problem-based learning in medicine and beyond: A brief overview." *New Directions for Teaching and Learning* 1996(68): 3-12. DOI: 10.1002/tl.37219966804

This paper presents a brief history of the development of problem-based learning in medical schools, and a thorough definition of the method is given. The main educational objectives of the method are discussed, as are issues of adopting problem-based learning and developing curricula. Though the paper focuses on medical education, it serves as a good introduction to important aspects of problem-based learning.

Blair, A. C., E. R. Fisher and D. Rickey (2012) "Discovering Nanoscience." *Science* 337(6098): 1056-1057. DOI: 10.1126/science.1215151

This essay describes the Model-Observe-Reflect-Explain (MORE) Thinking

Frame, an inquiry-based instructional approach that has been shown to increase students' understanding of science. Using the MORE Thinking Frame, the students describe their ideas about a particular system, conduct experiments about the system, then return to their original ideas to refine them, completing an iteration of MORE.

Brill, G. and A. Yarden (2003) "Learning biology through research papers: a stimulus for question-asking by high-school students." *Cell Biology Education* 2(4): 266-274. DOI: 10.1187/cbe.02-12-0062

This study compares four genetics classes that used research papers to supplement the information in their textbook and four genetics classes that used only the textbook. The goal of the study was to examine the effect of the research papers on the students' ability to ask questions. The students in all eight classes were surveyed periodically and the classes were monitored to obtain data throughout the semester. It was shown that students in the classes using the research papers asked more questions, deeper questions, and even were able to offer criticism-type questions in comparison to the students using only the textbook.

Chaplin, S. (2009) "Assessment of the Impact of Case Studies on Student Learning Gains in an Introductory Biology Course." *Journal of College Science Teaching* 39(1): 72-79. *https://www.jstor.org/stable/42993016*

The author describes the use of case studies in an introductory biology course. Portions of lectures were replaced with several days of examining a case study. Students are briefly introduced to the topic, and then work individually on part of the case study using the textbook as a reference. In the following class period, the class discusses questions posed in the case study and new information from the textbook. Two sections in non-sequential years were compared, one taught using only traditional lecturing, the second using case studies. In the case study section, more students showed improvement over the course of the term. Additionally, students in the case study section were better able to apply their knowledge in application-analysis-type questions, indicating an increase in higher-order thinking skills.

Coppola, B. (1996) "Progress in Practice: Teaching and Learning with Case Studies." *The Chemical Educator* 1(4): 1. DOI: 10.1007/s00897960050a

This paper provides a good description of the details of using case studies in instruction. Included are characteristics of good cases, a detailed example of implementation, and several examples of cases.

Fukami, T. (2013) "Integrating Inquiry-Based Teaching with Faculty Research." *Science* 339(6127): 1536-1537. DOI: 10.1126/science.1229850

This essay from a Science Prize for Inquiry-Based Instruction (IBI) winner briefly describes development and format of an inquiry-based biology course at Stanford University.

Hein, S. M. (2012) "Positive Impacts Using POGIL in Organic Chemistry." *Journal of Chemical Education* 89(7): 860-864. DOI: 10.1021/ed100217v

This paper discusses the use of process-oriented, guided-inquiry learning (POGIL) in a yearlong organic chemistry sequence. Students were monitored over six years, three taught using traditional lectures, three using the POGIL method. After the second semester, a standardized exam was administered as the final exam. Scores on this exam were compared for the six years to evaluate the effect of POGIL on student assessments. There was no significant difference in the average national percentile rankings between the traditional sections and the POGIL sections when using the same form of the standardized exam (a new form was implemented partway through the study). A significant decrease was observed in the number of students scoring in the 25th percentile or below upon implementation of the POGIL method. This suggests that the POGIL method does have a positive impact on student learning, having the greatest effect on lower-achieving students.

Jackson, D. P., P. W. Laws and S. V. Franklin (2012) "An Inquiry-Based Curriculum for Nonmajors." *Science* 335(6067): 418-419. DOI: 10.1126/science.1213444

This essay describes the Explorations in Physics (EiP) curriculum, which uses inquiry to increase scientific literacy of non-science majors. The curriculum emphasizes student-driven inquiry as a way of understanding the reality of ambiguities, measurement errors, and other uncertainties in science.

Luckie, D. B., J. R. Aubry, B. J. Marengo, A. M. Rivkin, L. A. Foos and J. J. Maleszewski (2012) "Less teaching, more learning: 10-yr study supports increasing student learning through less coverage and more inquiry." *Advances in Physiology Education* 36(4): 325-335. DOI: 10.1152/advan.00017.2012

The biology department at Michigan State University started an investigation after receiving negative feedback about biology courses and labs. The department carried out a 10-year study to investigate how the type of lab affects student learning. They started with the standard cookbook style labs, moved on to two seven-week studies ("two-stream" lab), and ended with a full semester long inquiry lab ("one-stream" lab). The inquiry labs allow the students to pick a question related to the topic, design a series of experiments to test their hypothesis and troubleshoot their experiments along the way. The students wrote multiple drafts of a manuscript and gave presentations in place of lab reports. The students in the standard two-stream labs showed higher levels of learning than those in the cookbook style labs. The students in the one-stream lab showed higher levels of learning compared to either of the other style labs. The one-stream labs had the highest approval rating from the students and faculty, after getting over the initial shock, found they liked them better too. Inquiry based learning allows the students to develop higher

level learning and problem-solving skills that are not covered in traditional labs. This higher-level learning allows them to approach topics and questions they may not have covered and apply their knowledge.

Pearson, R. J. (2017) "Tailoring Clicker Technology to Problem-Based Learning: What's the Best Approach?" *Journal of Chemical Educatio*n 94(12): 1866-1872. DOI: 10.1021/acs.jchemed.7b00270

The study looks at the best way to use clickers so students get the biggest benefit without creating a large burden on the instructor. This study focuses on pharmacy students taking their required chemistry courses. The authors followed a group of pharmacy students in their first two years of chemistry. The control group was a group of students that had taken the class previously. The first year focused on individual work and multiple-choice questions with the clickers being used primarily during problem-solving classes. After the first year the students felt the clickers helped them think more deeply, were useful, and enjoyable. The grades showed a small improvement over the control group and there was a decrease in failure rate for the students on the first exam. During the second year the students worked in groups to answer a mix of short answer and multiple-choice questions that were asked during lecture and problem-solving classes. The change to group questions, short-answer questions, and the addition of questions to class were made to address student feedback. Again, there was improved exam performance and positive feedback from the students. Overall, students preferred the team-based clicker questions because they encouraged peer instruction. The clickers can be helpful to create peer instruction, fun, and effective learning environments for students when used in the right conditions.

Serrano A., J. Liebner and J. K. Hines (2016) "Cannibalism, Kuru, and Mad Cows: Prion Disease as a "Choose-Your-Own-Experiment" Case Study to Simulate Scientific Inquiry in Large Lectures." *PLoS Biology* 14(1): e1002351. DOI: 10.1371/journal.pbio.1002351

The authors discuss a broadly applicable, in-class activity called An Inexplicable Disease. The authors provide all the materials for this activity in the supplemental materials. During this activity the students are introduced to a real-world outbreak in Papua New Guinea in 1957 and asked to take on the roles of scientists to investigate the outbreak in a "choose your own experiment" activity. After the brief introduction the students are divided into small groups and given different specialties. These specialties come with a list of possible experiments the students can choose from. After each experiment the students choose to receive results that provide them some information about the outbreak. The students then discuss the results and decide the next experiment they want to pursue given what they learned. No one group has all the time or all the "expertise" to obtain all the information. At the end of the activity the students draw a conclusion from their evidence.

They then participate in a full-class conference to learn about the conclusions and evidence of other groups to see if additional information changes their conclusions. After the activity there is a presentation the instructor can use to wrap up the activity and explain the conclusions of the outbreak and how the scientists drew these conclusions using collaboration. This can also be a point where the teacher can connect the activity to a variety of topics: protein folding, ethics, epidemiology, etc., that they want to introduce to the class. This activity has been used in a variety of biology courses and has received positive response from the students. Using a survey distributed at the beginning and end of the activity, the authors discussed increased understanding of science as a process, interest in taking additional biology courses, and an appreciation for collaborations in science by the students.

Yadav, A., M. Lundeberg, M. DeSchryver, K. Dirkin, N. A. Schiller, K. Maier and C. F. Herreid (2007) "Teaching Science With Case Studies: A National Survey of Faculty Perceptions of the Benefits and Challenges of Using Cases." *Journal of College Science Teaching* 37(1): 34-38. *https://www.jstor.org/stable/42992528*

This article presents the results of a survey of faculty using case studies in their courses and addresses the perceived benefits and obstacles. Generally, faculty view using case studies in instruction as beneficial, with few obstacles.

Just-In-Time Teaching

Marrs, K. A. and G. Novak (2004) "Just-in-Time Teaching in Biology: Creating an Active Learner Classroom Using the Internet." *Cell Biology Education* 3(1): 49-61. DOI: 10.1187/cbe.03-11-0022

The authors provide a summary of Just-in-Time Teaching (JiTT) and describe how it has been adopted in two different courses. JiTT combines active learning constructivism and formative assessment to more fully engage both student and instructor, and relies on web-based course content to create a feedback loop between student and instructor. Three key aspects of JiTT are discussed in the paper: warm-up assignments, interactive lectures, and "What is Biology Good For" extra credit assignments. Weekly warmup exercises are designed to identify student misconceptions and prior knowledge. This information is then used during class to address the misconceptions directly. Lectures described here consist of a short lecture/discussion for the first third of the class time, followed by cooperative learning exercises tied to the warm up exercises. "What is Biology Good For" are extra credit assignments that address biology in the news or address topics not covered in the course, and help students connect their classroom activities with the outside world. JiTT has several benefits: increasing classroom interactivity, providing ongoing formative assessment, and increasing retention rates, class preparation, and study habits. The authors note that while JiTT does require a large time commitment from instructors to implement, small portions of the program can be implemented at a smaller time cost and still be effective.

Novak, G., A. Gavrin and E. Patterson (2004) "Just-In-Time teaching." *http://jittdl.science.iupui.edu/.*

This website introduces the Just-In-Time teaching (JiTT) method, goals, and examples of different approaches.

Research and Mentorship

Carpi, A., D. M. Ronan, H. M. Falconer and N. H. Lents (2017) "Cultivating minority scientists: Undergraduate research increases self-efficacy and career ambitions for underrepresented students in STEM." *Journal of Research in Science Teaching* 54(2): 169-194. DOI: 10.1002/tea.21341

This article discusses the positive outcomes of an undergraduate research program at a minority serving institution (MSI). Research experiences have been shown to be important factors in student persistence in STEM fields. The trend is especially true for underrepresented minorities. Some programs have been developed to increase undergraduate research experiences but many of these are at large R1 institutions and very few are at MSIs. The authors focus on an undergraduate research experience program at an underfunded, commuter-heavy MSI. This case study was developed using formal and informal interviews, student work, and program data. It was found this program helped increase self-efficacy, increased students' expectations of themselves and their careers, helped them overcome barriers, and gain exposure to new career options and paths. The authors point out the parts of this program that they feel are unique and most important in achieving the above outcomes.

Davis, S. N. and R. M. Jones (2017) "Understanding the role of the mentor in developing research competency among undergraduate researchers." *Mentoring & Tutoring: Partnership in Learning* 25(4): 455-465. DOI: 10.1080/13611267.2017.1403534 and references therein

Several factors were examined to determine those that contribute to self-reported research competency of undergraduate researchers. Research competency was evaluated with a 19-item survey that asked about technical skills, research communication skills, distinguishing between personal beliefs and evidence, evaluating the quality of an argument or a study, understanding ethical conduct in the field, and making connections between research and coursework, among others. Undergraduate researchers were asked about the frequency of interactions and changes in formality of interactions with their research mentors and the extent to which their mentors engaged in active mentoring. Active mentoring was characterized by 10 survey items, which are mostly aligned with practices described by Shanahan (2015, below), including helping with technical details of the work and troubleshooting, communicating expectations, providing constructive feedback, and being available to the student. Of the mentoring aspects probed, only active mentoring behaviors were correlated with competency; frequency of interactions or changes in formality were not. The authors postulate that active mentoring practices signal the level of engagement of the mentor as well as their ability to model research practices. While this study did not focus exclusively on undergraduate researchers in STEM, these findings should be highly relevant to those fields.

Estrada, M., P. R. Hernandez and P. W. Schultz (2018) "A Longitudinal Study of How Quality Mentorship and Research Experience Integrate Underrepresented Minorities into STEM Careers." *CBE Life Sciences Education* 17(1). ar9. DOI: 10.1187/cbe.17-04-0066

This article examines how research experiences help students integrate into STEM fields and what social integration measures are good predictors of underrepresented minority (URM) persistence in STEM careers. Students in this study were surveyed about how different experiences affected their selection of a STEM, medical, or non-STEM field career. To probe effects over time the surveys were administered during the junior year, senior year, and six years after graduation. The authors use the tripartite integration model of social influence (TIMSI) in this paper because recent results indicated it predicted URM persistence in STEM fields. The model examines how scientific efficacy, identity, and values correlate to URM students choosing a STEM or medical career. It was found that quality mentorship and at least two years of research experiences are important for students choosing STEM careers. Additionally, it was found that scientific identity and values are better predictors of URM students choosing STEM careers than scientific efficacy.

Hanauer, D. I. and E. L. Dolan (2014) "The project ownership survey: measuring differences in scientific inquiry experiences." *CBE Life Sciences Education* 13(1): 149-158. DOI: 10.1187/cbe.13-06-0123

Research experiences are good for undergraduate students. Extensive research shows that students learn more and have more positive experiences in inquiry-based labs compared to the standard laboratory experience. One possible theory for these differences is that project ownership plays a large role in science retention by undergraduate students. This article discusses the creation of a survey tool that could be used to study project ownership in undergraduate research experiences. The Project Ownership Survey (POS) created covers three main components: discussion of the research project, assessment of degrees of project ownership, and emotional scales. The POS was taken by 68 students from 21 different universities who completed it voluntarily. The survey was validated by comparing the data to other data that already showed project ownership played a role in science retention. The survey was found to be a useful tool for measuring project ownership and differences between groups. This tool can be used to conduct further studies.

Limeri, L. B., M. Z. Asif, B. H. T. Bridges, D. Esparza, T. T. Tuma, D. Sanders, A. J. Morrison, P. Rao, J. A. Harsh, A. V. Maltese, and E. L. Dolan (2019) "Where's My

Mentor?!" Characterizing Negative Mentoring Experiences in Undergraduate Life Science Research" *CBE Life Sciences Education* 18(4):ar61. DOI: 10.1187/cbe.19-02-0036

This work reports a study to characterize negative mentoring experiences in undergraduate research, focusing on mentee perceptions of their mentoring relationships. The negative mentoring behaviors were classified into seven categories: absenteeism, abuse of power, interpersonal mismatch, lack of career and technical support, lack of psychosocial support, misaligned expectations, and unequal treatment. Absenteeism was interpreted by mentees as a sign that the mentee and their work was not worth the time and attention of the mentor. Abuse of power included the mentor failing to take responsibility for mistakes or blaming mentees for mistakes or misunderstandings. Misaligned expectations included expecting far too much of mentee knowledge and skills, providing too little oversight, as well as not allowing mentees to carry out experiments themselves and failure to give mentees opportunities to try to solve problems. These mentoring behaviors were placed on a spectrum from the absence of a positive mentoring experience (lack of career and psychosocial support, interpersonal mismatch) to actively negative and harmful mentoring experiences (abuse of power and unequal treatment), with absenteeism and misaligned expectations falling in the middle of the scale. Recommendations include discussing mentor and mentee expectations for the research experience, being available as a mentor to provide career advice and feedback, including formative assessments early in the research experience that can build in complexity. It is also recommended that mentors provide encouragement to mentees, especially when mistakes are made, and reflect on how they interact with mentees.

Lopatto, D. (2004) "Survey of Undergraduate Research Experiences (SURE): first findings." *Cell Biology Education* 3(4): 270-277. DOI: 10.1187/cbe.04-07-0045

Research experiences have been said to enhance student experiences and promote further scientific studies and careers. These outcomes seem to be especially important for underrepresented minorities (URMs). The author surveyed students across 41 universities regarding their undergraduate research experiences to investigate these claims. The survey used included questions about demographics, learning gains, and evaluation of research experiences. The author found that overall students' experience and knowledge were enhanced by summer research experiences. Additionally, the survey showed most students' plans to continue in the sciences were sustained by the experience. Some students had changed their minds about a future career in STEM, however this seems to be related to specific experiences. Differences were not observed across gender, ethnic group, or institution type.

Nagda, B.A., S.R. Gregerman, J. Jonides, W. von Hippel and J.S. Lerner (1998) "Undergraduate Student-Faculty Research Partnerships Affect

Student Retention." *The Review of Higher Education* 22(1): 55-72. DOI: 10.1353/rhe.1998.0016

Attrition rates are disproportionately high for underrepresented minority (URM) students. Integration into a field is known to be an important factor in retention, especially for URMs. This article discusses the Undergraduate Research Opportunity Program (UROP) that gets students involved in research early in their college careers, within the first or second year, in an effort to promote integration. Two groups were selected from the applicant pool that were considered similar based on their program applications. All participants in the study had applied to the program. Retention rate data and demographic information were obtained from the registrar's office. The authors found that this program seems to have a large effect on the attrition rate of African American students, with the largest effect seen for historically low-achieving students. There was some effect for low-achieving white students. The data indicates different racial/ethnic groups may have different needs or program aspects to help them develop a community and feel included at a university. Also, more research needs to be done to determine the parts of this program that were most helpful in increasing the retention rates.

Pender, M., D. E. Marcotte, M. R. Sto. Domingo and K. I. Maton (2010) "The STEM Pipeline: The Role of Summer Research Experience in Minority Students' Ph.D. Aspirations." *Education Policy Analysis Archives* 18(30). DOI: 10.14507/epaa.v18n30.2010

The percentage of STEM degrees being awarded to underrepresented minorities is disproportionate to the demographics. The authors conducted a literature search to obtain more information on the barriers to retention for URMs. They found many claims indicating undergraduate research experiences were important for persistence, but there was still little empirical evidence. The authors used several years of data obtained from a program at the University of Maryland Baltimore County to provide more empirical evidence. The Meyerhoff Scholarship Program engages students in a summer research opportunity that allows them to take their relationships and studies outside of the classroom and to establish scientific networks. The authors use statistical analysis to investigate if participation in a summer research program, the number of research opportunities, the timing of the research opportunity, and other demographic aspects have an effect on whether or not students attend a STEM PhD program. It is found that students who participate in summer research opportunities at any point after their sophomore year are more likely to go into STEM PhD programs. Some possibilities as to why this may be the case are discussed, but the authors suggest additional research be conducted on why these research experiences seem to be so important.

Pfund, C., A. Byars-Winston, J. Branchaw, S. Hurtado and K. Eagan

(2016) "Defining Attributes and Metrics of Effective Research Mentoring Relationships." *AIDS and Behavior* 20 Suppl 2: 238-248. DOI: 10.1007/s10461-016-1384-z

Mentoring is an important aspect in science persistence, especially for underrepresented minorities (URMs). There is often little training provided for mentors and mentees, assuming the involved parties can figure out how to foster the relationship on their own. Several funding agencies have expressed interest in supporting research to determine what types and modes of mentoring result in the best outcomes for all parties. To study these relationships there need to be standards and metrics that can be used to have a beneficial mentoring relationship. The authors discuss conceptual frameworks that currently exist and can be used to better understand and develop mentoring relationships. The authors supply a table with suggested attributes from the frameworks outlined in the paper, which also contains examples of objectives and currently available metrics to help assess mentoring relationships. The data presented in this paper are suggestions. More research needs to be conducted to test the theories presented here.

Shanahan, J. O., E. Ackley-Holbrook, E. Hall, K. Stewart and H. Walkington (2015) "Ten Salient Practices of Undergraduate Research Mentors: A Review of the Literature." *Mentoring & Tutoring: Partnership in Learning* 23(5): 359-376, DOI: 10.1080/13611267.2015.1126162

This review of 100 studies on effective undergraduate research mentoring finds 10 effective practices, which fit within the three important aspects of undergraduate research mentoring: intellectual support, personal/emotional support, and professional socialization (Thiry and Laursen 2011). The ten practices are: (1) tailor the research experience to the level of the student; (2) set clear and scaffolded expectations, including possibly using a syllabus or other formal document; (3) teach technical skills, methods, and analysis, including safety and ethics; (4) balance rigor with emotional and personal support of the student; (5) build a sense of community within the team; (6) dedicate time to one-on-one mentoring; (7) build increasing student ownership of the project over time; (8) support professional development through networking and socialization; (9) help students build skills in peer and near-peer mentoring; and (10) help students communicate their findings in conference presentations and in writing. Emotional and personal support, as well as professional socialization, were found to be especially important for underrepresented minority students. Additional examples of impacts on students are discussed within the article.

Student Self-Assessment and Concept Inventories

Bauer, C. F. (2005) "Beyond "Student Attitudes": Chemistry Self-Concept Inventory for Assessment of the Affective Component of Student Learning." *Journal of Chemical Education* 82(12): 1864-1870. DOI: 10.1021/ed082p1864

This paper describes the development and initial uses of an instrument, the chemistry self-concept inventory or CSCI, for measuring student attitudes in and toward chemistry. The CSCI seeks to better define "attitude" by differentiating several different mental constructs underlying the term, such as beliefs, interests, and understanding of the nature of science. The instrument is based on the well-developed Self Description Questionnaire III (SDQIII), which has been shown to be strongly valid and reliable; however, as the SDQIII does not address attitude toward science or chemistry, 10 of 40 questions were modified to address attitudes toward the subject of chemistry. The remaining questions probe attitudes toward mathematics, academics, academic enjoyment, and creativity. In the CSCI instrument, students rank their agreement with statements on a seven-point scale from "very accurate of me" to "very inaccurate of me." The instrument was tested on diverse student populations, establishing validity and reliability. The CSCI instrument is useful in understanding how students perceive themselves in chemistry, mathematics, academic performance, academic enjoyment, and creativity. While the absolute scores are not necessarily meaningful, pre- and posttests will provide significant insight into how students respond to a course or new teaching approaches.

Bauer, C. F. (2008) "Attitude toward Chemistry: A Semantic Differential Instrument for Assessing Curriculum Impacts." *Journal of Chemical Education* 85(10): 1440-1445. DOI: 10.1021/ed085p1440

This paper describes a survey instrument for assessing student attitudes toward chemistry and describes an initial use with a group of students. The ASCI, or Attitude toward the Subject of Chemistry Inventory, has respondents describe their attitude toward chemistry by choosing on a seven-point scale between two polar adjectives, such as exciting or boring. Adjectives were chosen that are conversationally relevant and understandable to college-age respondents. Adjectives could be grouped into several categories, allowing for averaging in these categories; categories included interest and utility, anxiety, intellectual accessibility, fear, and emotional satisfaction. The survey was given to students in a general chemistry course in two different years, as well as to peer leaders, chemistry majors, and non-science majors. Analysis of attitudes revealed several predictable responses: non-science majors rated highest in anxiety and fear, and students with little experience with chemistry rated low on interest and utility. The ASCI provides a means to measure students' emotions, and can be used before and after or throughout a course.

Grove, N. and S. L. Bretz (2007) "CHEMX: An Instrument To Assess Students' Cognitive Expectations for Learning Chemistry." *Journal of Chemical Education* 84(9): 1524-1529. DOI: 10.1021/ed084p1524

This paper describes the development and initial testing of an instrument, the Chemistry Expectations Survey or CHEMX, to assess student perceptions of what is expected of them for learning chemistry. These expectations affect the attitudes students have about chemistry and the decisions they make about such things as class attendance and time commitment to a class. Knowing these expectations can help faculty understand their students better and perhaps address differences in expectations between faculty and students. The CHEMX is based on the Maryland Physics Expectations Survey (MPEX) and contains statements from MPEX as well as a modified statement addressing chemistry more specifically. Respondents are asked to rank their agreement with statements covering seven areas. Statements on effort probe the extent to which a student devotes time and energy to studying. Concept statements query if the student contemplates underlying concepts and ideas rather than simply memorizing facts and formulas. Math link statements probe whether the student considers math and chemistry as interrelated. Reality link statements examine if the student connects chemistry concepts and ideas with life outside the classroom. Outcome statements probe the extent to which the student values learning chemistry: as essential to career goals or as an obstacle. Laboratory statements examine whether the student understands the concepts being used in experiments or is only following the procedures. Visualization statements query the extent to which the student regards visualization of atoms or molecules as important. Survey data from undergraduates at four diverse institutions were gathered, allowing comparisons between expectations of faculty and students as well as across several student populations. Significant differences existed between faculty and beginning general chemistry students, while more advanced students showed expectations closer to those of the faculty.

Hake, R. R. (1998) “Interactive-engagement versus traditional methods: a six-thousand student survey of mechanics test data for introductory physics course.” *American Journal of Physics* 66(1): 64-74. DOI: 10.1119/1.18809

The paper describes a survey of a physics diagnostic test and concept inventory based on literature review and personal communication to determine the effectiveness of interactive engagement, defined as classroom activities that yield immediate feedback through discussion, compared with traditional instruction. A detailed statistical analysis of the results reveals that interactive engagement courses are much more effective than traditional courses at teaching students basic concepts. Limitations and sources of error in the study are also discussed in detail.

Kennepohl, D., M. Guay and V. Thomas (2010) “Using an Online, Self-Diagnostic Test for Introductory General Chemistry at an Open University.” *Journal of Chemical Education* 87(11): 1273-1277. DOI: 10.1021/ed900031p

Authors describe an online, self-diagnostic test for prediction of student success in general chemistry. The test analyzes student background, conceptual basics, critical thinking, mathematical skills, and problem-solving.

Rather than predicting grades, this optional test gives students information about their preparedness for the course, and allows students to proactively address problems by seeking remedial help or redirecting their studies. Authors found that performance on the critical thinking section of the test correlated well with student performance on examinations and assignments, while the conceptual basics correlated with laboratory performance. Surprisingly, a very weak correlation was found between student background in chemistry and performance in the course.

See Lopatto, D. (2004) under Research and Mentorship
See Lopatto, D. under CUREs

McFate, C. and J. Olmsted (1999) "Assessing Student Preparation through Placement Tests." *Journal of Chemical Education* 76(4): 562-565. DOI: 10.1021/ed076p562

This paper analyzes several common chemistry placement tests for their ability to predict student success in general chemistry, as defined by a grade of C or higher. It identifies abilities required for success in chemistry, rather than knowledge. The authors address effectiveness of placement tests at predicting success and the types of questions that are particularly effective predictors.

Seymour, E., D. J. Wiese, A.-B. Hunter and S. M. Daffinrud (2000) "Creating a Better Mousetrap: On-line Student Assessment of their Learning Gains." *National Meeting of the American Chemical Society Symposium*. San Francisco, CA. *http://www.salgsite.org/docs/SALGPaperPresentationAtACS.pdf* and *https://salgsite.net/*

The authors discuss development of a tool for assessing student learning gains as a more insightful alternative to standard course evaluations. Standard course evaluations are perceived by faculty to poorly judge the efficacy of their teaching, provide little useful feedback, and ask the "wrong" questions. However, these same evaluations are used by departments and administrators to judge teaching effectiveness for promotion or tenure. The tool described here attempts to guide students to give realistic feedback on and discuss how much they have gained in specific aspects of the course, rather than asking about liking or disliking such aspects as the teacher, the course, or the textbook. This targeted feedback allows faculty to specifically address areas that need improvement or change. A template (available free online) provides sample questions in sections related to different aspects of the course, such as lab activities, or skill development, such as writing. Students rate the helpfulness of aspects of the course on a scale of 1 (was of no help) to 5 (was of very much help). The authors also discuss how to word questions so as to evoke the most detailed and useful answers. Poor questions end up with students drawing upon traditional course standards (lecture format) for comparison or are unnecessarily polarizing (liking or not liking something). The most helpful responses were to questions such as "what was missing from the course," "what suggestions do you have for us in revising the class." The authors also describe testing with faculty at a variety of institutions, and discuss how these faculty members altered the template, how quickly students responded, and what student feedback they received about the tool.

Villafañe, S. M., C. P. Bailey, J. Loertscher, V. Minderhout and J. E. Lewis (2011) "Development and analysis of an instrument to assess student understanding of foundational concepts before biochemistry coursework." *Biochemistry and Molecular Biology Education* 39(2): 102-109. DOI: 10.1002/bmb.20464

The authors report on the development and validation of an instrument to measure eight concepts that are prerequisites for biochemistry. These concepts were drawn from general chemistry and biology courses and represent essential knowledge for understanding biochemistry. Three questions for each concept are included in the test, which can be used as both pre- and post-tests. The authors developed a useful instrument, which can be obtained by contacting them. Additionally, they clearly outlined their method for developing and validating the instrument, allowing others to more easily design instruments in the future.

Virtual Labs and Computer Simulations

Davenport, J. L., A. N. Rafferty and D. J. Yaron (2018) "Whether and How Authentic Contexts Using a Virtual Chemistry Lab Support Learning." *Journal of Chemical Education* 95(8): 1250-1259. DOI: 10.1021/acs.jchemed.8b00048

There is a need to develop new approaches to teaching chemistry that do not isolate concepts from procedure. ChemVLab+ is a series of online activities that allow students to learn concepts and apply them to real-world investigations. The programs allow students to tackle real-world problems by creating a hypothesis, designing experiments to test their hypothesis, analyzing data, and interpreting results. The program was designed to give deeper understanding by focusing on authentic context, building on multiple representations, giving helpful feedback, and integrating science principles to help students use higher-order thinking. The article discusses 14 teachers and 1,473 students at California high schools using the program. The teachers could integrate the program into their lessons in any way they saw fit but were required to report how it was used. All students took a pretest before starting the material and a posttest once they had finished. The researchers found the online material made a significant difference in test scores. It was found to have the biggest effect when it was used as review and the students worked alone.

de Jong, T., M. C. Linn and Z. C. Zacharia (2013) "Physical and Virtual Laboratories in Science and Engineering Education." *Science* 340(6130): 305-308. DOI: 10.1126/science.1230579

This review paper summarizes the current literature comparing virtual and physical laboratories. Virtual experiments have certain advantages, such as less setup time and the ability of students to perform multiple trials. Additionally, equipment malfunctions are less likely to cause problems in virtual experiments. The authors cite several studies showing no difference in conceptual understanding by students performing physical or virtual labs. The authors also describe several studies effectively combining virtual and physical labs.

Yaron, D., M. Karabinos, D. Lange, J. G. Greeno and G. Leinhardt (2010) "The ChemCollective — Virtual Labs for Introductory Chemistry Courses." *Science* 328(5978): 584-585. DOI: 10.1126/science.1182435

This essay describes an online digital library, the ChemCollective (*www.chemcollective.org*), which includes a virtual lab to increase students' conceptual understanding of chemistry ideas. This resource is intended to supplement textbook problem-solving, not replace physical laboratory experience. Within the virtual lab, students can design and perform experiments that may not be possible in a physical lab. Additionally, some activities use real-world examples. The authors briefly describe the results of a study (Leinhardt, Cuadros and Yaron 2007 *Journal of Chemical Education*) showing that the virtual lab contributed significantly to learning.

Writing in Response to Lecture

Butler, A., K.-B. Phillmann and L. Smart (2001) "Active Learning within a Lecture: Assessing the Impact of Short, In-Class Writing Exercises." *Teaching of Psychology* 28(4): 257-259. DOI: 10.1207/s15328023top2804_04

The authors describe an exercise that combines minute papers and think-pair-share. In this exercise, students are prompted with a question related to the lecture topic. Students answer the question on index cards, then exchange cards and discuss the answers in groups of two or three. Several final exam questions were linked with questions from the exercise; students' performance on these questions was compared between a section that used the exercise and one that did not. For one-third of these final exam questions (4 of 12), performance of students who used the exercise was better than those who did not. Of the remaining questions, performance was the same for seven, and worse for one. While this is only a small success, the exercise is quick and easy to implement.

Harwood, W. S. (1996) "The One-Minute Paper: A Communication Tool for Large Lecture Classes." *Journal of Chemical Education* 73(3): 229-230. DOI: 10.1021/ed073p229

The "one-minute paper" is described as a tool to increase communication between the instructor and a large lecture class. The lecture is ended early, and students are given an opportunity to write anonymously one main point from the lecture and one question they have. In the following class, some questions may be praised (to encourage good questions) and addressed. Students quickly become more confident at asking questions, and more students ask questions during lecture. Also, the instructor can quickly address confusion and misconceptions. Additionally, the students praise and criticize the instructor, providing positive feedback and opportunity for improvement.

Hein, T. L. (1999) “Using Writing to Confront Student Misconceptions.” *European Journal of Physics* 20(3): 137-141. DOI: 10.1088/0143-0807/20/3/002

In this paper the author discusses the use of folder assignments that allow the students a chance to share their understanding of different physics concepts. The students are given a prompt asking them to explain a recently covered concept, to explain an answer to a question, or develop exam questions and then answer them. These written responses are collected, and extensive feedback is given without a number grade. This feedback helps the students learn and gives the professor a chance to look for and address misconceptions before exams. The students see the effort and time that goes into the feedback and this encourages them to turn in quality work. A few examples of the prompts and student responses are provided for further clarification. The author has found these assignments help students develop deeper understanding of the topics.

Paulson, D. R. (1999) “Active Learning and Cooperative Learning in the Organic Chemistry Lecture Class.” *Journal of Chemical Education* 76(8): 1136-1140. DOI: 10.1021/ed076p1136

See Cooperative Learning section

Strauss, M. and T. Fulwiler (1990) “Writing to Learn in Large Lecture Classes.” *Journal of College Science Teaching* 19(3): 158-63. *https://www.jstor.org/stable/42989214*

The author describes several ways to incorporate informal writing in a large lecture course. Students are instructed to write questions throughout the lecture period, which are submitted anonymously; selected questions are incorporated into the following lecture. Students are also encouraged to keep notebooks or logs of their thoughts and concerns as they study. Finally, group writing activities in laboratories are described.

Reynolds, J. A., C. Thaiss, W. Katkin and R. J. Thompson, Jr. (2012) “Writing-to-learn in undergraduate science education: a community-based, conceptually driven approach.” *CBE Life Sciences Education* 11(1): 17-25. DOI: 10.1187/cbe.11-08-0064

The authors discuss their work in developing a database of literature relating to writing-to-learn (WTL) and developing a community-based approach to encourage the use of WTL in the classroom. The authors organized a group of 12 experts to review literature pertaining to empirically validated WTL practices that could be used to create a database available for all educators. The database could be used to start a multi-university movement to continue to study effectiveness of WTL practices and focus on the current gaps in knowledge. The authors hosted a workshop to get feedback on the database and the plausibility of using WTL as a learning tool. During the workshop they received feedback on what steps should be taken next to continue their research. The feedback from many of the attendees was that WTL could be an effective tool. Using the review of current literature of WTL and current learning theories the authors outline a research plan to further develop WTL practices. They suggest reconceptualizing how writing fits into learning, showing the link between writing and critical thinking, investigating how writing helps students learn, elaborating how specific writing assignments improve learning in WTL, and using their hybrid method of research to work on these goals.

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Leinhardt, G., J. Cuadros and D. Yaron (2007) ""One Firm Spot": The Role of Homework as a Lever in Acquiring Conceptual and Performance Competence in College Chemistry." *Journal of Chemical Education* 84(6): 1047-1052. DOI: 10.1021/ed084p1047

Lopatto, D., C. Alvarez, D. Barnard, C. Chandrasekaranh, H.-M. Chung, C. Dut, L. Eckdahla, A.L. Goodman, C. Hauser, C. J. Jones, O. R. Kopp, G. A. Kuleck, G. McNeil, R. Morris, J. L. Myka, A. Nagengast, P. J. Overvoorde, J. L. Poet, K. Reed, G. Regisford, D. Revie, A. Rosenwald, K. Saville, M. Shaw, G. R. Skuse, C. Smith, M. Smith, M. Sprat,, J. Stamm, J. S. Thomson, B. A. Wilson, C. Witkowski, J. Youngblom, W. Leung, C. D. Shaffer, J. Buhler, E. Mardis and S. C. R. Elgin (2008) "Genomics Education Partnership" *Science* 332(5902) 684-685. DOI: 10.1126/science.1165351

Miller, J. E., J. Wilkes, R. D. Cheetham and L. Goodwin (1993) "Tradeoffs in Student Satisfaction: Is the "Perfect" Course an Illusion?" *Journal on Excellence in College Teaching* 4: 27-47.

Miller, J. E. and R. D. Cheetham (1990) "Teaching freshmen to think—active learning in introductory biology." *BioScience* 40(5): 388-391. DOI: 10.2307/1311217

Thiry, H., and S. L. Laursen (2011) "The role of student-advisor interactions in apprenticing undergraduate researchers into a scientific community of practice." *Journal of Science Education and Technology* 20: 771-784. DOI: 10.1007/s10956-010-9271-2

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