Teacher-Scholar
Teaching Statements

Research Frontiers in the Chemical Sciences

A Dreyfus Foundation Teacher-Scholar Symposium

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The Camille & Henry Dreyfus Teacher-Scholar Awards programs recognize the country's most promising young scholars in the chemical sciences, based on their forefront independent research accomplishments and innovative approaches to education. This compendium of teaching statements summarizes some of the initiatives and philosophies of these faculty.

Theodor Agapie, Chemistry, California Institute of Technology

Teaching Approaches in Inorganic Chemistry

1. a) Article Critique Modeled on NIH's Review Process in "Bioinorganic Chemistry" (Chem 212). Chem 212 is a course taken by graduate students and advanced undergraduates. The curriculum for course was designed to give students an overview of principles in bioinorganic chemistry, and included modern topics of focus. Given that this is a graduate course, emphasis was placed on preparing students for critical analysis of scientific research. Critiquing published articles related to the lecture material was the method of choice for exposing students to the most recent and exciting results in the field. To engage students, the discussion format was based on the NIH review process. Primary and secondary reviewers were selected for each class period at the beginning of the course. Assigned reviewers were responsible for initiating the critique of the paper; primary first, followed by second, then the rest of the class added comments and asked questions. This exercise engaged the students and made them comfortable even with asking questions beyond the material in the article. The analysis of the articles was deep and thorough and the students learned how to evaluate the quality of the papers in terms of significance, suitability of approach, innovation, data quality, and interpretation. Through these discussions, the students not only learned material related to the course, but also became confortable evaluating published reports, developed critical analysis skills, and learned about the criteria utilized by funding agencies to evaluate the quality of proposals.

b) Team Proposals Modeled on NSF's Centers of Chemical Innovation (CCI) in "Bioinorganic Chemistry" (Chem 212). In addition to the teaching goals above, Chem 212 is also intended to train students on how to develop new research ideas. The first major assignment was a written proposal for an original project. This was designed to allow students to become familiar with and identify a frontier of the current knowledge in the field, and to propose an idea to push science beyond those limits. To emulate in the classroom the NSF approach to grand challenges through collaborative CCIs, the final assignment of the course was a group project for which students proposed different but related approaches to solutions to a difficult problem ("Metals in cancer detection and therapy", "Bioinorganic approaches to energy or fuel production", etc). Each team developed a coherent set of connected proposals, and discussed it with the faculty. The proposals were presented orally at the end of the term by each group of students, making for a very stimulating symposium. Each group had three to five members representing both undergraduate and graduate populations. The interactions between students within each group made for an exciting experience in terms of learning from people with different backgrounds, collaborative efforts, and complexity of the problems analyzed.

2. Research Aspects in "Advanced Techniques of Synthesis and Analysis: Coordination and Organometallic Compounds" (Chem 5b). In order to better represent in Chem 5b the nature of the research experience, beyond teaching the experimental techniques, a new format was implemented that involved sharing data, new target design by students, and teamwork. An important aspect of understanding catalytic systems and, more generally, synthetic compounds, is the ability to perform structure-reactivity studies. A sampling of such studies was implemented in Chem 5b, for the synthesis and evaluation of olefin epoxidation catalysts based on manganese complexes supported by enantiopure salen ligands. Instead of all students performing the same experiment, the class was organized in two or three teams that prepared structural variants of the catalyst, by changing the nature of the chiral backbone and the size of the phenoxide substituents. With access to the data from the entire class, each team proposed the "next generation" catalyst targets designed primarily to interrogate the mechanism of

enantioselectivity. Options for precursors were left quite open-ended, based on availability from Aldrich. Each team prepared and tested their target, and again the data were shared with the class. This format allowed the students to analyze their findings in the context of the behavior of different catalysts. It engaged the students by allowing them to come up with their own ideas and test them. Most importantly, this module provided the students with an experience similar to the research process encountered in the research laboratory.

Hal Alper, Chemical Engineering, The University of Texas at Austin

Creating an Active Learning Environment

I highly prescribe to the notion that students learn best when they are motivated and actively engaged in the learning process. As a result, I try to engage students by encouraging their active participation in the learning and discussion process as much as possible. Two particular activities/aspects have worked well. First is a technique called student guided discussions which are question and answer sessions guided by student's interests. To enable this, I used a reading reflection sheet for each of the reading assignments for the course. One of the boxes on this sheet asks "what further questions do you have after this reading?" After students turned in these forms for each reading, I compiled these questions and spent a part of the next lecture answering these questions. Many students commented that this Q&A style lecture was a highlight of the course. Specifically, this enabled me to provide the most pertinent information to students. Moreover, these questions sparked further discussions in class. This active participation in the learning process was extremely successful. While initially done in a small class setting (<20 students), I am planning on incorporating this approach in my future large lecture courses as a way of obtaining continuous feedback on student performance and understanding of material.

Second, I have the opportunity to teach a small seminar-style course each year. This course was focused on the impact of biotechnology. Instead of a lecture-based course, pairs of students gave presentations and led discussions about the reading material and further implications. For this semester, students were paired into groups of 2 and were responsible for leading 45-50 minute of active discussions on reading assignments and topical material. The groups were tasked with the responsibility of highlighting the major topics of the reading assignment, creating thought-provoking questions about the implications of the technology discussed, and presenting several "what-if" and ethical questions/concerns about the area of biotechnology they were presenting. The quality of the presentations, discussions, and hence learning in this setting went far beyond my initial intentions. Students often brought in video clips from youtube and other sources to better explain book material. It was clear that the students were well-prepared and in doing so, learned much more than one could from simply reading a book and participating in a lecture-discussion. This concept of student led lectures gave students in the class an opportunity to practice public speaking. Moreover, one of the more unique outcomes of this approach was several students commenting that they had a newfound appreciation of the amount of work that goes behind making a lecture.

Theodore A. Betley, Chemistry and Chemical Biology, Harvard University

Addressing the Dreariness of a Beloved Subject

Pedagogically, there is a deficiency in the way inorganic chemistry is presented: it is boring! Much like general chemistry before it, inorganic chemistry is often presented as a compilation of empirical facts and observations (tedious and uninspiring). Organic chemistry, on the other hand, is presented as algorithm. We are taught to recognize functional groups as the currency for reactivity. With this recognition reactivity patterns emerge, allowing for a logical progression to employ simple building blocks to construct molecules with tremendous complexity. At this stage examinations transition from recital of minutiae to playing with an atomic Lego set. For many undergraduates, this is the first time chemistry avails itself as an opportunity and appeals to the creative element. When teaching inorganic chemistry, a subject I deeply love, I was desperate to show that similar opportunity exists in a far bigger playground with transition metal chemistry.

Developing electronic structure-function relationships. A lesson I try to instill very early on in the course is that chemistry's true value is that it is programmatic and predictable. To transform the *d*-block elements into movable pieces with the same degree of predictability present in organic chemistry, we need to develop a deeper understanding of chemical bonding. To refine our understanding of chemical bonding we introduce molecular orbital analysis, where symmetry-allowed interactions provide the glue that holds molecules together dictates when they will react. Molecular orbital theory provides the foundation to understanding molecular geometries and frontier orbital interactions between molecules, affording an entry point to discussing reactivity patterns and catalysis. Almost every course in undergraduate inorganic chemistry will present classic catalytic mechanisms (e.g., hydrogenation, acetic acid synthesis) for dissection. My goal is to have the students be able to decide what electronic properties are required of a catalyst to articulate a particular reaction, and then propose a catalyst that meets those design criteria. This foundation connects electronic makeup to structure and reactivity. The students are empowered to build the engine to drive reactions, and furthermore, know exactly how it runs.

Difficulties with this approach. A molecular orbital treatment of bonding and reactivity is done at the expense of other areas within the field that cannot be covered in a single term course. The current popular inorganic texts elect to give cursory introductions to all areas encompassed within inorganic (main group chemistry, transition element chemistry, organometallics, bio-inorganic), without much depth appropriated to any one area, leaving both student and instructors frustrated. While the students I have taught over the last seven years have enjoyed this approach of connecting electronic-structure to function, there is not a definitive text written for undergraduates on which to base the course. The closest undergraduate text I have seen that uses molecular orbital analysis as the central theme for understanding structure and reactivity is *Inorganic Chemistry* by Purcell and Kotz (1977), long out of print. Even the authors of this book address in their preface that this approach to understanding inorganic chemistry as a field presents only a small piece of the field. However, with an understanding of bonding interactions through molecular orbital theory, a student can seamlessly navigate the myriad topics spanning non carbon-centric reaction chemistry.

While I cannot say that my approach has solved the problem of how best to present inorganic chemistry, I am trying to capture the most desirable elements of how organic chemistry is presented: transition element chemistry can be programmatic and predictable, too!

Michelle C. Chang, Chemistry, University of California, Berkeley

I have been teaching an advanced preparative organic chemistry laboratory for undergraduate students. Since many of our students don't get a chance to carry out independent research, I see this class as an opportunity to give them that experience for at least one semester as we have at least 10 h of laboratory time together per week. They do work individually (every student has their own fume hood) and also learn to collect their own compound characterization data, such as NMR spectra or GC-MS traces. In addition, I further decided that we would design each class as a new research project, which means that the TA and I develop an idea for a multi-step synthesis of a new compound or set of compounds and also design functional assays for characterization at the end (e.g. spectroscopic studies for a sensor or coupling studies with a biological target for a click reagent).

Making new compounds also means that we don't run the whole synthesis first to figure out untested reactions or assay the target compounds before the students do! The first time I taught the class, I was concerned that the students might get overwhelmed and also be very unhappy with the situation, as things often times don't work out as planned and we have had some major changes in strategy mid-semester. However, I have found that the students really rise to the expectations and remain upbeat and excited to have a more experimental lab experience … even when we had to go back and repeat a macrocyclization reaction three times before they had enough material to move on! Overall, I have been surprised by how much students enjoyed the challenge as I initially thought that it would be significant problem if the class didn't proceed according to plan.

Paul Dauenhauer, Chemical Engineering, University of Minnesota

Undergraduate Education in Energy and Sustainability

Effective teaching methods aim to improve mathematics, writing and critical thought on the fundamentals of chemical education. However, students need a broader perspective on the importance of chemical sciences that addresses societal impact of their education. High performing undergraduates struggle to understand the potential of their education, and they lack the context provided by an understanding of the history of energy and chemistry that would allow them to develop realistic career goals and aspirations.

Courses with a focus on energy are designed to integrate within the chemical engineering degree such that technical electives and courses can be fulfilled with new courses in two general areas: (a) topics in energy, and (b) energy for sustainability. In the past ten years, the importance of energy and sustainability topics for chemical engineering students has dramatically increased. In addition to economic evaluation of chemical technology, it is expected that students: (i) understand the environmental impact of new chemicals (e.g. climate change), (ii) characterize the social impact of local, renewable carbon-based products, and (iii) provide basic understanding of the major technologies for biomass conversion (e.g. fermentation, pyrolysis).

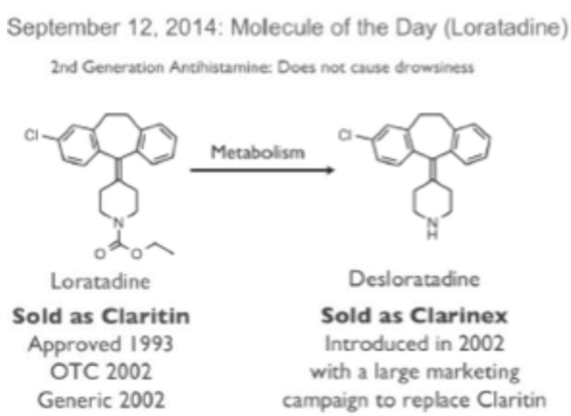
The foundation of education in energy and sustainability is a new course for sophomores entitled Introduction to Energy Engineering. Second-year students are introduced to energy and engineering topics such as energy accounting, environmental topics in energy production, and energy processing technology. Each week introduces a new topic such as fermentation/gasification of biomass, wind or solar energy. Special attention is given to the history of energy, and an entire week is provided for the history of petroleum for chemical/fuel processing. Students complete an independent research project where they write a report and give a 15 minute presentation on an energy topic of interest to them. The opportunity to explore a topic and develop expertise is a critical element to the course where the student takes ownership of their interests. Students at this point in the semester are eager to discuss their findings, and they express an attitude consistent with life-long learning combined with a strong desire to participate in the growing renewable energy sector.

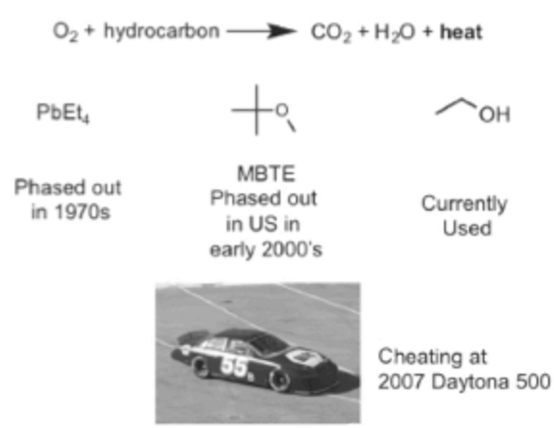
William R. Dichtel, Chemistry and Chemical Biology, Cornell University

I often meet intelligent and accomplished individuals who hated their undergraduate organic chemistry coursework. It is the first thing that physicians, veterinarians, and business professionals love to tell me – how they somehow did (or did not) "get through it." This sentiment has greater consequences than subjecting chemists to stale small talk at cocktail parties. Compartmentalizing and marginalizing the importance of chemistry – especially of organic compounds – negatively influences our society and has ingrained chemophobia into our culture. Food manufacturers advertise "chemical-free" products, and even the terms "organic" and "natural" have been hijacked to connote "free of chemicals." Pockets of families unwilling to vaccinate their children and the notion that essential oils can cure the ebola virus are downright dangerous notions that are circulating currently. I believe that organic chemists have a greater responsibility than to simply teach basic principles of our discipline – we must devote time in our courses to connect the material to everyday life.

Our two-semester organic chemistry sequence for non-majors comprises two of Cornell's largest courses. Just before this symposium, I completed co-teaching the first semester course, which is taken by 700 sophomores. The sequence serves as prerequisite for medical and other professional schools, and many of its students view it as a hurdle to be crossed, not recognizing the relevance of organic chemistry to day-to-day life. When I began teaching this sequence a few years ago, I introduced a course-wide effort to establish that organic compounds and polymers are ubiquitous in my students' lives. I devote the final three minutes of every lecture to a "Molecule of the Day" taken from current events. Representative topics include patent protection in the pharmaceutical industry, oxytocin (on Valentine's Day), terpenes found in food, and cellulosic ethanol. I ask routine questions about these molecules on midterms, and the resulting "free points" are just enough motivation for students to pay attention to the stories throughout the semester. I have received strong positive feedback from students as to their interest in the subject, and this practice was so well received that my colleagues duplicated it within our Honors Organic sequence. I also require that each student identify twenty organic compounds and five polymers found within their own household items. These exercises represent a small first step towards establishing the importance and relevance of organic chemistry to a generation of informed citizens.

Recent examples of the "Molecule of the Day" used to discuss drug patents and marketing and environmental issues associated with transportation fuels.





Chiles Wade Downey, Chemistry, University of Richmond

Not So Random Student Reviews

One of the advantages of teaching at a predominantly undergraduate institution is the relatively small class size in early chemistry classes. For example, a typical Organic Chemistry I or II course at the University of Richmond numbers around 25 students. With such a small class size, student-instructor interaction can be more personalized, and a greater number of assignments can be graded directly by the instructor. Nonetheless, it has been consistently challenging to ensure that the students are fully engaged in the homework, and that students consistently attend class. I have chosen to battle these problems through brief, somewhat randomly assigned student presentation. My small class size enables me to let every student present a problem from the homework to the whole class at least once each semester.

The students generally have a small homework assignment due every class. In order to assure attendance, at the end of each class I randomly select a certain number of names, and tell those "nominees" that they may be responsible to give a five-minute review at the beginning of the next class. When the next class begins, I randomly select from among the "nominees," and then that student presents a problem from the homework on the board in front of the class. This process provides a number of benefits:

1. Students must be present to learn if they are one of the "nominees" for the next class, and to learn what the assignment is.
2. "Nominees" must be present in case their name is drawn to present the review.
3. "Nominees" tend to work extra hard on the homework so that they don't embarrass themselves in front of the class. They are more likely to come for help in office hours or to make appointments. Because there are no graduate students to act as TAs at liberal arts colleges, it is vitally important that the students come to professors for help, but they often need a little bit of motivation to come the first time. Once they come the first time, I find that they are more likely to seek help later.
4. The presentation of a homework problem provides a useful review on material that was presented one or two class periods before.
5. Having a student work a problem on the board in front of the class allows the instructor to then talk through the problem. Importantly, the instructor can show how that problem would be "graded" if it were an actual test question, providing insights into just what details are actually essential.

The largest variable in this process is the number of "nominees" who are made responsible for potentially giving a presentation during the next class period. If the number of nominees is ten or larger, I find that many of the nominees are willing to risk not doing the homework (or not doing it well) because they know they are unlikely to be selected for the presentation. On the other hand, if the number of nominees is as low as three, then very few students benefit from the increased pressure to perform well. In the last two years, I have settled on six as the ideal number for my class size, which is typically 25 students. Typically, the presentation of the review material is worth 0.5-2% of the course grade for a given semester.

Abigail G. Doyle, Chemistry, Princeton University

At Princeton, I have contributed to the undergraduate and graduate education mission of the chemistry department with the goal of introducing active learning into all levels of the curriculum, stimulating our students' abilities as independent and creative thinkers and providing them with a more direct connection between their coursework and the cutting edge of the field. These activities are meant to complement and grow Princeton's goals as a student-centered research university.

Graduate teaching. During my first-year at Princeton, I designed a new course for advanced undergraduate majors and first-year graduate students (CHM 536: Methods for Complex Organic Synthesis), which I have offered for the past four years as part of the department's Industrial Affiliates Program. The class provides a multidisciplinary view of the field of organic synthesis by pursuing a single theme, catalysis, across a variety of subjects, including organic, inorganic, materials, and biological chemistry. Since the content is derived entirely from the primary literature, I produced a collection of course notes (~300 pages) as a stand-in for a course textbook. Not only did the enrolled students find "the class notes and references invaluable to stimulating intellectual curiosity," but I have also learned that many senior graduate students and postdoctoral fellows in the department have used them in their own research efforts. Even a few faculty members at other universities have solicited the notes, having learned about them by word-of-mouth. The course is delivered using a case-study approach, which encourages students to build their own framework through application, analysis, and synthesis of data. For example, we trace chemistry that has garnered the Nobel Prize back to its roots, investigating the process of discovery rather than just reviewing the state-of-the-art. The course culminates with an independent proposal, demanding that the students take the next step in their progression as a scientist by synthesizing their knowledge to design a novel catalytic system following the guidelines of NIH fellowship proposals. The comments of past students speak to the effectiveness of this project and the course: "this has been the most interesting and valuable course I have ever taken" and the final project required us "to critically evaluate [our] own ideas, elevating understanding of the material to a higher level than required for exams and problem sets." Over the next few years I envision adding a more interactive module to the course wherein each week we discuss in depth a single paper on the topic of the lecture. This approach will be used as a platform to help students develop a research-relevant skill set and gain the confidence to critically evaluate the primary literature.

Undergraduate teaching. I have also had the privilege to teach the first semester organic chemistry class at Princeton, CHM 303. Too often, undergraduates and pre-med students identify organic chemistry as only a rite-of-passage. I believe that the origin of their frustration stems from three sources: first, modern textbooks do not emphasize the underlying principles that unify the subject and its many reactions; second, the field is taught as if everything is "known" and direct connections to the "real world" are not emphasized; and third, the more esoteric/less intuitive topics (radical additions to alkenes, SN2/1, E2/1 reactions) are given first billing over the more relevant/simpler subjects (carbonyl chemistry). A key element of my classroom method is to take a mechanistic approach that emphasized recurring fundamental principles rather than rote memory. Alongside treatment of each curriculum unit, I introduced "real-world" examples of how the course material was relevant to the students' day-to-day lives. These examples included the chemical basis for how bleach de-colorizes their clothes and for the Thalidomide tragedy of the 1960s. I also encouraged active learning, beginning by engaging students in a back-and-forth discussion during each lecture and reinforced by weekly office hours with the purpose of teaching the students how to problemsolve; remarkably, approximately 50 students out of 300 attended my office hours each week.

These examples constitute the first phase of my planned innovations for this course. In the future, I am strongly committed to overhauling the sequence in which students are introduced to topics in the class, with a plan to first develop their understanding of reactivity in the context of carbonyl functionality and its biological relevance to protein, carbohydrate, and fatty acid biosynthesis. In addition, I have received initial enthusiasm from the department for a proposal to introduce a second organic chemistry section that runs alongside CHM 303 in the Fall semester but is offered exclusively to freshmen. Currently, approximately 50-60 freshmen take CHM 303 each year, having come to Princeton with advanced standing. Since these students are accustomed to the more individualized attention of high school learning, they often find such a large class intimidating and unappealing irrespective of the course content. I feel that offering a more intimate and engaging class for our youngest and most enthusiastic students may help encourage more of these students to stay within the STEM fields. As part of my participation in CHM 303, I was also involved in the discussions that led up to Princeton signing on with Coursera. I am eager to consider ways in which online learning and "flipping the classroom" can be applied to improve the chemical education we provide our students in the organic sequence.

Danielle H. Dube, Chemistry and Biochemistry, Bowdoin College

My educational philosophy is to teach students how to think about the chemistry of biological systems. I strive to catalyze the realization that chemical interactions are essential for each of our bodies to function and that, by understanding the molecular basis of disease, we as chemists have the power to tackle problems in human health. My approach to achieving this goal is to lay a core foundation of fundamental concepts, build upon the foundation in a logical, organized manner, and point out connections and how each set of concepts fits into the bigger picture. I then encourage my students to build upon this knowledge themselves, taking active roles as learners. I challenge my students to consider overarching themes and to apply what they have learned from representative examples to new scenarios. In this way, students become able to analyze chemical phenomena in meaningful ways. To prepare students for this level of thinking, I engage my students with problem solving in class and on weekly problem sets. To connect class material to the real world, I incorporate drug discovery vignettes and current articles from the scientific literature that illustrate that the information covered in my courses enables students to understand cutting-edge research. Finally, I encourage students to conceive of their own projects, design experiments to test their hypotheses, and personally contribute to research. Overall, I strive to teach my students how to think about the chemistry of biological systems and, in the process, demonstrate that this level of thinking is empowering. Below, I highlight a few examples that showcase my teaching philosophy in action.

Biochemistry: During my first few iterations of Biochemistry, I taught this course as a stand-alone lecture class. I recognized that coupling the lecture to a laboratory would substantially enhance the course. Thus, inspired by successful project-oriented biochemistry lab examples, I conceived of, designed and implemented a semester long lab for this course that focuses on purifying and studying a validated drug target, the enzyme urease from Helicobacter pylori (Hp). In this semester long project-based laboratory, students undertake a series of biochemical purification experiments to isolate Hp's urease, assess the effectiveness of their purification, and characterize the activity of their purified enzyme. Finally, they conceive of their own mini-projects, which have included (1) searching for urease inhibitors, (2) assessing urease's glycosylation status, and (3) comparing the kinetics of Hp's urease to urease from other organisms. Students then design experiments to test their hypotheses and carry out the work during the last weeks of the lab. This highly successful lab solidifies concepts covered in lecture and has enhanced learning outcomes.

Chemical Biology: I developed this senior-level course entirely around examples from the primary literature; I cover seminal examples during lecture and cutting-edge papers in weekly discussion sections. After we cover our first topic, the chemical biology of proteins, I assign recent papers about nucleic acids to my students and have them teach each other, through both chalk-talk style presentations and written assignments, about the work described in the papers. In essence, students craft short "New & Views" (Nature) style papers and presentations that put the work into a broader context and convey the take-home messages. The ability to effectively communicate science is absolutely crucial for any scientist, and this assignment helps students hone their communication skills.

Drug Discovery: Drug Discovery is a general audience course that is designed to help non-science majors enhance their scientific literacy by analyzing a particular area of chemistry, drug discovery, in depth. To promote student engagement with the material and participation in the class, I hold periodic in-class discussions that focus on Scientific American articles pertinent to class topics, ranging from the spread of antibiotic resistance, to the molecular basis of addiction, to rational drug design. These discussions are a fantastic opportunity for students to see how the material they learn in class directly relates to pressing problems of national and daily concern. By incorporating these discussions, students become informed citizens about controversies in the field. Another highly successful component of the course is a weekly laboratory. Toward the beginning of the semester, students perform laboratory activities to understand how chemicals can be separated from each other based on their properties, and how they can cause responses in our bodies. Later in the semester students take initial steps to identify novel antimicrobials and to directly compare conventional versus herbal remedies in self-designed experiments.

Mentoring Student Researchers: Through conducting independent research, students are challenged to develop research goals, design and conduct experiments, analyze their data, interpret results and present their findings. In this way, they take real ownership of a project. To conduct high-quality, cutting edge research with undergraduates, I design a series of projects that can be carried out in parallel, in a stepwise manner, and that ultimately link together to assemble a complete story. My students choose between projects that have different emphases in organic synthesis, molecular biology, and microbiology, so students can choose projects that are tailored to their interests. In this context, they gain a solid and broad foundation in chemical biology that prepares them for their future research endeavors, and they realize how they personally can have an impact on the field.

James Ferri, Chemical and Biomolecular Engineering, Lafayette College

Experiential Learning in Hybrid Courses in the Chemical Sciences

Experiential learning is one of the hallmarks of chemical engineering education at Lafayette College. We enjoy the tension created between theory and practice introduced in our Experimental Design and Integrated Chemical Engineering hierarchy. This three-course sequence is composed of hybrid courses that emphasize experiential learning. Here, in addition to illustrative lab experiences, which translate key mechanistic concepts from transport phenomena, fluid phase equilibrium, mass transfer and separations, and chemical reaction kinetics, students are exposed to the lectures in the systematic empirical approach of statistical experimental design together with both descriptive and inferential statistics enabling them to parameterize highly coupled complex chemical systems.

We also have created specialty hybrid courses across several sub-disciplines including interfacial and colloidal phenomena, micro and nanofabrication, molecular bioengineering, and environmental engineering. For example, CHE344 Interfacial Phenomena is an elective course which includes topics such as the thermodynamics of surfaces and interfaces, adhesion, spreading, intermolecular forces, DLVO theory, electrostatic and electrokinetic effects in colloidal systems, and characterization techniques such as scanning force microscopy, light scattering, and microscopy. The course is approximately evenly divided between lectures, lab experiences, and seminars in current literature. We use seminar and laboratory experiences as didactic opportunities to train students in lifelong learning methods. For each weekly two-hour seminar or lab experience, self-selected student groups identify a topic or method from a list of fifteen or so subjects designed to complement the lectures. Each group of three or four is mentored to develop a hosting strategy to engage the rest of the class in a meaningful experience. For seminars, this means selecting (and learning how to select) current literature and developing study/discussion questions for the class by serial jury-like selection of articles. For laboratory experiences, this means setting up rotating stations that enable all students in the course to learn sophisticated research techniques such as dynamic light scattering and zeta potential measurement, axisymmetric drop shape analysis, confocal microscopy, and scanning force microscopy while simultaneously mitigating the risks associated with new users and expensive equipment by pre-training the hosting group.

The feedback we have received from both students and faculty at Lafayette and in national venues, such as the American Society for Engineering Education (ASEE), has been highly positive suggesting that our approach would be well received in a variety of other venues.

Paul J. Fischer, Chemistry, Macalester College

The aspect of my Assistant Professorship that sparked the most anxiety was the scholarly expectations within the research laboratory. The College anticipated an inorganic synthesis program that would regularly generate publishable outcomes of a quality on par with universities with graduate programs. While being eager to accept this challenge and gracious for the opportunity, my affirmative response to Macalester's offer came with trepidation after toiling as a graduate student. Even in my final years, after accumulating extensive experience, my own "success rate" with new inorganic/organometallic reactions was still lower than that of the batting average of the weakest hitter on a major league roster. And I had the advantages of significantly more experience, coursework, and literature exposure than undergraduate research assistants can bring to the enterprise. In addition, most students interested in research can only realistically contribute to projects when classes are not in session- mostly just in summer. Synthetic chemists know that a common route to success is to conduct as many reactions as possible; increasing throughput increases the frequency of successful outcomes.

The challenge presented to chemistry faculty at a scholarly-demanding PUI is to defy these constraints. Despite my presence at this symposium, I will confess to not having found the secret to surefire success in chemical synthesis within this environment. Indeed, each research period still arrives with the same concern, mainly: Will we obtain a critical mass of meaningful results? My goals in research at Macalester are fourfold and equally weighted: (1) students should learn the general practice of synthesis research, (2) students should learn fundamental techniques for synthesizing and characterizing air-sensitive metal complexes, (3) students should gain confidence that they can "do synthesis", and (4) a critical mass of publishable results is obtained. This aspirational list is sufficiently ambitious that my hope is to make progress on all fronts, accepting (sometime stubbornly) that these objectives might not be uniformly achieved at their maximum potential.

Research project design is vital to make progress on these objectives within quantized time intervals, and I extensively "outline" student work in advance. These outlines, which my students examine later in their experiences as a learning tool, detail contingency plans and incorporate key literature references for each project as a flow chart (if reaction A fails to give desired result, try reaction B…if reaction A works, try reaction C, etc.). Each spring I plan approximately one month of chemistry for each summer student. These plans are valuable since teaching laboratory techniques and fundamentals requires so much attention that the time available to think about the chemistry on the fly is a scarce commodity. The same goes for my students, who generally employ nearly all their bandwidth in the first few weeks to master the techniques for handling air sensitive substances and using instrumentation. In essence, this is my strategy for tackling the "throughput challenge." My students endeavor to engage objectives 1, 2, and 4 simultaneously, even from the first week of being in my lab. The outlines make this possibility realistic for me to manage once the bell sounds on Day 1. In an ideal summer, the students sufficiently mature at the bench within the first four weeks to be able to digest additional chemistry content, and each project gains sufficient momentum to be manageable for me to be creative and to share increasing insights of the experimental design with the students.

Good synthesis research design undoubtedly requires realistic reaction ideas. My ongoing quest for these ideas evokes images of the Canaanite woman in the Gospel of Matthew who pleads with Jesus: "for even the dogs eat the scraps that fall from the tables of their masters." Indeed, I search for these "scraps" in the form of underutilized ligands. My students have exclusively employed ligands synthesized previously by other groups that subsequently moved to greener pastures. We aspire to fill in missing "reaction space" using these ligands that will still be of interest to the inorganic community without needing to carry out laborious ligand design. In this regard, my laboratory is indebted to Peters' phosphinoborate work at the turn of the century (Thomas, J.C.; Peters, J.C. Inorg. Chem. 2003, 42, 5055). Another such "scrap" is developing "companion" projects that compare our work to previous reports. The inherent throughput advantage is that valid comparisons require strict adherence to established experimental methodologies; we don't need to invent a new wheel, but turn an existing wheel with a related system. In this regard, we are grateful of late to Hahn's well-detailed study of template syntheses of Œ≤-amino-substituted isocyanides (Dumke, A.C.; Pape, T.; K√∂sters, J.; Feldmann, K.-O.; Schulte to Brinke, C.; Hahn, F.E. Organometallics 2013, 32, 289).

Transition-metal chemistry provides a wonderful device for research projects: the triad. As a chemist who works extensively in group VI, my students tend to synthesize analogues- usually in the order: Mo, W, Cr. Once a student has developed a Mo complex synthesis, confidence can be built by subsequent preparation of the W analogue. While Mo and W complex analogues often can be prepared using similar reaction conditions, the corresponding Cr complexes generally arise via alternate procedures; my students are ready to tackle these variations upon climbing the triad. And this strategy provides natural opportunities for periodic trend discussions.

Working as a PI in organometallic synthesis with exclusively undergraduate research assistants requires tenacity, courage and drive if one prioritizes regularly publishing student efforts. But the sensation of being a contributor to the field of inorganic chemistry while simultaneously motivating students to enter my favorite subfield continues to light my fire.

Neil K. Garg, Chemistry and Biochemistry, University of California, Los Angeles

Since 2010, I have taught "Chem 14D," an undergraduate organic chemistry course geared toward Life Science students. One fundamental aspect of my approach to teaching this class has been to introduce modern technology to complement my more traditional 'chalk-talk' teaching style. An example of this is the use of 'classroom clickers'. The system functions in real-time, thus providing critical feedback to both the students and me. I have also offered an unconventional assignment for students to create organic chemistry music videos in exchange for a small amount of extra credit. Briefly, the students work in teams and are graded on their ability to incorporate chemistry from the course curriculum into their videos and lyrics. This has proved to be an effective study tool. The assignment also allows students to be creative in ways that are less common in lower division science classes, while fostering a spirit of camaraderie and teamwork. Over five years, more than 1000 students have tackled this optional task in teams to produce roughly 500 videos, many of which are of stunning quality. Some of the best videos are available here:

http://www.chem.ucla.edu/dept/Faculty/garg/Garg_Group/MusicVideo.html

Most recently, I have created an online resource called BACON AT UCLA (Biology and Chemistry Online Notes and Tutorial, UCLA) that connects organic chemistry to topics in medicine and pop culture. We recently piloted this teaching tool in a UCLA course of nearly 400 students. Each week, students were required to complete a fun, educational, and highly interactive online tutorial. Students read about current events and contextual information, examined visual aids, and even watched video clips (e.g., from YouTube - both instructional and from pop culture) linking medicine and biology to chemical reactions learned in the classroom. For instance, when students learn about 'alcohols', the tutorial demonstrates to them how the body breaks down ethanol and how breathalyzer tests work, all with a focus on chemistry. Then, breathalyzer tests are connected to movies and recent celebrity drunk-driving incidents that students are presumably well aware of. As students navigate the electronic system, they answer multiple-choice questions about chemistry that test their understanding and intuition. We are currently expanding the content of this online tutorial and are building an easy-to-use web-based platform that will allow chemistry students to access it from anywhere in the world, at no cost to students or instructors.

Brian Goess, Chemistry, Furman University

I have developed and implemented at Furman University a sophomore-level organic chemistry sequence featuring one semester of accelerated organic chemistry followed by one semester of bio-organic chemistry. The first course in organic chemistry is an accelerated version of the traditional two-course organic sequence and covers all concepts critical to understanding introductory bio-organic chemistry, especially carbonyl chemistry. Both courses together preserve the best qualities of the traditional two-course sequence, namely rigor, emphasis on mastering fundamental scientific principles, and the frequent application of careful logic to solve complex problems. Both courses together meet the organic chemistry requirements for an approved degree as outlined by the American Chemical Society's Committee on Professional Training. And both courses meet the needs of chemistry majors and biology majors and pre-health students, and are therefore adequate preparation for advanced studies in preparation for both graduate and professional schools. Assessment data collected over a six-year period reveal that such a course sequence can facilitate student mastery of fundamental organic chemistry in the first organic course (as measured by their satisfactory performance on the two-semester ACS standardized organic chemistry final after just one semester of work), which is then reinforced during a second semester that is centered on the organic chemistry of biological molecules. Importantly, this bio-organic course covers material relevant to many of the key Competency Areas on which the new Medical College Admissions Test is based, including "Demonstrate knowledge of how biomolecules contribute to the structure and function of cells," "demonstrate knowledge of the structure, biosynthesis, and degradation of biological macromolecules," "demonstrate knowledge of … enzyme catalyzed reactions and metabolic pathways, regulation, integration, and the chemical logic of sequential reaction steps," and "demonstrate knowledge of the biochemical processes that carry out the transfer of biological information from DNA …," making this new organic chemistry sequence particularly beneficial to students hoping to enter health-related fields. A full paper describing this sequence has been published in The Journal of Chemical Education (DOI: 10.1021/ed400264w)

The major challenge facing the development of this course was the lack of a suitable textbook. Through Furman's Bio-organic Chemistry Wiki Project, we have facilitated the creation of an accompanying course text that is the work of students and not of faculty, thus ensuring content that better reflects students' ways of learning rather than our ways of teaching. Instructor input into the developing text has been minimal, and students have exercised complete authority over its creation. We are using an approach to the construction of this course text that expands the potential of a wiki implementation as exemplified by Wikipedia. In short, students have been given the tools necessary to create, referee, and modify a course wiki, thus allowing students themselves to design an online text for the course based on the content provided in class. Each subsequent class of the course then uses, augments and edits existing content. In this manner, all students benefit from and have the concurrent responsibility to improve the online text, with the outcome being the most student-friendly text possible, since it has been created entirely by successive generations of Furman students. To mimic the end-of-chapter problem sets that are included in traditional texts, students have also created their own problem set questions and have recorded themselves solving their own problems on video. The result is an online problem set and video solution manual that grows with each subsequent offering of the course. A sample of the student-created wiki content is available here: https://confluence.furman.edu:8443/display/FurmanStudentCreatedBioOrganicElectronicTextSample/Home

Amanda M. Grannas, Chemistry, Villanova University

Looking back at my own experiences as a student, I can identify several teachers and professors who had a significant influence and impact on my academic career. Although their areas of expertise were diverse, each of these instructors held several things in common: their enthusiasm for teaching, their love of learning, and an uncanny ability to relate the topic at hand to something I could appreciate. It's that love of learning that I hope to instill in my own students, through my own enthusiasm for the subject. I endeavor to be a catalyst in my students' education, helping them foster their own creativity and curiosity. One example of these goals is reflected in the redesign of our Instrumental Analysis lab course, designed for sophomore Chemistry majors. Laboratory techniques are used to obtain qualitative and quantitative information about the composition of various sample types, as would be expected in any lab of this nature. The course has been extensively modified and the curriculum developed to incorporate problem-based learning strategies and more "real world" applications. Multiple 3-week laboratory sessions that involve use of 12 different instrumental techniques have been developed. These labs cover topics as diverse as forensics, pharmaceuticals, gemology, environmental chemistry, art conservation, and food chemistry. Students participate in role-playing scenario-based laboratories, and are often confronted with ethical decisions to make regarding the implications of their results. Student response to this approach has been overwhelmingly positive. Students are required to present their results in oral, poster, and written format - all forms of communication they will encounter as future professional scientists. Each laboratory experiment is prefaced with the "scenario" that will guide the students' experimental design and data interpretation. In each scenario, one group represents an accusing group, one group represents a defending group and one group represents a governmental agency. As an example, for a pharmaceutical chemistry scenario, the accusing group is a consumer advocacy group that is making an accusation that a pharmaceutical company has purposefully included less iron in a multi-vitamin than is reported on the label in an effort to cut costs and increase company profits. The defense group represents the pharmaceutical company being accused and the governmental group represents the U.S. Food and Drug Administration. Each group is presented with the same scenario information, samples, and analytical instrumentation and is expected to complete the lab in the allotted time. The samples are over-the-counter vitamin tablets, however the instructors have relabeled the bottles and changed the reported values (and as such the scenario results can be altered every year). During a one-hour recitation one week following the conclusion of the experiment, each group presents the results of the analysis, as well as their interpretation of what should be done regarding the original accusation. The accusing group is required to give a poster presentation. The defending group is required to give an oral presentation. The governmental agency is required to write a formal report. For the ensuing laboratories, the groups rotate roles. Thus, by the end of the semester, each student group has the opportunity to play each role (accusing, defending and governmental) and to present their results in all three formats. We have designed the final presentation as an oral defense, where each laboratory section gives a 20 minute oral presentation, competing against each other in the final recitation period of the semester. We have found that their competitive spirit makes this approach very enjoyable for the students. The students appreciate that the measurements relate to something they can envision occurring in the "real world" and scenarios they might be presented with as professional scientists. This innovative approach to the instrumental analysis lab was published in the Journal of Chemical Education (vol. 87, no. 4, 416-418, April 2010).

Thomas W. Hamann, Chemistry, Michigan State University

This fall I am teaching the first semester of honors general chemistry for the fourth time. I have structured this course with three goals in mind: to teach a few key concepts in depth (rather than many topics superficially), to convey how these concepts were developed, and to relate the material covered in class to the everyday world. I have become increasingly convinced of the importance of the last goal.

First of all, relating the material helps keep all of the students engaged throughout the long semester - especially since a majority of the students are not chemistry majors. This also solidifies their understanding of chemical concepts. In addition, I choose examples to demonstrate the broad impact of chemistry (and chemists) on people's lives and the world in order to encourage them to continue studying science and pursue a career in science (Chemistry). I have found this to be effective enough that I now have guest lecturers and several half-classes devoted to "special topics." For example, when talking about structural isomers of inorganic complexes, I might use the example of cisplatin to show how the structure matters in the activity of cancer treatment, then segue into a larger discussion of the role of inorganic chemistry in medicine. As another example, talking about radicals allows a segue into atmospheric chemistry and how chemists identified the cause of the ozone hole and the chemical solutions to repair it.

I have had a lot of positive feedback from the students in my class about these special topics. My favorite example is from one of my student evaluations last year: "When I started this course, I was a Mechanical Engineering major. Now I'm a Chemical Engineering major and may switch to simply a chemistry major. Nuff said."

Nilay Hazari, Chemistry, Yale University

'An hour in the library can save you a week in the laboratory' is a common refrain that a young researcher hears from their advisor. However, time spent in the library can be ineffective and unproductive if a researcher does not know how to efficiently search databases and find appropriate references. In fact, there are many skills associated with both research and the presentation of research that influence the success and productivity of a student, which do not directly involve proficiency in the laboratory. These include the ability to use scientific databases such as SciFinder Scholar, Web of Science, and the Cambridge Structural Database, and familiarity with computer programs for the presentation of research such as ChemBioDraw, Microsoft Word and PowerPoint, and Endnote. In the long run a student's proficiency in these areas, which are not often included in undergraduate teaching, can help or hinder their job prospects, as most scientific job interviews include some form of written or oral presentation.

The vast majority of training in research techniques and the presentation of research occur in individual faculty member's laboratories, and there is a wide disparity in the level of education provided. In reality it is often taken for granted that students will be given advice and guidance on the important topics of searching databases and presenting research, but this is not always true. Some students are never given feedback on their scientific presentations and many are unaware of the existence of important databases, let alone the full range of features that they possess. Therefore, as part of his graduate course Physical Methods in Inorganic Chemistry, the PI conducts a mandatory weekly one hour workshop. In this workshop students are introduced to many of the databases and programs, which are critical to performing and presenting research. Tutorials are given on tools such as SciFinder Scholar and the Cambridge Structural Database and the students complete in class activities to make them aware of key features of the programs. In addition, through detailed feedback from both the PI and other students on written and oral assignments, the students gain familiarity with computer programs for the presentation of research such as ChemBioDraw, Endnote and ORTEP.

In the second half of the workshop, the students are tested on the skills that they have learned. Each student gives a 20-25 minute talk on a physical method in inorganic chemistry, which is not discussed during class. They are required to give the physical background to the technique and then with reference to the current scientific literature give two examples of how the technique is currently being utilized in inorganic chemistry. All the presentations are assessed both by the PI and other students in the class.

Mandë Holford, Chemistry, Hunter College of the City University of New York

Venomous marine snails produce a dazzling array of biochemical tools to hunt their prey. Whether the snails drill holes, suck blood, or sting fish with venom filled harpoons, the diversity of compounds produced has significant applications in chemistry and biology and I have used this interdisciplinary connection to steer the development of my career in science and my approach to science education in the chemical sciences.

My teaching and mentoring philosophy addresses the need to educate high quality scientists who can engage on several levels to solve questions and transform scientific knowledge in a manner that impacts society for the better. For me, the integration of disciplines is an exciting mixture that allows participants with diverse training to create new language. I integrate my interests and experiences in the areas of scientific research, education, and policy to provide students in my laboratory and in the classroom with a skill set that will allow them to have a discourse beyond scientific boundaries and advocate for resources and policies that are beneficial to science and society. This is accomplished by relaying how specific concepts apply to scientific discovery and innovation.

Specifically, I have transformed the Chemical Investigations course at Hunter College to focus on group projects using emerging technology, such as 3D printing. As 21st Century technology advances, 3D printing is fast becoming "mainstream machinery" and has already been used to produce objects that range from basic industrial building blocks to the most intricate of cell tissue. Despite this promise, incorporating 3D printing into scientific research projects remains somewhat of a mystery in academia. Working in teams of 4-5 students, each group develops a research project that ties together the opportunities for novel and integrative research approaches available by 3D analysis and then print the objects. Group projects have ranged from investigating the chemical structures of chimeras, to applying mathematical models that govern shell patterns of mollusk shells and devising 3D shell variations by altering MatLab code (Fig. 1).

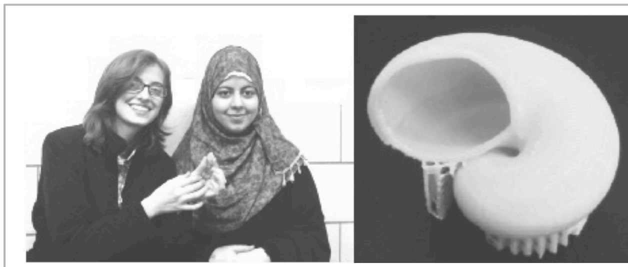


Figure 1. 3D research. CHEM291 students with their 3D printed project (left), 3D printed shell (right).

Tim Hubin, Chemistry and Physics, Southwestern Oklahoma State University

Integrating Undergraduate Research into the Chemistry Curriculum: Project-Based Labs

My most intellectually challenging and rewarding pedagogical output at SWOSU has to be the Advanced Inorganic Chemistry Laboratory course. For this Junior/Senior level of student, my perception was that a more meaningful experience might come from research-type lab setup where each weekly lab contributed to the development of a long-term project. I had never seen this type of approach for an Inorganic Chemistry Lab before, so I decided to develop one myself. I planned a synthetic route to related metal complexes and the typical inorganic characterization techniques for each complex. I chose a set of analogous bridged macrocyclic ligands as the beginning synthetic target for the students. About five weeks of multi-step synthesis resulted in multi-gram quantities of each ligand for each student. The NMR, IR, and Mass Spectrometer were used often to confirm the success of the various steps. Next, we spent a similar amount of time making the divalent metal complexes of the ligands in the glovebox (they are air sensitive), chemically oxidizing them to the trivalent oxidation state (air stable), and purifying the products. Finally, we spent the last third of the course performing characterization experiments native to Inorganic Chemistry, such a magnetic moments, conductance, IR, UV-Vis, and cyclic voltammetry. Mass spectrometry and elemental analysis supplemented this data. To complete the research process, the students prepared a research paper for the fictitious "Cantaurus" (bulldog) chemistry journal and gave a poster presentation to their peers. This course has now been taught five times, with excellent student buy-in, enthusiasm, and student evaluations each time. I have recently presented a well-received talks on incorporating undergraduate research into the chemistry curriculum at statewide and national (NCUR 2010, ACS Dallas 2014) meetings. My plans are to continue to integrate elements of my research projects into the described Advanced Inorganic Chemistry Lab.

Advantages of the Project-Based Lab
-Focuses on instructor's expertise throughout
-Students become invested with semester-long series of related experiments
-Focuses on the "Discovery" element of doing science
-Centered on an in-depth study of one system
-More like what "real chemists" do
-Opportunity to write-up, present, (and publish) original research

Lessons Learned
-This is a lot of work. Each instructor must make a research course based on their own expertise.
-Things will go wrong. Will you be able to "fix" them? Re-extracting five water layers over the weekend. Re-making two cobalt complexes because of an unexpected oxidation outcome
-Consider your project carefully before diving in. Semester-long project vs. several week project as part of "normal" lab. Scope of project and equipment needed may make it impractical
-Rewarding for students and instructor. Students gain confidence in their ability to "Do Research." Students understand how the many different facets of a compound's behavior are related. Students and Faculty can produce peer reviewed publications based on laboratory work.

Peter Iovine, Chemistry and Biochemistry, University of San Diego

Over the years I have taught a collection of courses that would be considered standard offerings for an organic chemist: sophomore organic lecture and lab, organometallics, advanced organic chemistry, and polymer chemistry. Beyond these bread and butter courses, I have also designed and implemented a course that teaches cross-cutting skills to STEM majors and features embedded community engagement work. Community engagement pedagogies are ones that combine learning goals and community service in ways that can enhance both student growth and the common good. I became interested in adapting these strategies, more commonly used in the humanities and social sciences, to STEM disciplines. So, in 2010 I taught an upper-division course, titled "Science in the Public Domain", that focused on teaching STEM students cross-cutting skills rather than specific content knowledge; these skills include critical reasoning in a complex setting, project development through iterative refinement, contextualizing the role of science and technology, effective collaboration, and communication of core and advanced science concepts to diverse audiences.

Students were encouraged to construct connections among the sciences, deepen their understanding of core concepts, and develop abilities essential for a flexible and sustained approach to learning. One of the key innovations of the course was the inclusion of a service-learning component that was intimately tied to the intellectual content of the course. Undergraduate students enrolled in the course formed interdisciplinary teams charged with developing and implementing semester-long scientific projects in the after-school environment. We partnered with a local community center that serves a diverse population of elementary and middle school students. One of the main goals of the experience was for the undergraduates to utilize their STEM-based skills and knowledge under new constraints and in new environments.

Ultimately, both the community partner and the undergraduate students benefitted tremendously from the experience. An unanticipated secondary benefit of the course was that it served a population of students who were interested in teaching but had not formally committed to that pathway. Going forward, I have plans to repeat this course and allow undergraduate students the opportunity to continue their community engagement work in the summer and follow-on semesters.

Matthew Kanan, Chemistry, Stanford University

Connecting an Introductory Course to Recent Literature and Global Problems

In teaching an introductory undergraduate course for the past five years, I have learned that incorporating recent chemical literature into lectures as early and often as possible motivates students regardless of their comfort level with the course material. I teach the first quarter of organic chemistry to a class of mostly Freshmen. When teaching this course the first few times, I thought that talking about recent literature would intimidate many of the students because the concepts in an introductory course were too many steps removed from modern research. I was also concerned about taking time away from the fundamental course content. On the suggestion of a senior colleague, I tried using the first five minutes of class to talk about recent research. For example, when I lectured on alkane isomers on the second day of class, I showed a paper about zeolite catalysts that isomerize linear alkanes to branched alkanes. The paper gave me an opportunity to discuss the thermodynamic properties of isomers and explain what “high octane” means at the gas station. (It also connected me to a field of catalysis for which I previously had little appreciation.) As another example, after discussing acid–base properties of organic molecules, I discussed how acid–base reactions are essential to producing the microelectronics that they rely on every day. I showed a paper that describes the use of phosphonium photoacids to deprotect Boc-protected poly-4-hydroxystyrene polymers during photolithography, ultimately enabling the patterning of Si microchips on the 100 nm–1 μm scale. These brief forays into chemical literature stimulated questions in class and during office hours both from students who were performing well and students who were struggling. Some students even looked up the papers after class each time to read them in depth. Course evaluations were also uniformly positive about including literature in class.

A second change that I have made in my introductory course is to aggressively promote the need for chemistry to solve global problems. I tell the students on the first day of class that chemistry is unparalleled in its opportunities for innovation and that the world’s most pressing problems demand molecular solutions. While medicine provides many powerful examples to illustrate this point, I find that it is difficult for students to relate to complex molecular structures on the very first day of class. To make this sentiment more accessible (and connect with my own research interests), I discuss fuel and CO_2. I give the class a very brief “history of hydrocarbons” by showing them that sunlight, water, and CO_2 are combined by the photosynthetic machinery to make carbohydrates and then geology performs dehydrations and disproportionations to transform the sugar into coal and hydrocarbons. I then show them the rate at which we are changing the carbon balance of the planet to pump CO_2 into the atmosphere. I tell them that all of the technologies that provide sustainable energy or mitigate CO_2 emissions were built on breakthroughs in chemistry. We compete for majors primarily with biology and computer science. Many students come in with the impression that these fields have the greatest opportunities for technological development. I have found that emphasizing, from the very first day of class, the power and necessity of chemistry to solve global problems motivates ambitious students to continue in chemistry and look for research opportunities.

Munira Khalil, Chemistry, University of Washington

Teaching Philosophy and Curriculum Development at the Undergraduate Level

At the University of Washington, I teach CHEM 452, "Physical Chemistry for Biochemists," which is a large (> 130 students) senior-level undergraduate lecture course. The course covers the subject of classical thermodynamics with an emphasis on biochemical processes, and it requires students to use multivariable calculus and regularly derive mathematical relationships. The majority of students (> 80%) in this class are senior biochemistry majors wishing to pursue careers in the health sciences after graduation. For most students in the class, physical chemistry is a dreaded subject, perceived to be irrelevant to current or future goals and often left until the last quarter of undergraduate study.

My aim for undergraduate curriculum development in CHEM 452 has been to enhance traditional homework assignments with problems based on current scientific literature in order to increase student interest and engagement. During Summer 2011, I worked with a talented undergraduate student to re-write the weekly problem sets for the course. Using journal articles that focused on concepts of thermodynamics important in biochemistry, we developed homework questions designed to test the students' comprehension of the literature as well as their ability to solve quantitative problems based on research presented in the article. My Autumn 2011 class served as a test run for these literature-focused homework assignments; at the end of the quarter, the students completed an online survey evaluating the homework, the results of which were then used to make adjustments prior to the Winter 2012 class.

We received positive feedback from the majority of students, who encouraged the continued use of the new literature-based homework sets, and we found that this new approach had many benefits. While the large lecture class setting makes group discussions logistically challenging, the literature-based homework provides a method for integrating scientific literature and current topics into the curriculum. My one-on-one discussions with students revealed that working with scientific literature helped them to put their coursework into context. For a lot of students, it allowed them to think about concepts of enthalpy, entropy, and Gibb's free energy at the microscopic level. It was very exciting to find students posting links to articles they read through their own initiative following the homework assignments on the online class discussion board, and to see how this approach helped students to discover for themselves the relevance of course topics to their own interests. The homework assignments and other class materials are now used by other Chemistry faculty members in their own courses, and we will soon make them available to the general public.

I have been teaching CHEM 452 since I first started my position in Autumn 2007. The feedback that I have received from my students has enabled me to become a better teacher, and it has been extremely gratifying to see the direct impact of my efforts reflected in my student evaluations. Through the years, I have realized the importance of (i) explaining abstract macroscopic phenomena with microscopic examples, (ii) interacting with students one-on-one in my office hours and before/after lecture, and (iii) encouraging students to vocalize their thought processes to help them become better communicators, a skill that is useful both within and outside of the scientific community.

Christopher Kim, Chemistry, Chapman University

Conducting a Viable In-Class Independent Research Project

For all the value that science faculty put into the scientific method, I've found that it is uncommon to incorporate an actual application of it in the context of a standard class format. Even many standard science labs hammer the inquiry part out of the experiment and often have students work through a prescribed set of steps towards an eventual outcome. One way to counter this and to include an element of exploration into a standard science lecture class is to devise a manageable group project that takes place over several weeks during the semester. I have successfully done this at the intro and advanced levels (with corresponding levels of oversight and expectations) and found that it engages students in ways that are not often met by lectures, problem sets, and exams. A few suggestions based on my several years of in-class research project experience follow:

<u>Mini-deadlines:</u> The key element of making this a successful experience for the students is to establish a number of mini-deadlines up front, with grades and feedback provided after each deadline (the final grade of the project is then an accumulation of these grades). This prevents procrastination, ensures constant feedback and improves the chances of a successful experiment. The drawback of course is that it represents a significant amount of grading for the faculty member, but if submissions/comments are done electronically (via Blackboard or even Google Docs) and if the project represents a substantial part of the overall course grade, I feel it is worth it.

<u>Multiple hypotheses:</u> Requiring students to provide multiple ideas for projects at the beginning allows them to stretch beyond just a single hypothesis, gives each group member the opportunity to contribute an experimental proposal, and allows the faculty member to choose the ideas that allow the greatest chances for success and also the widest diversity of projects.

<u>Meet with groups:</u> You should plan to meet with each group at least once during the course of the project, preferably just before or during their data collection phase, to get an update, offer suggestions on experimental design, and find out if something didn't work so that you can offer a fix with enough time left to still produce something presentable.

<u>Combining data:</u> In some cases, such as when similar projects are proposed, it may be advantageous to have all data available to the different groups for them to work with as they see fit. This allows multiple interpretations of larger datasets and also provides some external pressure on the groups to make sure their data quality is good since it will be seen by the whole class.

<u>Presentation of results:</u> It is critical to provide an avenue for oral, poster, and/or written presentation of the projects. This is also a good opportunity for peer evaluation.

<u>External references:</u> Encourage or require students to look for references and background information outside of their textbooks so as to engage with primary literature where feasible. Don't let them use this as a chance to steal experimental ideas from online sources, though!

Stephen Maldonado, Chemistry, University of Michigan

As a chemical educator, I view the process of learning a new concept as intrinsically an 'uphill' reaction for the student (Figure 1). My opinion is that a student learns something when they make the transition from a 'ground' state of unawareness to a higher state of comprehension. Without exception, a student must supply the driving force to learn. However, as a teacher, I feel my role is to be the catalyst for this transition. A good teacher makes sure the student's drive to learn is used efficiently. A good teacher minimizes the barrier(s) preventing a student from understanding an idea. A good teacher presents a student with a clear, direct pathway for comprehension. Most importantly, a good teacher remains active throughout the whole process. My teaching efforts in the chemical sciences have tried to follow this philosophy, i.e. all have been designed to make science more relatable, interesting, and/or exciting about my group's research area (semiconductor electrochemistry). My educational activities thus far span a wide range of learning levels (middle school, high school, undergraduate, graduate, and general population). For brevity, I share below my specific viewpoints on making a graduate course on Electrochemistry more appealing.

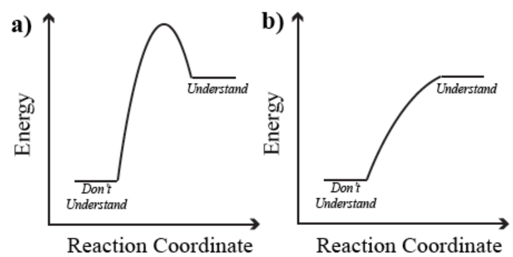


Figure 1. a) Bad teaching. b) Effective teaching

Since Fall 2008, I have taught the graduate course on Electrochemistry in our chemistry department 5 separate times. My approach to the course has developed iteratively, with a gradual shift away from rote lecturing of only equations and data plots. I use the tried-and-true textbook "Electrochemical Methods" written by A. J. Bard and L. R. Faulkner. Although it is a really great resource for the underlying concepts and history of the field, I have determined that following the chapters explicitly is difficult for many motivated but less enthusiastic students. Accordingly, I use the book as a guide but I now spend a lot of time supplementing and humanizing the topics and concepts. For example, the schematic of an electrochemical cell (Figure 1.1.1a) didn't mean much until the term that I brought it to class. The students used this cell to generate preliminary current-potential data. The data was not at all illuminating, but it did contextualize the concepts of 'current', 'potential', and 'electrodes' (which are the foci of the next two month and a half). Separately, the beauty and power of potentiometric pH sensors had been historically difficult for me to relay. This changed when I started giving their backstory (i.e. they were originally invented to check the 'tastiness' of lemon juice, they made Arnold Beckman a billionaire/philanthropist, profits from their sales helped seed the creation of 'Silicon Valley'). My lectures and the students' retention greatly improved. Along those lines, the underlying meaning of "+" and "-" still induces student headaches, but knowing that Ben Franklin had a hand in the confusion always breaks the tension. Similarly, describing the feud between Nernst and Arrhenius may be a bit 'gossipy,' but doing so makes discussions of free energy and electrochemical potential more real and substantive. Such stories also seem to help students appreciate another very important concept, i.e. that landmark ideas that lead to Nobel prizes are totally within their power to grasp, appreciate, and (eventually) surpass.

Thomas F. Miller, Chemistry and Chemical Engineering, California Institute of Technology

Having benefited from interactions with great educators, I am keenly aware of the impact of excellent teaching and mentorship, and I am determined to help my own students at Caltech realize their potential. Prior experiences have led me to a teaching philosophy that is governed by two themes. The first is that new material must be learned in context, and in the chemical sciences, that context is provided by modern scientific research. Consequently, I am dedicated to the melding of classroom material with research questions, challenges, and methodologies. The second theme is that modern research questions can be compellingly explained to scientists of almost any level of expertise or experience; so educators should make every effort to engage young scientists - especially high school and undergraduate students - in the collective pursuit of new chemical understanding. My educational activities reflect an effort to put action behind these ideas.

Teaching and mentoring in the context of the research group. As a "hands-on" advisor, I place particular emphasis on working interactively with my students in both formal and informal settings. I greatly enjoy detailed research discussions with individual students or small groups, which I find to be an effective way to keep projects and students on track. More structured, weekly meetings of the full research group include (i) a 1-2 hour research presentation by a visitor or member of the group, (ii) an informal "brainstorming" session in which each member discusses his/her latest results, new ideas, and ongoing strategies, and (iii) a "journal club" meeting in which one group member presents either a classic or a recently published paper of interest. Finally, as a mentor, I strive to be sensitive to the stresses and uncertainties of student and postdoc life, and I try to provide group members with useful encouragement and information as they develop their individual plans for the future.

Mentoring undergraduate research. My decision to pursue academic research in theoretical chemistry was largely shaped by outstanding research opportunities during my undergraduate career and by completing three summer Research Experiences for Undergraduates (REU) internships at various institutions. I therefore feel strongly about the importance of creating research opportunities for motivated undergraduate students. The benefits of such programs are manifold: top students are recruited into scientific careers; graduate students and postdocs are given mentorship opportunities; and new project areas are explored with the help of talented and energetic young researchers.

Undergraduate and graduate teaching. In my undergraduate teaching, I supplement traditional lectures and homework with examples drawn from research that is being performed at Caltech. In addition to providing a modern scientific context for the physical chemistry class material, this approach builds connections between the undergraduate student body and the Caltech faculty and researchers. In my graduate teaching, I emphasize the relationship of course materials to modern research problems, and I encourage students to grapple with the subject matter in the manner of a practicing research scientist. As part of this approach, I assign an end-of-term project in which students use newly learned statistical mechanics methods to characterize a compelling physical system. In addition to developing physical models and performing the theoretical and computational analysis, the students prepare a manuscript that discussed their work in the context of other recently published studies.

The TRIDENT Program - Team Research yielding Integrated Educational Tools. I have developed and implemented a program in my group that provides original research opportunities for local high school students and teachers. A total of eight (8) high-school students and six (6) science teachers have participated in this program to date. Key aspects of the TRIDENT program are outlined below.

INVESTIGATE INTEGRATE ITERATE

1. A team composed of a local high-school student, a local science teacher, and the PI collaborate on a computational summer research project.
2. Using newly developed skills and ideas, the team develops a strategy to integrate computational research tools into the science classroom.
3. To maximize impact, the PI visits the classroom to gain feedback on the implementation of the tools, to discuss modern science research, and to refine and enhance the educational tools.

Elizabeth Nolan, Chemistry, Massachusetts Institute of Technology

Some Highlights from Chemistry 5.08

As an educator, I aim to teach my students to be critical thinkers, inquisitive chemists, and skilled experimentalists, to encourage problem solving, and to share my passion for scientific investigation and discovery. My goal is to provide students with the intellectual and practical tools necessary to be successful, advance chemistry/science, and also communicate the importance and wonders of science to society. One class that I teach at MIT is Chemistry 5.08 – Principles of Biological Chemistry II, an advanced undergraduate course in biological chemistry that focuses on macromolecular machines and the experimental basis for our understanding of their structures and functions. This full-semester upper-level undergraduate course is currently co-taught by Professor JoAnne Stubbe and myself. It is an elective for Chemistry majors and typically has an enrollment of 35-50 students. Most of the undergraduate students are Chemistry and/or Biology majors, but each year some students from engineering and other majors take 5.08. The course also attracts a number of first-year graduate students pursuing biological chemistry or microbiology. In all aspects of this course, we place significant emphasis on the experimental basis for our understanding of cellular processes at the molecular level. The weekly recitation sections are dedicated to the detailed analysis of results presented in select papers from the primary literature and the experimental methods, including strengths and limitations, employed in these studies. Moreover, our exams questions are taken from the primary literature and are intended to educate as well as evaluate.

For many of our students, 5.08 is the first course in which they have encountered the complexities of primary data. For some, it is also the first time learning about the limitations of various techniques. In this context, some of my goals as a 5.08 instructor are to facilitate the students' comfort with scientific uncertainties, appreciation that one method alone does not solve any problem, and understanding that far more is unknown than is known despite high levels of experimental sophistication and a continually expanding toolkit of new techniques. Moreover, I aim for students to leave 5.08 with the ability to critically evaluate and question the experimental methods and data presented in the primary literature, and understanding that scientific hypotheses continually evolve based on new experimental or theoretical results. On of my favorite aspects of teaching 5.08 is presenting my closing module on assembly line enzymology (polyketide synthases and non-ribosome peptide synthetases). This unit is an extremely captivating one for the chemistry students because it incorporates macromolecular machines and protein biochemistry with small molecules exhibiting amazing and complex structures. Moreover, the assembly lines and the biosynthetic logic employed to create natural products are completely new to the students. It's terrific to see the facial expressions and excitement when they learn that an "assembly line" the size of the gigantic ribosome is dedicated to the biosynthesis of one small-molecule natural product, and that the dome-shaped vancomycin scaffold is based on a simple heptapeptide. Moreover, for many chemistry (and other) students, this unit provides the first opportunity to consider how a living organism produces a complex natural product - it is very different than executing a total synthesis in the fume hood! I close the assembly line unit with a detailed case study of enterobactin biosynthesis. Enterobactin is an iron chelator that is biosynthesized by the enterobactin synthetase, an iterative nonribosomal peptide assembly line comprised of three proteins EntDEF. In this case study, the class works through all of the hypotheses that were proposed, experiments that were performed, and results obtained by Professor Christopher T. Walsh and co-workers to elucidate how the enterobactin synthetase produces this beautiful C_3-symmetric natural product. In total, this exercise unifies many techniques that we introduced in prior lectures and recitations - protein purification, SDS-PAGE, radioisotopes, enzymatic activity assays, bioinformatics, identifying intermediates, and analytical methods including HPLC and mass spectrometry - and presents a wonderful story of scientific questioning and persistence, hypothesis testing, and experimental validation.

Catherine M. Oertel, Chemistry and Biochemistry, Oberlin College

Illustrating Chemistry Through Visual Art

I am engaged in using connections between chemistry and visual art to enhance teaching of both science students and non-science majors. I initially became interested in the chemistry of cultural materials through a research project on corrosion and conservation of historic organ pipes. I have since joined "Crossing the Street," a group of Oberlin faculty who work with the educational staff at the on-campus Allen Memorial Art Museum (AMAM) to take classes into the museum. Learning in the museum lets students see vividly observable properties that are linked to chemical structures and reactions and helps them to visualize the sometimes abstract atomic-scale world.

In teaching inorganic chemistry, I have shared examples of the reactions of metals that are provided by the substances making up works of art. During a class visit to the museum, we viewed Hendrik ter Brugghen's 1625 painting St. Sebastian Tended by Irene, in which the cobaltbased pigment smalt has undergone alteration and fading. Recent research by conservation scientists has shown that the mechanism of smalt degradation can be understood using ligand field theory. We also discussed Iznik pottery glazed with oxide-based materials fired at high temperatures and a 19th-century silver-plated bust sculpture that was recently conserved to remove sulfide-promoted tarnish.

Works of visual art can illustrate chemical ideas not only in their substance but in their content. In fall 2013, I took my general chemistry class to the AMAM to see photographs by the MIT physicist Harold Edgerton. These famous images, taken with ultrafast exposure times, capture events including bullets slicing fruit or playing cards, a tumbler reaching the top of an acrobatic leap, and the initial microseconds of an atomic bomb test explosion. We viewed these images at the start of our unit on chemical kinetics, using them to discuss rates of change and how the timescale of a probe is important in measuring or capturing a fast event. While these ideas may seem abstract on the molecular scale, they become more relatable using the slower, larger analogies depicted in the photographs.

In spring 2014, I developed and taught a new course, "Materials at the Museum," as part of Oberlin's interdisciplinary First Year Seminar program. This course, enrolling primarily nonscience majors, addresses the chemistry of materials used in artwork and the methods that conservation scientists use to study them. Concepts including the electromagnetic spectrum, elements and the periodic table, solvents and solubility, and reaction types are explored using both published case studies and examples from the AMAM. Though the course doesn't have a formal laboratory component, workshop sessions are used to synthesize pigments and incorporate them into egg tempera paintings. Many students in the first offering of the course were not naturally drawn to science but had strong interests in the visual arts, and the bridge to visual examples was especially important in teaching chemical ideas.

Devoting time in a chemistry course to visiting an art museum may initially seem wasteful. Why not project an image in the classroom and discuss it there for a quick example? I have found that there are benefits to visiting the museum that go beyond the chemistry content that students may learn. In seeing a work in person, students are able to observe its scale, shape, evidence of construction, and textural appearance in a way that using a projected image cannot reproduce. The museum staff and I have the chance to guide students in careful, detailed-oriented looking – a practice that is also important to their success in making observations in the laboratory. Taking a class out of its typical environment energizes the students for the day, disrupting the semester's patterns of which students participate and which groups of students interact with one another. Using "Crossing the Street" pedagogy has invigorated my teaching as well. Within this program, the museum staff does not take over a class but instead works with the faculty member to develop a lesson and co-teach the session. Teaching in an interdisciplinary area in which I am not already an expert has put me in the position of learner and observer and, I believe, has made me a more flexible and creative teacher.

Baron Peters, Chemical Engineering, University of California, Santa Barbara

Teaching philosophy: In real settings, technical problems are solved in three stages: problem formulation, strategy selection, and finally execution. Yet coursework and exams often emphasize execution over formulation and strategy selection. The emphasis on calculational exercises can leave our students with a 'hollow' understanding.[1] As our graduates move into the workplace, they will not get instructions like "Assume the reactor is isothermal…" or "Solve this equation by Laplace transform…", and yet we do the formulation and decide the strategy for them in courses. Following J. Biggs' philosophy (Constructive Alignment),[2] course activities, exams, and homework should be aligned to reinforce the learning objectives. It is not sufficient to explain how strategy and formulation is done. If we want students to learn problem formulation and strategy selection skills, our exams and homework must emphasize these activities. To emphasize problem formulation and strategy selection, I have adopted four practices: (1) I never reuse an exam question so that students are truly seeing each question for the first time and having to decide how to approach it. (2) Questions are always crafted so that very little time is spent on calculations when the problem is formulated and approached correctly. (3) I post all of my old exams and solutions on the web so that students have a fair opportunity to practice. (4) I give exams every three weeks to incentivize practice and to minimize the "luck" variable in assessment. Students comment that these "Peters tests" are difficult and different, but also indicate that they appreciate the importance of these skills.

YouTube channel: I maintain a YouTube channel[4] with lectures from my graduate and upper division undergraduate courses. Students can watch the videos while folding laundry, etc., and replay as needed with no embarrassment about 'not getting it.' The channel has a sizeable following beyond UCSB with approximately 50,000 views.

Book "Reaction rate theory and rare events": No existing book bridges the reaction rate theories of chemistry and the rare events theories of physics. Universities around the world teach these closely related topics from separate books, in separate courses, to separate groups of students. The 1990 review article by Borkovec, Hanggi, and Talkner notes[5] "*…books on physical chemistry and kinetics do not discuss Kramers' results. Likewise, rarely does one find a book on kinetics or nonequilibrium statistical mechanics written by a physicist in which is discussed the important transition state theory….*" 25 years have passed since the observation by Hanggi et al., and still the gap in our literature remains. Moreover, most books on theoretical chemical kinetics give insufficient attention to rate laws for multistep reactions – an essential link between theory and experiment for mechanistic hypothesis testing. I hope to change our curriculum with the first comprehensive book on kinetics and rare events. The contents include (1) rate laws and multistep reactions, (2) catalysis, (3) diffusion control, (4) collision theory, (5) RRKM theory, (6) transition state theory, (7) methods for potential energy and free energy profiles, (8) tunneling, dynamics, and transmission coefficients, (9) discrete and continuum stochastic models, (10) Kramers theory, (11) path sampling methods, (12) reaction coordinates and hypothesis testing, (13) nonadiabatic rate theories, and (14) free energy relationships. No existing book has even 50% overlap with this book (nearing completion with Elsevier).

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[1] www.npr.org/2012/01/01/144550920/physicists-seek-to-lose-the-lecture-as-teaching-tool.
[2] J. B. Biggs and C. Tang, *Teaching for Quality Learning at University, 3rd Edition* (Open University Press/McGraw Hill Education, 2007).
[3] T. J. Shuell, Review of Educational Research **56**, 411 (1986).
[4] www.youtube.com/user/baronpeters.
[5] P. Hanggi, P. Talkner, and M. Borkovec, Rev. Mod. Phys. **52**, 251 (1990)

Rodney Priestley, Chemical and Biological Engineering, Princeton University

Part of my reason for pursuing a career in academia was to become an educator and mentor to both undergraduate and graduate students. I believe that educators and mentors play a vital role in developing future generations of students to solve problems that impact society. I am humbled to have the opportunity to participate in educating our society as well as still having the opportunity to lead a research group. To date, I've had the opportunity to teach freshman/sophomore, junior/senior and graduate level courses in chemical engineering. I have noticed a marked difference in my course evaluations when teaching a freshman/sophomore course, as opposed to an upper-level undergraduate or graduate course. The former is statistically lower. To address this issue, I participated in a yearlong (AY 13/14) teaching seminar through the McGraw Center for Teaching and Learning on campus. The aim of the program was to understand scholarly approaches to teaching with the outcome of engagement in research and literature on learning that will frame opportunities for course development and assessment of teaching. Important to me was our discussion of the literature on the differences between novice and expert learning.

There were two underlying themes in the differences between novice and expert learning: overview and pace. Novices desired more of an overview of the topic and discussions related to contemporary themes. They wanted a connection with everyday life, that is, a direct connection to something impactful. In addition, the pace of the teaching should be slower for an introductory-level course. More student-student exchange was also desired. This fall semester, I am teaching Introduction to Chemical Engineering Principles, a freshman/sophomore level course. This is my first opportunity to apply the lessons learned from the McGraw Center's yearlong seminar to my teaching. New activities that I am undertaking in the course include the following: one-week overview of the discipline, in class demos and videos, small group discussions on review handouts, etc. In addition, all in-class examples are done on the chalkboard, as opposed to using PowerPoint in an effort to slow the class pace. Though the new techniques have only been applied for two weeks, I do feel as if the students are welcoming of the changes. At the end of the semester, I hope to report course evaluations commensurate with those of upper-level undergraduate and graduate courses that I've taught.

Kathleen L. Purvis-Roberts, W.M. Keck Science Department, Claremont McKenna, Pitzer, and Scripps Colleges

As an Environmental/Analytical chemist, my teaching has focused in General Chemistry, Accelerated General Chemistry, Advanced Laboratory (combination of Analytical and Physical chemistry), and Environmental Chemistry for both majors and non-majors. The Keck Science Department where I teach houses Biology, Chemistry, and Physics (and now Environmental Science and Neuroscience), which allows for innovative, interdisciplinary curricular developments. A while ago, I started talking with some of my colleagues in biology and physics about the possibility of offering an integrated first year science sequence where students could explore the intersections of each of the core sciences. After much discussion, we applied for and were awarded a National Science Foundation grant with the purpose of attracting more students to the physical sciences.

The main goal of the proposal was to develop this new course, which we named the Accelerated Integrated Science Sequence (AISS). I developed the course with two of my colleagues, one in biology and the other in physics, and taught AISS during its inaugural year. AISS covers all of the essential material from year-long sequences in introductory Chemistry, Biology, and Physics, but uses a different ordering of topics, integrated case studies, and laboratories to facilitate student thought in an interdisciplinary manner. We have observed that students who took the AISS course are better able to synthesize complex ideas and draw connections across disciplines in upper division courses. In addition, many have gone on to major in a physical science. The faculty who teach in the course report that this has changed the way that they teach both the lower and upper division courses in their field, as they tend to think more at the intersections of the disciplines.

AISS has now been running for eight years, and it has sparked somewhat of a revolution in my department. AISS works for very well prepared students who can handle the rigor of taking all three introductory science courses in one year at an accelerated pace, but what about all of the others who are the majority of the students we serve? Recently a non-accelerated integrated course was developed. This one-semester course, entitled Introduction to Biological Chemistry (IBC), combines the first semester of general chemistry and biology (focusing on molecular/cell biology topics), and the participating students do not need extensive high school preparation in math and science to enroll in the course. Other interdisciplinary, non-accelerated courses such as Chemistry/Physics and Physics/Biology are being discussed as well.

Khalid Salaita, Chemistry, Emory University

Teaching for the first time was not without challenges. After receiving weak evaluations in my first year of teaching, I subsequently signed up for the "Teaching Consultation Program" sponsored by my University. Through this program, I partnered with a senior colleague and had a semester-long series of consultations that dramatically improved the quality of my teaching. I owe much of the improvement in student evaluations to responding to my mentor's extensive feedback for each of the classes that he attended.

As a result of these consultations, I implemented a sweeping overhaul to my courses that ranged from the selecting the right type of room with movable chairs that accommodate active learning, to surveying students more regularly and better tailoring exams. One of the key pieces of advice was to conduct frequent surveys, and then to follow up by addressing the class with a publically shared rebuttal or response. Indeed, there was no reason to wait until the end of the semester to find out the weaknesses and strengths of the instruction. Accordingly, with each of the surveys conducted, I prepared a point-by-point response to comments voiced by more than a single student. In responding to critique, one empowers the students and makes it clear to them that the class is a dynamic dialogue that can lead down new paths. This information was critical in making sure that I was addressing concerns and tuning the course so that the largest number of students benefitted. Based on student feedback, I doubled office hours, reduced use of PowerPoint slides and made more use of the board. Of course, there were comments that I disagreed with, but rather than ignore the anonymous student comment, I articulated a detailed response. This is an effective tool that I now employ regularly.

Another important improvement pertained to the structure of examinations. I realized that I was slamming the students with exams that were hard and long. Instead, I now maintain the rigor of exams, but reduce the number of questions. This still tests understanding and problem solving skills without including the additional and unwarranted anxiety of a long exam. I also helped students focus on the key concepts by generating a detailed topic list for each exam, and by scheduling additional review sessions. Interestingly, the combination of the shorter exams and the review sessions did not influence the mean of the test scores; however, student complaints were drastically reduced. This has been a fruitful strategy for my graduate courses as well.

Most of the seniors and juniors taking my course are highly responsible and driven students; yet, like all of us, they still require motivation to prepare for each class. To address this, I followed another recommendation, and introduced daily reading quizzes. These were short (2-4 min) quizzes that tested the students on whether they read the chapter before coming to class. It accomplished three important goals: 1) it prepared the students for lecture, 2) allowed them to critically think about the topic, and 3) incentivized the class to arrive early and obtain credit for the quiz which was held in the first few minutes of class. I found that these quizzes dramatically increased the ability of the students to grasp the upcoming lecture, and to also arrive in a timely manner. Not fully understanding all aspects of the reading underscored to them the importance of the lecture and was an excellent motivator to become fully engaged during class.

Finally, one student critique was that the course could be better organized. I responded by generating a detailed weekly topic list (see example below). These detailed schedules listed the reading assignment for each class, reading quizzes, homework, and suggested reading from the current chemical literature. This new format helped the students plan their schedules ahead of time, and thus contributed to significant improvement in evaluations when responding to the question, “How well organized was the course?” I now use this same strategy for my graduate courses, where it is also well received.

				/n3/full/nchem.984.html
Feb 20	15		Fluorescence anisotropy and fluorescence lifetime	“Fluorescence Lifetime Measurements and Biological Imaging**”** *Chem. Rev.*, **2010**, *110* (5), pp 2641–2684 http://pubs.acs.org/toc/chreay/110/5 “Fluorescence Polarization/Anisotropy in Diagnostics and Imaging” *Chem. Rev.*, **2010**, *110* (5), pp 2685–2708 http://pubs.acs.org/doi/abs/10.1021/cr900267p
Feb 22	16	Reading Quiz Homework set 4 due	IR spectroscopy	• Skoog Chapter 16
Feb 25	17		IR spectroscopy	• Chapter 7 pages 206-211 in Skoog • Chapter 16 in Skoog
Feb 27	18	Reading Quiz	IR spectroscopy	• Chapter 17 Skoog
Mar 1	19	Reading Quiz Homework 5 due	Raman spectroscopy	• Chapter 18 • “Raman Heads For The Clinic” http://pubs.acs.org/cen/coverstory/88/8838cover.html?featured=1 •
Mar 4	20		Raman spectroscopy	• Chapter 18
Mar 6	21	Practice exam	Raman spectroscopy	• Chapter 18
Mar 8	22	**Exam II**		

Charles M. Schroeder, Chemical and Biomolecular Engineering, University of Illinois at Urbana-Champaign

Teaching How to Teach in the Chemical Sciences

Educational training philosophy & research group overview

In my group, we pursue molecular-level research in soft materials and biomaterials. Our work often relies on single molecule and single polymer techniques, which offers an ideal opportunity for an interdisciplinary training and education for students at all levels. In particular, our research critically relies on concepts from seemingly disparate scientific fields, such as biochemistry, materials chemistry, molecular biology, rheology, fluorescence microscopy, and microfluidics. Students are trained to work in a collaborative workspace with fellow students from diverse backgrounds. Regarding educational training, I strive to promote a scholarly and open environment that emphasizes scientific freedom and individual creativity for all students, together with teaching conduct of integrity and respect for fellow academic citizens. In this way, students at all levels are inspired to exercise creativity in research and to reach beyond the current state of knowledge, while always maintaining scientific rigor.

Illinois iRise: Teaching graduate students how to approach K-12 education

At the University of Illinois, my group has been extensively involved with the Illinois iRise program, which aims to teach graduate students how to approach K-12 outreach education. The iRise outreach program was formalized into a new course offering in Spring 2011 (PHY 598SE: Introduction into K-12 Science Education). The program consists of a two-pronged effort: (1) to actively engage local K-12 science teachers to develop hands-on experimental labs, and (2) to mentor middle school students from underrepresented groups through the local Don Moyer Boys and Girls Club, with a particular focus on sparking an interest in science through hands-on experiments. In the first effort, my lab has worked with 40 local high school science teachers in developing a series of new laboratory modules appropriate for high school education. These efforts were effectively implemented through a two-week summer program consisting of lecture/lab demos.

In the second effort, 4 graduate students from my lab mentored local middle and high school students from underrepresented groups over a 10-week period. The main goal of this program is to focus on teaching “science as inquiry” and to bridge graduate students’ university-based research with K-12 curricula. Graduate students also learn how to develop, teach, and assess lessons for middle-grade learners and are asked to prepare lessons and assessment tools for publication online or in a science education journal. In this program, graduate student mentors developed laboratory experiments and worked with the K-12 students to effectively implement and carry out the experiments. In one example, middle school students learned about diffusion and the relationship between fluid viscosity, momentum transfer, and fluid mixing. Future outreach efforts could include the development of new hands-on lab modules for K-12 students that demonstrate the effect of non-Newtonian properties on fluid mixing and flow properties. As one example, students could explore the frequency-dependent elastic properties of silly putty and solutions of cornstarch and water, which will directly show the effects of the elastic properties of complex fluids compared to simple liquids.

Alexandra Stenson, Chemistry, University of South Alabama

My courses have always been fast-paced and interactive. I hate talking at my students and try to involve them as much as possible. For every concept I present, I give my students an opportunity to practice its application. From the start, I have encouraged students to compare their answers and help each other during in-class problems. Naturally, I had to accept that a number of students simply refused to collaborate. Gradually, however, I am learning that I am able to reach more students by having them form permanent teams. In small classes, I even ask them to come up names for their teams and allow teams to compete with each other in terms of class participation for a small prize such as a few more drop grades on the homework. For large classes, I tell them that one question on each exam will test them on their knowledge of their teammates (names, majors, etc.). So far, I am noticing that this approach is working remarkably well. Everybody is participating during at least some part of each class. Obviously, not all students love this approach, but they do participate, which can only help them retain the material. In addition, working together helps prevent bright students from getting bored and struggling students from getting lost. Finally, working in teams is such a critical skill that I believe any opportunity students have to hone without risk to their grade is simply invaluable.

Corey R. J. Stephenson, Chemistry, University of Michigan

Modernizing the Undergraduate Organic Chemistry Laboratory Experience. As I began my career as an assistant professor, I found it surprising that the undergraduate experience in sophomore organic chemistry (lab and lecture) was very similar to the one I experienced some years earlier. The laboratory experiments, in particular, failed to maintain a connection to technological and scientific advancements relevant to the core course curriculum. Modern techniques, such as continuous flow chemistry, were not introduced to our students. Continuous flow chemistry is rapidly gaining acceptance as a standard laboratory technique in industrial synthetic research labs as companies increase their efforts to improve efficiency while reducing waste output. My research group has found it very easy to implement flow chemistry techniques into their daily research routine with excellent outcomes in terms of productivity. In this age of technologically savvy students, It seemed natural to consider its implementation into the undergraduate teaching curriculum, initially into an advanced laboratory and ultimately for the broader sophomore organic chemistry lab.

Students in my research group are currently developing two separate continuous flow experiments to be piloted in an upper level organic chemistry laboratory course at the University of Michigan. The first experiment merges well with the core curriculum as it involves the reduction of a carboxylic acid ester followed directly by a Horner-Wadsworth-Emmons reaction. These efforts are being undertaken in collaboration with Professor Tim Jamison (MIT), adapting a protocol introduced from his laboratory. Some key challenges for the implementation of this experiment are the use of neat diisobutylaluminum hydride (DIBAL) and high flow rates necessitating the use of stainless steel syringes and high end syringe pumps. Optimization of the reaction using readily available solutions of DIBAL and syringes commonly available in undergraduate teaching labs are critical to the successful implementation of this experiment.

The second experiment will introduce students to a modern aspect of catalysis in conjunction with continuous flow chemistry. Specifically, we are adapting a photocatalytic Appel reaction (conversion of alcohols to bromides or iodides) developed in my laboratory. Traditionally this reaction is conducted with stoichiometric triphenylphosphine, generating triphenylphosphine oxide as the stoichiometric waste byproduct. Although it may seem more challenging to implement, I anticipate the photocatalytic Appel reaction will be realized in the undergraduate teaching laboratory first. The reaction apparatus (right) is inexpensive (<$100) and does not require a significant investment beyond simple syringes and syringe pumps. Furthermore, this experiment will introduce the students to concepts in Green chemistry and the importance of catalysis in chemical synthesis. Implementation of these experiments in microfluidics platform is also of interest and will be particularly attractive as a means to reduce the waste footprint of the undergraduate teaching laboratory.

David A. Vosburg, Chemistry, Harvey Mudd College

Invitation

To teach is to invite.
We invite students to learn, to grow, to discover with us.
We invite them to engage with the unknown.

We invite students to walk with us, to take risks, to try something new.
They listen, step to the board, and share their ideas.
They ask questions.
We listen.
We ask questions.

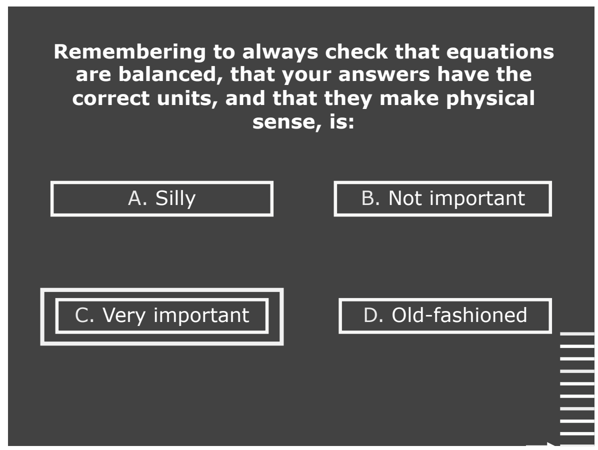
We invite students into our offices, our laboratories, our homes.
We share chemistry, wonder, a meal – even our lives.
We open the world to them.
They reveal their weaknesses, and our own.
We are humbled.
True community forms.

We invite students to think, to create, and to explore.
But most of all, we invite students to hope.
For we too have been invited.

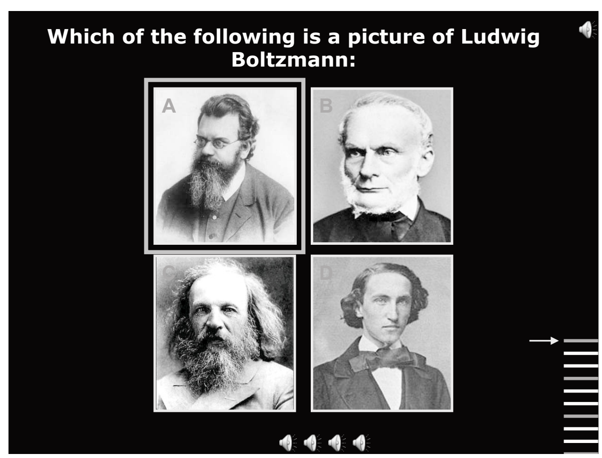
Adam Wasserman, Chemistry, Purdue University

More than a general teaching philosophy, I would like to share a simple activity that worked well for me when teaching general chemistry to a large class (450 students). Although I did this to review material for a midterm, the activity actually accomplished more. It created a fun atmosphere in the class that lasted for the rest of the semester, promoted camaraderie among the students and made me feel comfortable teaching. It is very simple. Nothing too involved if you are used to i-clickers: Play "Who Wants to Be a Millionaire." Dim the lights of the room and play the music from the TV show (this has an immediate effect on students' attention). Then welcome them to the show, explain the rules of the game (same as in the show, with the same lifelines: poll the audience, 50-50, call-a-friend. Only the prize is different, a golden Purdue-Chemistry pencil, with Dove chocolates along the way).

Start with simple questions:



and end with hard ones:

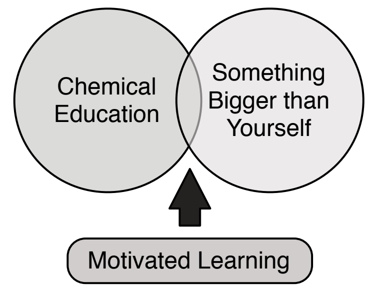


In between, try to actually teach some chemistry.

Daniel Weix, Chemistry, University of Rochester

Motivated Learning in the Classroom and in the Lab

During my first five years at the University of Rochester I developed new methods for motivating and educating young chemists in the classroom and laboratory, and pursued improving writing instruction in the sciences for students. These efforts grew out of my interest in self-determination theory, pioneered at the University of Rochester (E. Deci and R. Ryan). This work has shown that the best types motivators are those that are intrinsic (i.e., doing X because it is interesting) or extrinsic with "buy-in" from the student (believing in the importance of the goal).[1] Thus, besides keeping the work inherently interesting, I bring elements of working for a greater cause into each project, including public service, educating the public on science, connecting lab work to publication, and to a larger research program.



I think that the most success I have had motivating students has been to get them working on projects useful outside of class. Working with advanced undergraduates and beginning graduate students to improve the Wikipedia proved to be a satisfying, highly motivating task for students. While this is not appropriate for underclassmen, the more senior students produced outstanding material, reported being highly motivated, and that motivation appeared to help the exam performance of some students. These articles are highly viewed (28 articles produced, over 1 million page views) and are a continual source of pride for the authors! The key to implementing this, or any writing-in-chemistry project, was supporting all the different parts of the task (writing, technical guidance, education about the Wikipedia community, and peer review). Similarly, in an advanced lab course, I developed a lab to make chiral 1,2-aminoalcohols that were unknown in the literature (inherently interesting) and were immediately useful in my NIH-sponsored research program (part of something bigger). This proved to be a big hit with many of the students, who were very excited about "their" compound.

[1] Ryan, R. M.; Deci, E. L., Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. Contemp. Educ. Psychol. 2000, 25, 54-67. dx.doi.org/10.1006/ceps.1999.1020

Michael Zdilla, Chemistry, Temple University

1. Undergraduate research: I believe the key to molding the future of chemistry is to access the most promising chemical researchers when they are Undergraduates. In my 3 years at Temple I have advised eleven undergraduate students. Six of them, Regina Baglia, Carol Lam, Garvin Peters, Becky Clymer, Aziz Jalil, and Sean McWilliams are contributors to articles in J. Am .Chem. Soc., Inorg. Chem., and to submitted or in-preparation articles. Students performing this work have gone on to several excellent Ph.D programs such as Yale, Johns Hopkins, and Boston College.

2. Crystallographic Undergraduate and Informal Education: If one examines the history of the Nobel Prize, one will find the crystallography has been at the center of many awards (6 Nobel laureates over the last 9 years was directly tied to crystallography). The topic is essentially unrepresented in undergraduate curricula. I have developed a new, well enrolled undergraduate X-ray diffraction course at Temple, which theory along with an integrated laboratory section. By the end of the semester, the students perform a structure determination from start to finish. My approach to teaching in this and other courses is to encourage and foster independent thinking, while being maximally accessible to students for guidance. A second component of my crystallographic education mission is to host "The Database of Crystallographic Online Resources" or "DECOR," http://astro.temple.edu/~mzdilla/DECOR/

3. Community outreach and education: Since science is ultimately funded by the public, it is essential to establish community relationships and a display a positive image for science through engagement with and accessibility to the public. I am actively involved in community outreach events, and give presentations to the public with a focus on energy, green chemistry, and our own laboratory research. These public presentations have a high entertainment value and include entertaining chemical demonstrations, and silly songs performed on voice and guitar at venues such Philly Nerd Nite Cafe, the Chemistry Cabaret at the Chemical Heritage Foundation in Philadelphia, Philadelphia Science Festival, and various urban school outreach programs.

Hua Zhao, Natural Sciences, Chemistry Program, Savannah State University

One of the most rewarding aspects of teaching is to satisfy the curiosity of students and observe their academic growth. That is why I enjoy teaching. My primary goal in teaching is to stimulate a student's enthusiasm in science and to lay solid foundation in basic concepts.

I strongly believe that in chemistry the understanding of concepts and the ability to solve problems should be emphasized over illustrations and experiments. Letting their hands on the experiments will further strengthen their comprehension over fundamental concepts and principles. Being a good teacher means being supportive and understanding. Every time when I start a new concept or theory, I always think about how I learn it and how I can illustrate those abstract ideas in a more understandable way to the students. Being in a position of a student makes me an understanding teacher who can provide what a student needs.

Advisement and mentoring is a key to the success of a student. A proper advisement for students to take the right sequence of classes is a first-step to this success. More importantly, students are often seeking good suggestions on their career plans. Many students are confused about if the medical school is the right choice for them, what kind of preparation is needed for graduate school, or if they need a Plan B in considering their future careers. With advisement and mentoring, a student can realize his/her potential, take the correct career path, and know how to get ready as early as in the freshmen year.

Ultimately, the goal of education is learning, not teaching. I believe that students should be encouraged to think on their own. I always try to answer a question with a question, to show the students how they can find answers by understanding the underlying relationships. Using computer programs can sometimes illustrate more vivid pictures of abstract theories and help students to understand them better.