Teacher-Scholar
Teaching Statements

Research Frontiers in the Chemical Sciences

A Dreyfus Foundation Teacher-Scholar Symposium

Friday, October 26, 2018

The Camille and Henry Dreyfus Foundation
The New York Academy of Sciences

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. In addition the Dreyfus Teacher-Scholars are leaders in innovative approaches to education in the chemical sciences. The following statements by the Teacher-Scholars in attendance summarize their initiatives and philosophies on educating the next generations of scientists.

Alexander B. Barnes
Chemistry
Washington University in St. Louis

Teaching the next generation is a privilege and provides an opportunity to expand the positive impact I can have on society. Accordingly, I invest heavily in teaching and teaching methods to ensure that I can clearly describe concepts and motivate students to learn and maintain a long-term interest in science. I have taught: (i) thermodynamics, statistical mechanics, kinetics; (ii) graduate-level magnetic resonance; and (iii) freshman seminars. My courses receive some of the highest-rated evaluations at Washington University (see Figure 1 and student comments below). One strategy I employ in my teaching is to integrate my current, cutting-edge research into the classroom to illustrate the application of basic concepts.

Integrating research and education

If students understand WHY concepts are important and HOW they are actively applied in current research and beyond, then they tend to learn the material better. This is because (i) they are willing to put more time into mastering difficult mathematics and concepts if they can perceive a wider benefit; (ii) when students think ideas are important they are better at committing knowledge to long-term memory; concepts sink-in because they matter; and (iii) using real-world examples also provides students multiple frames of reference to retrieve learned concepts which can improve long-term retention.

I also apply other concepts from education research into course design and teaching approaches. For example, anonymous grading to remove bias, providing partial notes for current lectures to increase learning retention, and using a "flipped" classroom to engage students in the learning process.

Teaching undergraduate thermodynamics from the research frontier

Thermodynamics is not typically a favorite course of undergraduates, but it can be when instructors successfully integrate research (that is, applied concepts) into the classroom. I bring my research into nearly every lecture, which successfully engages students. This is illustrated by the following student reviews:

> "Professor Barnes made a topic I previously viewed as esoteric and irrelevant fascinating and clear. His ability to inspire interest in me was unrivaled in my four years as an undergraduate."
>
> "The integration of course material with contemporary research made everything seem more relevant and more engaging."
>
> "I appreciated that Dr. Barnes tied in his research to what we were learning- it helped so much to see a practical application to what we were doing in class, and it made the material more interesting."

Teaching from the frontier of research in the classroom allows me to get students as excited about science as I am. This is demonstrated by the ratings I received for my first three semesters of teaching thermodynamics. My course received the highest student ratings of any 400 level physical chemistry course at WUSTL on record for thirteen years.

Research examples incorporated into thermodynamics: magnetic resonance, cryogenic engineering, and biophysics

The diverse nature of my research program lends itself to finding numerous examples of how the concepts I teach in thermodynamics are being used in current research. ***Table 1*** illustrates a section of thermodynamics topics and the related concepts in my research program that I incorporate into my teaching. Fore example in my laboratory we have recently been able to cool NMR samples to 75 Kelvin even though the input temperature of the N_2 gas is 82 Kelvin. This is possible because the $N_2(g)$ has a positive Joule-Thompson coefficient and cools when it expands out of the bearing and turbine cup within the MAS stator.

Boltzmann statistics	EPR and NMR energy splittings, thermal equilibrium, NMR sensitivity
Partition functions	Ligand and protein binding modes
Free energy	Perturbations of structure at cryogenic temperatures
Joule-Thompson expansion	Cooling of $N_2(g)$ in cryogenic MAS experiments
Binary mixture	$N_2(g)$ and He(g) mixtures in cryogenic MAS

Table 1. Course topics and the related concepts from my research used in my teaching.

Conversely, teaching thermodynamics has had a profound impact on my research program. For example, after reviewing all of the derivations from first principles of why temperature affects free energy and thus the equilibrium structures of biomolecules, I modified my research program to also implement DNP experiments at physiological temperature rather than cryogenic environments.

Telling the story of entropy with quantum mechanics and statistical thermodynamics

When I started teaching 2nd-semester physical chemistry, I took a very different approach than that of the previously-offered course. Rather than starting off with macroscopic thermodynamics and the three laws, I first introduced statistical thermodynamics as a bridge between quantum mechanics and thermodynamics. At WUSTL, students take quantum mechanics in the fall before my course, and it is important for them to make connections to the material they have just learned. Another benefit to this microscopic approach is that students can leverage a quantized theory of energy levels and states to understand entropy. Entropy is a recurrent theme in my course and threads microscopic underpinnings with macroscopic phenomena.

One of my faculty mentors told me that every course should have a story—my thermodynamics course is the story of entropy. I teach entropy as a reflection of the number of states accessible to a system as Boltzmann presented it ($S=k\ln\Omega$), rather than ever mentioning it as “disorder” or “randomness”. This physical perspective provides students with a more accurate conceptual basis from which they can also apply quantitative treatments.

Specialized graduate-level course in MAS-DNP

I will utilize the instrument design and spin physics developed in my research program for my graduate-level magnetic resonance course. In addition to learning magnetic resonance theory and instrumentation design, students will engage in hands-on training. A 300 MHz magic angle spinning (MAS) NMR spectrometer and a 9 GHz EPR spectrometer will be integrated into the laboratory section of the course.

Writing and using spin physics calculation programs

In addition to lecture material and problem sets as tools to teach NMR theory, I have students write their own spin physics calculation program. Once they know how a spin physics calculation program works (because they wrote their own code), they can effectively use an efficient, commercially-available package. Example datasets from recent publications are included in class assignments.

Future Teaching Plans

I will expand my teaching to include two more courses in graduate level magnetic resonance, and I will also teach a large General Chemistry course. Our General Chemistry course is one of the best rated courses by freshman, and will provide me an excellent opportunity to recruit students into the ranks of chemistry and STEM fields. My graduate courses will include both a "user-based" course on NMR & EPR focusing on data acquisition and data processing for applications, as well as a quantum mechanics based theory course in magnetic resonance.

Chase L. Beisel
Chemical and Biomolecular Engineering
North Carolina State University

I view teaching as an important and humbling responsibility. I am tasked with educating the next generation of chemical engineers who will touch every aspect of our lives: from everyday household products and food to fuels and medications. Ensuring that my students are not only knowledgeable in the field but also creative problem solvers with unquestionable integrity and deep concern for society is no small undertaking. To help students reach these goals, I endeavor to adopt the most effective means to engage, excite, and challenge students. I also regularly seek advice from the most effective and recognized educators. Finally, I have found a synergy between my efforts in education and in the lab. Teaching has taught me how to better motivate concepts to audiences of varying backgrounds, while research constantly exposes me to new subjects and emphasizes the importance of creativity, innovation, research-based methodologies, and life-long learning. Below I describe some of the major teaching activities that I have pursued through my academic career. Each activity underscores my dedication to teaching as an integral part of my professional responsibilities.

COURSE INSTRUCTION.

Coursework in Chemical Engineering. At NCSU I have taught five different core and specialty courses as part of my regular teaching responsibilities. These include the entry-level chemical engineering course (CHE 205) four times and the follow-up chemical engineering course on computational techniques (CHE 225) one time. These courses were an excellent opportunity to develop active learning strategies and incorporate clicker technologies. I learned about many of these strategies and tools through the ASEE teaching summer school and mentorship by Dr. Richard Felder and Dr. Lisa Bullard—two faculty members in my department who are world-renowned for their teaching pedagogy. I have also co-taught the senior undergraduate capstone course in biomolecular engineering (CHE 551) numerous times, where I created new modules on binding kinetics, protein engineering, synthetic biology, and RNA engineering. I also had the opportunity to develop and teach a specialty course on Synthetic Biology (CHE 596-023).

Every semester, I have received consistently strong evaluations from my students: the average instructor rating across these courses was 4.4/5.0 with a maximum of 4.8 and a minimum of 4.0 (Fig. 6). For all but one semester, my instructor rating exceeded the average score for my department that is known across the university for its teaching excellence.

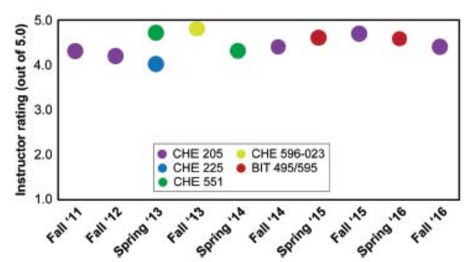


Figure 6. Student teaching evaluation scores. Students are asked to evaluate courses and instructors on a scale of 1-5, with 3 being "average" and 5 being "among the best teachers I have ever had." The applicant has been consistently rated well above average (and above the Departmental average; data not shown).

Laboratory module on CRISPR technologies. As part of my NSF CAREER award, I developed and taught a laboratory module on CRISPR technologies (BIT 495/595) in Spring 2015 and Spring 2016 through NCSU's campus-wide Biotechnology Program. The module offered hands-on experience with an increasingly popular genome-editing technology. A representative flyer from the program in shown in Figure 7. This has been a great opportunity to translate my research area into techniques that are in high demand across campus. The course was taught to a collection of undergraduate and graduate students from four different colleges.

EDUCATIONAL OUTREACH AND ENRICHMENT. I have also engaged in educational opportunities outside of the classroom. Within NCSU, I co-founded and have been running the "Biolunch" graduate seminar series. The series takes place each summer and has grown from a few presentations by graduate students in chemical engineering to a campus-wide series that is funded through the Provost's office and includes industrial speakers, a poster session, and professional development workshops. In my local community, I spent two years presenting "Science Hour" to grade-school students at two local community centers in Southeast Raleigh. As part of "Science Hour," I administered interactive modules developed through NCSU's Engineering Place and talked about careers in engineering.

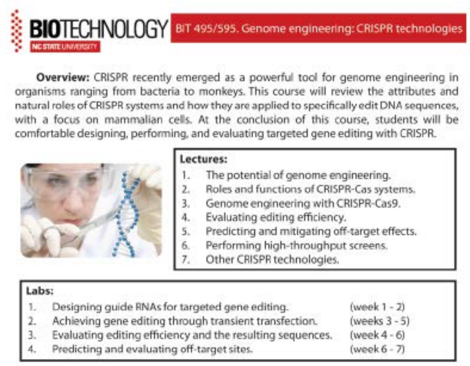


Figure 7. Flyer advertising BIT course on genome editing with CRISPR technologies.

CSHL synthetic biology summer course. I am serving in my second year as an instructor for the Synthetic Biology summer course (https://cshlsynbio.wordpress.com/) through the Cold Spring Harbor Laboratory. The two- week, intensive laboratory course exposes students from academia and industry to modern techniques in synthetic biology. As part of this course, a teaching assistant and I have developed and taught laboratory module on CRISPR technologies. I also partnered with Dr. Vincent Noireaux, another instructor, to develop a mini-module on using CRISPR in cell-free systems that became the basis of two papers currently in submission.

UNDERGRADUATE MENTORING. Undergraduate mentoring has been a consistent theme during my career. As a graduate student, I co-mentored a team of undergraduate students for the international genetically engineered machines (iGEM) competition. As a postdoc, I mentored an undergraduate student (Ben Janson). My NCSU career has shown the same commitment.

Supporting undergraduate research. I was actively involved in research as an undergraduate and value the perspective it provides on the research enterprise and career opportunities. As a PI, I have made a concerted effort to recruit promising undergraduate students in chemical engineering and other disciplines to engage in research. In total, I have hosted 19 undergraduate researchers who have worked on varying projects. For each student, my goal has been to match him or her with a capable and enthusiastic graduate student or postdoctoral fellow and provide a pseudo-independent project. I have also encouraged the students to write research proposals for an NCSU undergraduate research grant. This model has been successful so far, whereby roughly half of my publications at NCSU have included undergraduate authors.

Mentoring senior design teams. I have also had the opportunity to mentor two teams through the undergraduate senior design course in chemical engineering (CHE 450/451). This year-long course challenges teams of four students to apply their chemical engineering knowledge to real-world problems. Teams are matched with mentors who submit original problems and mentor students as they assess the technical and economic feasibility of their solutions. In the first year (2013 – 2014), my team designed a synthetic protein supplement to replace whey protein. In the second year (2014 – 2015), my team analyzed the costs of scaling up bacteriophage production for phage therapy. This has been a rewarding experience, particularly working with students as they wrap up their undergraduate study and enter the next phase of their careers.

Lauren Benz
Chemical and Biochemistry
University of San Diego

Flipped Fridays: Utilization of a Partial-Flip in Semester 2 General Chemistry

The flipped classroom is all the rage nowadays in the realm of effective pedagogical approaches, however, often the first attempt at a flipped classroom results in a total flop. I found that a partial-flip works well for Freshman-level chemistry, as it provides a space for instructor-guided peer-learning, while still maintaining the more traditional (though interactive) lecture-style classroom two days a week (for a Monday-Wednesday-Friday lecture schedule).

After teaching general chemistry for 6 years I decided to flip my classroom one day per week in a course that meets three times per week. My motivation for doing so came from the desire to have students spend more time solving challenging problems in groups in class. Normally, I would have students break into groups regularly, but for short periods of time, and precious time was wasted just getting the groups together and going. We also did not have enough group time to work on advanced level problem solving. I particularly felt that more group work was needed with the introduction of kinetics and equilibrium-type problem sets in part II of the general chemistry sequence where even strong students with past chemistry coursework typically enter new territory. General Chemistry II was also a good place to start since I had data on hand from student performance in General Chemistry I, and could strategically form groups with a diversity of academic strength in chemistry. I surveyed the students on aspects of their personality and their feelings about chemistry to try to form groups that I thought would work well together.

Prior to the start of the course I spent part of my sabbatical term making videos in which I modeled how to solve basic problems on a given topic. Ultimately, I required students to view these problems before coming to class, and I covered the topic beforehand conceptually during lecture (Mondays and Wednesdays). To motivate students to watch the videos, I gave announced quizzes at the start of class that closely mimicked the questions covered in the videos. This also ensured that students come to class rather than watching the videos only! Students received some credit for their work on the group problem solving on Fridays, and were given an opportunity to provide input into how the group-dynamic was working. Out of approximately 80 students and 20 groups across 2 sections, I only needed to rearrange a group once due to a conflict between 2 students.

I plan to continue to utilize the flipped classroom at least once per week going forward in this course, and possibly others, and I plan to expand my video collection to include advanced problems since many students requested this in the student evaluations. I believe the partial flip was a success since student performance increased by about 0.1 GPA points on average, and student feedback was quite positive. Also, prior to using flipped Fridays, 61% of the students (N = 145) rated the course as either excellent or above average, while after flipping Fridays, this number increased to 75% (N = 80). Finally, I plan to utilize the flipped Friday groups further to encourage further peer-learning through formalized group study sessions outside of class, though I'm still thinking about exactly how to do this well.

Amie K. Boal
Chemistry
The Pennsylvania State University

Providing young people with opportunities to practice scientific problem solving and data analysis is the most important part of my job as a faculty member and independent investigator. Last semester, I was sitting after class discussing a research article with a 3rd year undergraduate in my general biochemistry course. The assignment was for another class, but he wanted to discuss the figures and conclusions with me to make sure he understood them. He analyzed the information in the paper adequately and didn't really need my help. At the end of our conversation, he said, "In this assignment, I really underestimated how difficult it is to read and understand primary scientific literature. But talking to you about it helped!" There are two things that I found significant about that statement. First, it shows that many undergraduate students find reading scientific literature and analyzing data to be overwhelming tasks. And second, an effective way to overcome that barrier in scientific research/coursework is to spend time engaging with data and discussing interpretations with other scientists. Enabling students at all levels to acquire the necessary skills and resources to effectively analyze data and solve scientific problems lies at the core of my educational philosophy.

In my 4.5 years on the faculty at Penn State, I have served as instructor to more than 1000 undergraduates in large lecture-format introductory chemistry and biochemistry courses. These are challenging classroom environments in which to develop analytical and scientific problem-solving skills, but I have viewed these teaching assignments as a laboratory in which to practice evidence-based teaching methods, including peer instruction and active learning techniques. I have attended workshops at the national level (ACS/Cottrell Scholars Workshop for New Faculty) and institutional level (Center for Excellence in Scientific Education, PSU) for training in these instructional strategies. I also work with two teaching mentors with expertise in these approaches in my home departments at Penn State. In my assigned courses, I have contributed to curriculum design and developed new instructional and assessment materials that incorporate real-world examples and applications. I have also implemented new opportunities for students to critically analyze data, develop creative scientific problem-solving skills, and participate in small-group discussions to further nurture these skills.

In my upper-division biochemistry course, a major challenge to students in understanding biological structure-function relationships is the degree of complexity inherent in the structures of biological molecules. To help students more effectively evaluate biomolecular structures in lecture courses, I have provided training in computer-based resources for biochemical data analysis and designed projects that use molecular visualization software and other computational resources for analysis of biochemical datasets. These efforts include organizing tutorial and help sessions to facilitate software installation and student Q&A, resulting in 20 hours of out-of-class training per semester in the use of computational resources and databases. Assessment of skill development is based on completion of worksheets and examinations with open-ended questions/activities that link use of the software tools to biochemistry learning objectives. For example, in the spring and fall semesters of the 2017 calendar year, these exercises focused on modeling tasks to reinforce shape/structure recognition of amino acids, analysis of the folds of hemoglobin and myoglobin using protein structure viewers, and structure-based inhibitor design activities for HIV viral proteins. I have also encouraged students to use structure viewing resources and databases to evaluate proteins or nucleic acids selected independently based on their own interests and report their selected systems to me. This approach is beneficial in illustrating to students how analysis of biochemical data can be useful in other contexts, such as in scientific or medical research. It also allows me to learn more about the applications of biochemistry of the most practical interest to my students, for the purposes of new curriculum development. Deploying these projects in a large classroom (160 students in spring semester of 2017 and 200 students in fall term 2017) presents significant logistical challenges in assessment and implementation. To aid in short-term assessment of skill acquisition, I have made use of the learning assistants (LA) program in the College of Science at Penn State, an undergraduate assistantship in which students serve as peer mentors and learning facilitators in large lecture-format science classes. I have three years of experience working with the LA program at Penn State and have already utilized senior LAs and Honors College students in the design of new computational training exercises on a pilot basis over the last year.

My future instructional goals include contributing to ongoing efforts to use 3D computer-based molecular structure viewers in introductory chemistry courses for first-year undergraduates and in advanced coursework at the graduate level. For the latter objective, I am currently teaching a discussion course for a small group of upper-division undergraduates and graduate students. The format involves extended in-class work with structure viewing software as well as problem sets and original written research proposals that will require students to use these resources independently in the development of advanced research questions. I have a 6-year track record of participation in a Penn State workshop targeted at Ph.D./postdoctoral-level trainees focused on instruction in bioinorganic chemistry experimental techniques and crystallographic data analysis. The workshop also provides important opportunities for the graduate and undergraduate students in my research group to gain teaching experience and contribute to curriculum design.

On a smaller scale, I have served as research mentor to more than a dozen undergraduates, with ten papers published or in preparation as an independent investigator/collaborator containing undergraduate coauthors. My instructional activities have allowed me to recruit a large number of talented undergraduates to participate in my research program. I have made an effort to reach out to the top-performing students in my lecture classes and LA cohorts to offer them the opportunity to join my research group, particularly in cases in which the candidates in question are women or members of underrepresented minority groups. At a large undergraduate institution, even though many faculty are research-active, it can be challenging for students to identify mentors, and I have made a concerted effort to facilitate these opportunities for students who exhibit talent in my undergraduate courses.

With research trainees, I have encouraged grad/undergrad students to attend training workshops in x-ray crystallography and spectroscopic/analytical methods and to engage in independent collaborative work with other scientists. I encourage and facilitate independent formulation of research questions by my graduate and postdoctoral trainees, as detailed in my research program description. My laboratory space is contiguous with three other groups in the chemistry/BMB departments focused on bioinorganic chemistry problems. The environment has allowed my students to expand their projects into areas beyond structural biology – including organic synthesis, spec-troscopic/kinetic analyses, microbiology, and other analytical techniques. Additionally, I have prioritized training and mentorship in visual and written communication of results and active inclusion of students at all levels in preparation of manuscripts and participation in conferences/workshops. My undergraduate and graduate students have earned admission to competitive summer research programs and recognition via departmental research awards, merit fellowships, and conference poster prizes. I have placed my first two Ph.D. students in research laboratories at the Whitehead Institute and Caltech. Undergraduates I have mentored have successfully gained admission to medical schools and Ph.D. programs at high-ranking institutions including MIT and Caltech.

Fadi Bou-Abdallah
Chemistry
The State University of New York at Potsdam

Quality teaching has always been a priority of mine. I believe that one the most important factors that contribute to students' learning and achievement is the quality and dedication of the teacher. My expectations are no less than excellence in undergraduate education, service, and research with the goal of creating a unique learning experience for students. I think students learn more effectively from an approachable and friendly teacher who sets up a comfortable atmosphere conducive to learning. I adhere to a high standard of being very approachable and supportive of my students. The positive rapport that I have fostered with students is evident in my exemplary teaching evaluations which have consistently been in the excellent category with every course I have taught, major or non-major.

Accomplishments

When I came to SUNY Potsdam in 2007 as a tenure-track assistant professor, the expectations of the chemistry department were that I would update the physical chemistry curriculum that we provide for our chemistry and biochemistry majors. Indeed, in my first year, I revamped the biophysical chemistry lab, created my own pchem lab manual and implemented a whole new set of lab experiments that included a writing intensive component. In my second year, I was successful in obtaining an NSF MRI grant to acquire an isothermal titration calorimeter (ITC) and a differential scanning calorimeter (DSC) to a) further enhance existing undergraduate teaching and research, b) help incorporate advanced technologies into the science curriculum and c) expose students to state-of-the-art techniques and allow them to learn cutting-edge experimental methods that are commonly used in the studies of many chemical and biochemical reactions and finally d) improve the quality of education by bridging existing gaps between coursework and laboratory. In addition, I was able to bring a stopped-flow rapid kinetic instrument interfaced to a diode array UV-vis spectrophotometer and more recently, through an NIH research grant, I was able to acquire a Capillary Electrophoresis (CE) system from Agilent Technologies. These instrumentations did not only provide teaching and training opportunities for undergraduates but further enhanced the chemistry department research capabilities and increased interdepartmental collaborations between faculty of both chemistry and biology departments as well as collaborations with other departments at nearby Universities. The operation of these instruments and interpretation of the research data allowed me to introduce new educational components in my upper division physical chemistry classes on protein thermodynamics, binding interactions and chemical and enzyme kinetics. Additionally, I have developed four new pchem lab experiments that involve the use of stopped-flow techniques, ITC, DSC, and fluorescence spectroscopy to investigate the rapid formation of iron-thiocyanate complex which occurs on a millisecond time scale, the thermodynamics of protein unfolding including lysozyme, bovine and human serum albumins, ferritin and transferrin in the presence or absence of metal ions and ligands, and the binding interactions between Non-Steroidal Anti-Inflammatory Drugs (NSAIDS) and serum albumins. As I continue to improve and update our chemistry curriculum, I anticipate developing a pchem lab that is fully research-based where students participate in the investigative process and the creation of knowledge. Lastly, for the past two years, I started teaching twice a year (winterim and summer) a non-major chemistry course entitled "Chemistry and Human Health." The course is 100% online and open to anybody who is curious to learn how chemistry is vitally involved in almost every aspect of our life.

Notably, I have created a "Regional Center" at SUNY Potsdam for the kinetic and thermodynamic characterization of macromolecules using the three newly acquired research equipment (ITC, DSC and CE) and a rapid kinetic stopped-flow diode array system (which I was able to bring with me when I came to SUNY Potsdam). Significantly, there are no ITC, DSC or CE instruments available to students and faculty at any of the four Universities (SUNY Potsdam, SUNY Canton, St. Lawrence University and Clarkson University) in the St. Lawrence County in upstate New York. The closest campus to house any of these sophisticated instruments is hundreds of miles south of Potsdam. Thus, the creation of such center will greatly benefit these Universities, enhance undergraduate education, foster collaborations and expand the research capabilities of several faculty and students at these institutions and others in the area.

Furthermore, my voluntary service to the discipline of chemistry, the local communities and SUNY Potsdam is rather extensive. I have served on a number of administrative committees that directly affect students including the Arts and Sciences Council, the Student Affairs Committee, Student Initiated Interdepartmental Major Committee, the Arts and Sciences Curriculum Committee, the Research and Sponsored Program Committee, the Diversity Task Force Committee, and the UUP Individual Professional Development Award Committee, and have been heavily involved in community outreach and the public awareness of chemistry. Since my arrival to SUNY Potsdam, I have presented three times per year (on average) general chemistry talks, demonstrations and chemistry magic shows to the public and to over 1200 high school students at the High School Science Day and other public events. I am the creator and organizer of the Annual Undergraduate Chemistry Research Symposia for the Northern New York Section of the American Chemical Society (7 years in a row) and a few other events including an annual ChemQuest and a Chemistry Jeopardy Game.

Some of the key elements that define my teaching style and effectiveness

1. The best teaching is active and varied: Given that the flipped classroom has been in vogue in the past few years, I have been working at implementing this relatively new pedagogical model while trying to use my lecture time strategically. There are numerous topics in physical chemistry, such as enzyme kinetics and chemical equilibria where lecturing is perhaps the best way to convey concepts along with guided problem- solving. Other topics like quantum mechanics are perhaps best taught using illustrative demonstrations, videos and animations. Other strategies such as weekly assessments, daily one-on-one meetings with students, and weekly review sessions help me adjust instructions, address deficits and misconceptions in a timely fashion. Combined, these strategies have noticeably lowered the failure rate in my pchem class and allowed students to better grasp concepts and do well on exams. As educators, it behooves us to make sure that our students are not only able to absorb information, but to analyze and communicate knowledge and potential implications. We need graduates who are broadly trained, thoughtful and articulate. To foster those skills, I routinely involve my students in reviewing papers, writing and publishing our own results, and presenting poster and/or oral talks.

2. To teach well is to relate, organize and adapt: The Internet and Google have changed the way people learn, just as Gutenberg's printing press revolutionized learning several hundred years ago. College students are not lacking for information anymore, but a skeptical reading of information, generating questions and hypotheses is an important 21st Century skill. I am always pleased when students ask challenging questions, thoughtfully evaluate experimental design, data, and arguments. In my physical chemistry course, I often give students data or share with them recent science news to critique and evaluate. I believe the role of a college professor has changed from being a provider of knowledge to a facilitator who would organize and relate relevant material for students. Despite my extensive experience working with disadvantaged, low income, first generation, and at- risk students through our Educational Opportunity Program (EOP) and the Collegiate Science and Technology Entry Program (CSTEP), I strive to continuously evaluate, improve and adapt my teaching style to best fulfill the individual learning styles (i.e. personalized education) and information-processing needs of our culturally diverse student body.

Role in Experiential Learning: Research is a critical teaching tool that prepares students to graduate work or scientific careers. Students in my lab gain significant experience in the biophysical characterization of protein binding studies, chemical kinetics and folding thermodynamics. For the past decade, over thirty students have performed undergraduate research in my lab during regular academic years and over summer. The summer research experiences have been made possible through research grants I have received that procured major research instrumentation, thus providing undergraduate students the necessary resources and salaries to carry out advanced research projects. All students who conduct research in my lab present their findings at local, regional, or national conferences, and many of them end up co-authors on peer-reviewed articles. As an independent investigator, I have published twenty eight articles since my arrival in 2007 to SUNY Potsdam, nineteen of which are co-authored with SUNY Potsdam undergraduates. I am constantly impressed with the ability of my students to carry out difficult experiments and to effectively contribute to the success of our research program.

Abhishek Chatterjee
Chemistry
Boston College

As for so many other scientists, my path to a career in science was paved by a few outstanding educators. The passion for science they lit in my heart continues to guide me to this day. I feel privileged to be in a position that provides me the opportunity to have the same kind of influence on young students. My key goal in education has been to get students excited about science through rejuvenating their innate sense of wonder, and by helping them see the transformative role science continues to play in our lives. Throughout the last four years I have tried to implement this philosophy to inspire students in the classroom, within my research program, and in the context of summer research programs targeted to high-school students.

Classroom teaching
Since joining Boston College in 2013, I have taught two distinct courses: i) an advanced interdisciplinary course (CHEM556001) that introduces the concepts in modern biological chemistry to graduate students and advanced undergraduates, and ii) Biochemistry II (CHEM4462), a course focusing on key metabolic pathways, for Chemistry and Biochemistry majors in their Junior year.

In the former course, I have focused on student participation by: i) including regular student presentations on current topics, ii) helping students craft original research proposals at the end of the semester, which are peer-reviewed by the class, iii) engaging students in various hands-on learning experience, such as the use of freely available bioinformatics resources, molecular visualization software, etc., and iv) replacing traditional tests with collaborative projects where groups of students find solutions to complex contemporary challenges. For the relatively larger Biochemistry II course, I have incorporated alternative techniques such as the use of interactive quizzes (using iClicker), group learning, etc. Both courses have been highly popular, and consistently rated significantly above the departmental average by the students. It has been highly rewarding to see that the students routinely note in their review that that they found the subject to be engaging and exciting – which I believe is critical for effective learning.

Undergraduate research
As an undergraduate, I found the exposure to scientific research highly stimulating and beneficial. I have been deeply committed to provide training opportunities to undergraduates from our community. My group has already hosted over 13 undergraduates in the course of the last four years. Interested students are typically recruited in their sophomore year and stay with the group for the next two years, getting an immersive research experience. The students are trained by the senior graduate students or postdoctoral fellows for the first year, and assume a more independent role in the following year. Our group has also participated in a program involving sophomores in the Chemistry (Honors) track that allows students to join a research laboratory for a semester in lieu of traditional organic chemistry laboratory. These students typically continue participating in research beyond their first semester in the laboratory.

Many of these undergraduate researchers are or would be coauthors in several papers that are at various stages of publication (please refer to CV for further details). Research accomplishments of the undergraduates from our group have been recognized by numerous accolades, including the Barry Goldwater Scholarship, Scholar of the College (a very select Boston College honor), The McCarthy Prize (the most outstanding undergraduate research thesis in the sciences at Boston College), the Kozarich Fellowship, the Jolane Solomon Research Fellowship, etc. Undergraduates trained in our group have also been admitted into the top graduate programs in the country.

Summer Research Program

It has been well-established that students motivated in their early years to gain interest in STEM subjects are more likely persist in a STEM major. We have developed a summer research program titled "You Evolve a Protein!" (Yep!) that exposes local high school students from the greater Boston area to scientific research. This program, initiated in 2015, is designed to convey the principles and technology associated with directed evolution of proteins to high school students in a visually captivating way. To make this somewhat esoteric concept more appealing and readily demonstrable to high school students, we have chosen green fluorescent protein (GFP) as our model system, with the goal of changing its color (emission wavelength). Participants in this program are exposed to basic manipulation in molecular biology, dealing with lab strains of E. coli, analytical characterization of fluorescent proteins, connecting genotype (DNA sequencing of evolved clones) to phenotype (change in color), and advanced instrumentation (e.g., multi-mode plate reader, fluorescence microscopy, cell sorting, etc.). Over the last few years, the program has been highly popular. Additionally, I have also contributed to the development of another interdisciplinary summer research program "Paper to Plastic" (P2P) in collaboration with my colleagues Jeffery Byers and Eranthie Weerapana.[1]

Development of an Interdisciplinary Laboratory Program

Due to the limited size of our research-active faculty, less than 40% of the students in the aforementioned Honors Chemistry Program are able to find a host lab for research, while the rest of the students participate in traditional organic lab (CHEM2234), with no exposure to cross-disciplinary science. In collaboration with our teaching faculty (Dr. Christine Goldman and Dr. Lynne O'Connell), I am developing new interdisciplinary experiments that will complement their largely traditional training. In this course, the students will synthesize noncanonical amino acids (e.g., photo-caged tyrosine) [2] and incorporate them into the green fluorescent protein to create mutants whose fluorescence can be turned on in response to a physical/chemical stimulus (e.g., light).[2] Exposure to such exciting cross-disciplinary experiments in the laboratory has the potential to enhance students' experience and improve their retention in STEM disciplines.

---

1. J.A. Byers, E. Weerapana, A. Chatterjee. (2017) ACS Symposium Series, 1259 (5), 51–68.
2. D. Groff, F. Wang, S. Jockusch, N.J. Turro and P.G. Schultz (2010) Angew. Chem. Int. Ed. 49, 7677-7679

Irene A. Chen
Chemistry & Biochemistry
University of California, Santa Barbara

In 2012, the President's Council of Advisors on Science and Technology (PCAST) estimated that, over the next decade, the United States would need to produce 1 million more STEM professionals beyond the current rate, in order to maintain its position as a world leader in science and engineering[1]. But maintaining the competitiveness of the U.S. is only one motivation for improving science education. We also owe it to our children to give them the best conceptual and technical tools we can to confront the serious challenges that current and future generations are facing. From climate change to antibiotic resistance, the challenges of the world will require both STEM professionals and also a scientifically informed citizenry working together. Thus my goals as a teacher are to both introduce the scientific concepts of biochemistry and to expose students to the 'culture', i.e., ways of thinking, of science.

In classes, I have tried to create this exposure by having students read from the primary literature, where discoveries unfold. In the past four years, I regularly taught the last quarter of Biochemistry (to our Chemistry majors) and a half-course on Nucleic Acids for graduate students. In Nucleic Acids, my class reads through the primary literature of major discoveries in the field, such as papers that describe Nobel Prize-winning work. This critical reading of the literature is highly rewarding for all of us, with students actively engaged in interpreting the papers. The students inspired me to see them as a part of the scientific community, so this past year I added a Wikipedia component to the course. The students learned, outside of class, how to edit existing articles, generate new articles for Wikipedia, and conduct peer review of each other's articles [https://en.wikipedia.org/wiki/RNA_spike-in]. The material they contributed has been widely read; of articles substantially edited (added >1000 characters), the number of article views ranges from a few hundred to >50,000 as of this time. More importantly, the students themselves gave overwhelmingly positive feedback about this course component. It was extra homework, but they were eager to apply their knowledge and engage in a larger community.

The PCAST report proposed that the expected shortfall of STEM professionals could be largely filled by a relatively modest increase in the retention of STEM undergraduate majors, from 40% to 50%. This estimation inspired me to think that even small interventions that improved undergraduate teaching could be very worthwhile. The progression of my Nucleic Acids course motivated me to search for ways to translate these approaches to undergraduates. At first, I tried asking my Biochemistry students to read and present an article from the primary literature. However, I realized that the students were often missing basic tenets of scientific culture despite their readings (e.g., the importance of controls, the meaning of error bars, how to identify good sources of information). A similar pattern emerged during General Chemistry, which I taught last year. In hindsight, the journal club format of my small Nucleic Acids class, where we could discuss details of design and interpretation, did not translate well to these large undergraduate classes. What did work? During Biochemistry, I saw that the students were highly engaged whenever we used simple hands-on materials. For example, to illustrate DNA supercoiling, I passed out twine and asked the students to create twist and writhe, and to simulate nucleosomes with their fingers. To illustrate the topological problems associated with DNA replication, we twisted strips of paper, taped them into loops, and cut them along the long axis. The students loved those small labs; they were engaged and alert during these activities. But while the topic of DNA topology lent itself naturally to manipulatives, I did not have a strategy for engaging students when lecturing about other biochemical concepts.

To address this problem, I am moving from experimenting with admittedly ad hoc teaching tools toward incorporating evidence-based, best teaching practices from the science education literature. I gleaned a few strategies from a recent book by the National Research Council[2]. Some of these proven strategies will be relatively easy to implement, such as having students write a 1-minute reflection on what they learned and the 'muddiest point', focusing less on information and more on 'big ideas', including ideas that are broader than my discipline (e.g., error bars), and administering team tests, in which students can improve their grade after discussing problems with their peers. I am eager to see whether students will improve on objective measures (i.e., tests, retention rates in the Biochemistry major) as well as subjective ones (i.e., course feedback).

The strategies outlined above are of particular interest for efforts to retain women and URM students. I am naturally interested in supporting these groups, in the moral interest of fairness to all. In addition, studies indicate that diversity and greater equality among group members enhance group performance[3]. Given the increasingly collaborative and interdisciplinary nature of science, group performance of science is becoming the norm. Interestingly, women and minorities benefit more from evidence-based teaching methods[2]. This phenomenon may be connected to nurturing the 'growth mindset', which is associated with grit and success, as female and minority students who display a growth mindset are more resilient in the face of negative stereotypes[4]. For example, the reflective exercises would encourage students to recall their improvements over time, and the group tests give an opportunity to correct their mistakes. I plan to incorporate more growth mindset activities into the classroom in the future, as these may have implications for their lives that reach beyond the classroom.

I have also been active in mentoring undergraduates in the lab. Eight papers from my lab have undergraduate authors; of these, six have an undergraduate as first author. I have mentored through the ICB SABRE program and the NIH MARC U-STAR program, which place excellent disadvantaged or under-represented minority undergraduates in research labs. I am proud to note that the first undergraduate student in my lab at UCSB, Daniel Chu, was awarded the Thomas More Storke Award for Excellence and the Chancellor's Award for Excellence in Undergraduate Research in 2015 - the highest academic honors for graduating seniors at UCSB. I also enjoy volunteering annually in conjunction with National Chemistry Week. For example, last year I worked with a first-grade classroom to develop a simple lab to purify water (as well as the classic Mentos/soda experiment). Through these activities, I hope to contribute to educating both future STEM professionals and a scientifically informed citizenry.

---

1. President's Council of Advisors on Science and Technology (2012) Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Executive Office of the President. Washington, DC.

2. Kober, N. (2015). Reaching Students: What Research Says About Effective Instruction in Undergraduate Science and Engineering, (National Academies Press).
3. Woolley, A.W., Chabris, C.F., Pentland, A., Hashmi, N., and Malone, T.W. (2010). Evidence for a collective intelligence factor in the performance of human groups. Science 330, 686-688.
4. Dweck, C. (2006). Mindset: the new psychology of success, (Random House).

William C. Chueh
Material Science & Engineering
Stanford University

The ability to seamlessly integrate classroom instruction and student research is one of the most powerful educational tools at my disposal as a university professor. Since 2012, I have had the pleasure of teaching thermodynamics, electrochemistry and materials chemistry to hundreds of undergraduate and graduate students. Additionally, I have hosted 4 high school students and 9 undergraduates in my lab, and am actively supervising 6 master's students and 12 PhD candidates. In addition to preparing students for careers in science and engineering, one of my main responsibilities is to inspire: to inspire students to think deeply about fundamentals of materials and chemistry, to inspire students to appreciate the intimate connection between fundamentals and applications, and to inspire students to apply what they learned to solve real-world problems.

Re-developing three materials science courses between 2013 and 2014 has been one of the highlights of my time at Stanford. My teaching philosophy can be summarized as follows: (1) show students that diving deep into the fundamentals can be intellectually rewarding and motivating, (2) connect class materials to exciting topics in research and technology development, and (3) energize the classroom though new teaching methods.

Undergraduate thermodynamics is a challenging topic to teach in any department, because the concepts are often obscure (e.g., entropy) and the examples dated (e.g., refrigerator, steel manufacturing). When I took over MATSCI 154, I broke from the usual mold of starting with the First and the Second Laws, etc. Instead, I divided the course into four, two-week modules, with each one focusing on a cutting-edge energy conversion technology: CO_2 capture, fuel cells, solar thermal electricity, and lithium-ion batteries. Each module begins with one lecture highlighting the technological progress and challenges, usually given by a guest lecturer working in the field. The introductory lectures end with one slide on the ultimate limit of the energy transformation efficiency. The subsequent lectures then present the basic concepts that underlie the technology, and derive the thermodynamic limits to efficiency. Using CO_2 capture as a vehicle to teach entropy of mixing, and using batteries to teach phase transformation, takes full advantage of the students' interest in energy technologies. Fittingly, the class is titled "Thermodynamic Evaluation of Green Energy Technologies". The success of this course is felt outside of the classroom: many of the students have asked me to become their academic advisor, some have declared their major in materials science, and three students have even taken a further step by working as research interns in my lab.

Another class that I re-developed is MATSCI 303, an elective course on energy storage, taken by approximately 60 undergraduate and graduate students from many departments. To highlight the importance of fundamental materials science to technologies such as batteries, the first half of the course devotes lectures to connecting thermodynamics and kinetics principles to device properties such as the voltage and capacity of batteries. The second half, on the other hand, focuses on reviewing recent developments in materials for energy storage, and draws heavily from the fundamentals covered in the first half of the course. This course culminates in a final team project where students propose a new energy storage technology. Each team makes a ten-minute "pitch" (in true Silicon Valley fashion) where students explain their proposed concept and convince the rest of the class that the technology is sound and is rooted strongly in the fundamentals. A few of the proposals were so interesting that I have encouraged the students to reach out to faculty members at Stanford to try their ideas out!

Finally, I re-developed MATSCI 206, a graduate course on defect chemistry in crystalline solids. I designed the course to focus on of zero-, one- and two-dimensional defects, and made strong connections to timely materials science topics such as non-volatile memory, nanoparticle catalysis, and ultra-thin-film growth. To strengthen the connection between fundamentals and applications, I moderated student-led journal club discussions every two weeks. Rather than selecting the papers solely by myself, it is an open process where students submit papers online. This ensures that the topics are drawn from the students' immediate research areas. Fueled by breakfast and coffee, the students participate actively in dissecting the papers by applying concepts they learned in class.

I tell all of my undergraduate academic advisees that learning in the classrooms goes hand-in-hand with learning in the lab. Consistent with this belief, I have hosted 9 undergraduates over the past four years. In particular, I would like to share my experience in mentoring two talented undergraduates: Jing and Sophie. A visiting junior from Peking University, Jing was motivated and knew that the internship was to prepare her for graduate school. Undergraduates typically have extensive exposure to well-structured, "planned" research through laboratory courses. With undergraduate research in the lab, my philosophy is to expose students instead to real-world research where sometimes the conclusion is not so obvious. In this light, Jing was given a project on elevated-temperature water splitting, an approach that my group just started to work on when she arrived. Not only was the work not well defined, the direct literature on this subject was nonexistent. The circumstances motivated Jing to adapt: she learned to develop hypotheses, design experiments, and to look for literature in related field such as chemical catalysis. At the end of the two-month summer research experience, Jing wrote a paper that was published in Journal of Materials Chemistry A. Presently, she's pursuing her degree in materials science at MIT.

Sophie, a Stanford sophomore majoring in engineering physics, joined my group during the 2013 academic year. In contrast to Jing, Sophie did not have clearly defined research interests and wanted to use the experience to explore disciplines other than physics. She worked on understanding the fundamentals of ion-insertion reactions in lithium-ion batteries. Over the course of two years, Sophie became the group's expert in making battery cells, accumulating valuable experience especially when the batteries did not work. She published her work as a joint first author in Advanced Materials. What fascinated me is that in the process of co-mentoring Sophie, my PhD student Yiyang became a better mentor himself as well. Yiyang is currently applying to faculty positions in research universities. Stanford recently highlighted Sophie and Yiyang's paper with a press release titled "Battery experiments highlight Stanford's dual mission of teaching and research". Having observed the direct connection between materials science and energy technology, Sophie is now completing her master's degree in materials science, and plans to work in the energy sector when she graduates.
Circling back to my teaching philosophy: blur the lines between fundamentals and technology, and between education in the classroom and in the research lab. There is nothing more

satisfying than seeing students leave Stanford feeling truly inspired and ready to apply what they learned to address societal challenges.

Timothy B. Clark
Chemistry & Biochemistry
University of San Diego

The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark. -Michelangelo

This quote by Michelangelo captures the message that I target to all students with whom I interact as an educator. I have found that some students lack the confidence to consider a science degree in higher education, others have plenty of confidence but lack the drive to excel. As a first generation college student I am well aware of the impact that my teachers and mentors had on me throughout my development as a student, so I have taken many opportunities to encourage and challenge students from a wide range of education levels, including high school students, high school teachers, community college students, traditional undergraduates, and postdoctoral research associates.

High School Students. I have committed a great deal of time and effort to engaging high school students in outreach activities and in research experiences. I chose to approach an outreach project comprehensively, focusing my attention on several activities for a couple of classes of chemistry students each year. My approach began by providing an authentic research experience to a high school teacher. The first high school teacher worked in my research lab for six weeks over the summer. During that summer, he was given a project and worked closely with me and undergraduate students also working in my lab. The purpose of this research experience was to infuse him with the underlying principles of chemical research with the expectation that this experience would inform his approach to teaching in the classroom. Ultimately, this approach was expected to have long ranging effects on his teaching for the rest of his career. During the following academic year, I recruited 4 undergraduates from the University of San Diego (USD) to work with me in the planned outreach program to two of of the teacher's classes. Three outreach events were completed: 1) a visit to the teacher's classes to discuss careers in chemistry where the undergraduate students described their experience as science majors and discussed their plans after graduation; 2) the classes then came to USD for a tour of the science facilities, followed by presentations by the undergraduate students on their research projects at a level accessible to the high school students; 3) a visit to a local company in the chemical industry field involving a presentation by the company and a walking tour. The project then involves a second year of summer research and outreach activities with the same teacher and a new set of students. For the second summer of research, one of David's students was chosen for a summer research experience. The high school student learned a great deal and made significant contributions to a project in collaboration with the teacher, resulting in both of them as co-authors on a published paper. A second cycle of this two-year project has also been completed with another teacher. All of the outreach activities were assessed to quantify the effectiveness of the program and the approach and results were published in an *ACS Symposium Series* Book Chapter in 2018.

There are several benefits to the outreach program described above. First, the outreach has long-term benefits by changing the way the high school teacher thinks about science. Many high school teachers have never had a research experience, so chemistry is completely theoretical. The research experience is an important way to provide more concrete and practical examples of scientific inquiry. The multi-faceted outreach is also a very important component of the program. Individual outreach interactions have limited impact. The three activities outlined above provide information about careers in science, long-term educational choices, and short-term educational options. Critical to the success of the program is the role of the four undergraduate students who are not significantly older than the high school students, modeling the experience of the next stage of their education, and student considerations regarding choices after earning the BA or BS. Equally important is the experience of the undergraduate student assistants. In the process, I am training these students to be effective in outreach and communication of science. In particular, students give 15–20 minute presentations on their undergraduate research projects (students from different sub-disciplines of chemistry are chosen). I work with the students to prepare the presentations and to focus the material at a level that can be understood by a high school chemistry student. The entire process will encourage and empower them to be more proactive about outreach opportunities.

USD has a long-standing relationship with a local high school and 6–8 students come to USD every summer for a research experience. I have also mentored 4 of these high school students.

Transfer Students. A significant portion of college students that are from underrepresented minority groups, low socioeconomic situations, or are first-generation college students choose to attend community colleges initially. Of these students, a disproportionately small number transfer to 4-year colleges, and even fewer pursue post-graduate education. Therefore, community college students represent a significant source of diversity in the STEM workforce pipeline. As a first-generation college student aware of the uncertainty that college can represent, I have found a number of avenues to encourage community college students to continue their education in the sciences, and more importantly, have sought opportunities to facilitate their transition to USD and other 4-year universities.

I have worked with Dr. Linda Woods, faculty member at San Diego Miramar Community College to bring her students to USD for a tour of the facilities, a discussion of the curriculum, and the central role of undergraduate research in our curriculum. A small number of these students choose to come to USD but I try to emphasize the importance of interacting with faculty as they consider various universities. To facilitate interactions with other community college faculty, I was on the planning committee for a Jean Dreyfus Boissevain Lectureship. We used funds from this grant to bring a renowned speaker, Dr. Colin Nuckolls from Columbia University, to USD and invited the local community college faculty and students to participate in the seminar and a dinner reception that followed. We have had two additional symposia funded by *Organic Syntheses* in which two renowned speakers have come to USD for each symposium. Again, we have invited the San Diego chemical community, including community college faculty and students.

Most of my interactions with USD transfer students have resulted from my role as the transfer advisor for our department. Every student that transfers to USD and is interested in majoring in chemistry or biochemistry meets with me prior to the start of classes. I use this opportunity to invite them to be fully engaged in the life of the department. I also encourage these transfer students to get involved in undergraduate research early to supplement their classroom preparation and to help them to be connected to other students in the department. I value my interactions with transfer students and the opportunity to give them as much guidance as they seem to want/need. In several cases, I have also had transfer students work in my research lab. Two in particular have joined my research group the summer before beginning classes at USD. I was also a research mentor for a National Science Foundation-Research Experience for Undergraduates (REU) grant at USD (2015–2017). This REU focused on community college students and veterans.

Undergraduate Students. As an educator at a predominantly undergraduate institution (PUI), I spend most of my time working with undergraduate students. In the classroom I focus on providing a rigorous and dynamic curriculum. I put a great deal of thought and effort into motivating and challenging students to have regular study habits rather than waiting until a quiz or exam to learn the material, in order to improve their retention of the material. As a demanding instructor, I make a point to be available to students outside of class to help them make the necessary connections within the material. I also make a point to incorporate research projects into a number of the lab courses that I teach, including our senior lab and a major's organic chemistry lab. These experiences are critical to broaden the student experience since many students who are involved in one area of research do not have a sense of applying research principles to other areas.

I have devoted much of my scholarly career to providing authentic research experiences to undergraduate students because I believe that it is the most effective way to instill confidence, comfort, creativity, and knowledge in the field of chemistry. Over the course of my eleven year career (4 years at Western Washington University and 7 years at USD) I have mentored 41 undergraduate students. 18 of the 33 graduated students have gone to graduate school in chemistry or a closely related field. In addition, 20 of the 41 students have been co-authors on published papers.

Post-Doctoral Research Associates. Since coming to USD I have initiated a post-doctoral research associate mentoring program in my group. I have mentored four post-docs that are explicitly interested in a career at a PUI. Post-docs who have worked in my lab supplement their experience in the research lab, which is their primary focus, with teaching experiences (1–2 course per year) and mentoring undergraduate students in research. A post-doc experience of this nature provides full preparation for a faculty position, preparing post-docs to excel in their career. In addition to mentoring post-docs in research, I attend many of their class lectures and provide feedback throughout the course. I have seen significant growth from post-docs during this process and feel that they are highly prepared for beginning their careers as independent faculty members. The two post-docs that have completed their time at USD have secured faculty positions at SUNY-Cortland and the University of Wisconsin-Steven's Point.

Brandi M. Cossairt
Chemistry
University of Washington

Success in STEM requires consistent institutional support throughout a student's educational journey, in the form of classroom engagement, access to opportunities for participation in research, and mentorship/sponsorship beyond the classroom. I learned these principles in my own journey starting from a blank slate as a female, first-generation college student. These lessons inform my teaching and mentorship approach at the University of Washington, with the goal of fostering the next generation of diverse leaders in STEM fields.

Classroom Innovation and Curriculum Development to Increase Student Engagement
While I have taught a variety of introductory- and upper-level undergraduate courses since 2012, my primary teaching responsibilities have included Transition Metals (CHEM 416) and introductory Honors General Chemistry (CHEM 165). As both courses typically enroll 50-70 students, they have historically been taught using a traditional lecture-style format. Based on feedback I solicited from students in my first UW courses, I sought to develop a hybrid format—between a lecture and a flipped classroom—where problems are actively worked in small groups. Using a tablet platform combined with systems for real-time online polling (Poll Everywhere) and feedback (Sli.do), I have turned the lecture portion of my classes into an interactive experience that allows me to regularly and directly check in with students, increasing their engagement. In addition to the interactive lectures, during 1-2 weekly class meetings I devote 15-20 minutes to in-class problem solving. This is done most typically in a "think-pair-share" motif to encourage student discussion and intellectual growth. Students have responded positively to this approach, which they have made clear through their course evaluations. In response to being asked about which aspects of the class contributed most to their learning, students have said, "amazing lectures and interactive learning," and "lectures were more helpful than the book in learning the subject."

I have independently developed a graduate-level materials chemistry course from a special topics course I taught during my first two years. Due to its popularity, Electronic Structure and Application of Materials is now a permanent course offered to graduate students (as CHEM 585) and to senior undergraduate students (as CHEM 485). This new course augments the theory from a traditional solid-state physics course with real-world research and applications of emerging classes of materials such as graphene, metal oxides, and nanomaterials. A major course component is the inclusion of lectures from industrial experts in electronic materials (e.g., batteries, photovoltaics, semiconductors). Starting this year, I have added a final project for CHEM 585, requiring students to acquire expertise on a material or device relevant to the class and then translate that knowledge to a general audience in the form of an infographic and demonstration. This project allows the students to pursue a topic of interest while underscoring both the difficulty and importance of effective science communication. It will also yield a compendium of infographics and demos that we will compile and publish as outreach material targeting middle and high school STEM learners. Over the next few years, I plan to extend the concepts from this course to create a problem-solving-based curriculum in Materials Chemistry of Energy Systems with the goal of ensuring that students both obtain the relevant knowledge and are prepared and ready to work on this global problem right after graduation. I have begun to lay the ground work for this goal through the creation of laboratory modules to pair with CHEM 485; these will ultimately be complemented with an introductory-level course on The Chemistry of Energy and Sustainability, and an outreach program to aid in training the next generation of energy leaders.

Early Integrated Research Opportunities for Undergraduates

I firmly believe that all students in STEM fields need the opportunity to pursue scientific research at an early stage of their scientific training. One common practice that undermines student involvement in research is requiring specific (and often advanced) classes and/or prior research experience as a pre-requisite to working in a lab. We know that many students think about pursuing research only to decide "it's not for them" because they have insufficient preparation and lack the role models to help them envision their own potential success in these positions. We also know that direct outreach is the best way to recruit students of diverse backgrounds to STEM fields. I have focused on reaching out to students at the earliest possible opportunity to get them involved in independent research in my laboratory. Over the last four years, I have mentored twelve undergraduate students (Yuting Lin, Emily Reeves, Connor McCue, Douglas Waterman, Tianna Ibea, Molly Steimle, Dante Magdici, Harrison Sarsito, Ashley Mathews, Noushyar Eslami, Justin Brown, Nathan Lai) in hands-on laboratory research. As with these students, beginning in their first or second year (or as summer research students from abroad), all receive the training to prepare them for graduate-level study in the chemical sciences: they undertake immersive self-directed research projects, participate in weekly laboratory meetings, attend scientific conferences, and co-author peer-reviewed publications. I work to pair each student's individual research experiences to their coursework, which allows them to see directly how the pedagogical information they receive in lectures relates to scientific investigation in the lab. As an example, Ashley Mathews took an organic chemistry course last quarter that included a spectroscopy component. Her graduate student mentor and I worked her through the basics of assigning 1H NMR spectra using the known compounds she was making herself in the laboratory. This then translated into her ability to gain insight into the outcomes of her chemical reactions involving the activation of small molecules by ruthenium carbene complexes where the product outcomes were unknown.

Chemistry Women Mentorship Network: Strengthening STEM Diversity Across the U.S.

Despite a growing number of women obtaining PhDs in the physical sciences, there is still a critical gap in the advancement of women into the academic workforce. While women now earn 37% of PhDs in the field of chemistry, they comprise only 18% of the tenure-line faculty at the top 50 ranked schools. While there is increasing awareness of this gap, many programs do not have career workshops or other professional development opportunities specifically geared toward women, and even those departments with exceptional resources continue to struggle with connecting students in need to the proper resources. Mentoring is thought to play a particularly critical role in the underrepresentation of women in academic science and engineering programs, as it has been suggested that women typically do not receive the same level and frequency of mentorship as their male counterparts, likely due to the gender disparity within the academe. To help address these issues, I co-founded the Chemistry Women Mentorship Network (ChemWMN, http://brandicossairt.wixsite.com/chemwmn) with Assistant Professor Jillian Dempsey (University of North Carolina–Chapel Hill). The mission of ChemWMN is to create a vertical mentorship network with a focus on one-on-one interactions at all stages of the academic pipeline. We have successfully recruited over 60 female faculty members from around the U.S. and Canada to serve as one-on-one mentors for female graduate students and postdoctoral scholars interested in pursuing careers in academia. Our mentor network provides a vital resource for future leaders in academia.

Myriam L. Cotten
Chemistry
The College of William & Mary

At W&M, I have taught Membrane Proteins: Structure, Function, and Biomedical Research (APSC 640/CHEM 640) and Directed Research in Medicinal Chemistry and Structural Biology of Bioactive Marine Compounds (APSC 480/BIO 314/CHEM 314). At Hamilton, I taught Principles of Chemistry (CHEM 120), Biological Chemistry (CHEM 270), and Biophysical Chemistry (CHEM 320) lectures. I also taught lab sections for CHEM 120, CHEM 270, and CHEM 125 (Principles of Chemistry in the Context of Health and Environmental Chemistry). At Pacific Lutheran University, I taught Biochemistry (CHEM 403 and 405), a course for non-science majors (CHEM 105), and introductory lab sections.

Teaching Approaches
The same commitment to understanding the molecular structures of living systems that drives my research stimulates my teaching and inspires me to use research as the basis for my teaching, mentoring, and outreach activities. Effective teachers must continuously innovate, remain current in their disciplines, demonstrate integrity, and take time to reflect. My goals as a teacher are to challenge students intellectually; engage them in active learning and scientific debate that challenge established models; develop their critical-thinking, problem-solving, communication, and decision-making skills; expose them to thought-provoking ideas; transmit to them my enthusiasm for chemistry; and create a nurturing learning environment that welcomes diversity.

Course Structure
My courses and lectures are organized around this overarching question: What are the important concepts for students to master so that they can develop proficiency, perform well on exams, appreciate the significance of advances in the field, and move successfully to the next academic level or future career path? To achieve the goal of engaging the students' skills, interests and abilities so that they can develop a rigorous scientific approach and apply their critical-thinking skills, I use a structure that is basically similar in the courses I teach: after the students obtain a good understanding of early course materials and concepts as presented in the textbook, we move quickly to material that prompts them toward more advanced understanding of chemistry concepts. We then apply the concepts in an integrative way by examining chemical applications and engaging in related lab experiments. In more advanced courses, we read papers from peer-reviewed journals and discuss news articles in the field. When students integrate concepts and read non textbook material, they face the challenge of trying to understand the more advanced scientific content; they ponder and ask questions. My guidance is intended to help them realize that there is tremendous complexity in the world of science and answers are not necessarily clear-cut. Often, limits of knowledge are reached, and scientists must consider alternative theoretical approaches.

Lecture Format
I work at delivering lectures with force, passion, and enthusiasm. The operative phrase is: "Start with gusto and finish strong!" I develop clearly organized lectures that reinforce, but do

not repeat, material in the textbook. Lectures instead focus on the most important concepts, and supplement the text with alternative viewpoints and newly published information. I relate topics in my classes to the ideas from other courses, including Organic Chemistry, Physical Chemistry, Biology and Physics. I help students see the “big picture” and understand the significance of the subject matter. I emphasize that science is a method with several valid approaches to solve problems and it is a flexible and creative process for that reason. To inspire students, I refer to great scientists and thinkers and mention their involvement in all aspects of life.

I am dedicated to engaging students in active learning, including in large classes. I assign pre-lecture reading assignments and online quizzes to prepare them for the next day lecture. Rather than lecturing continuously, my lecture format is a combination of white board problem-solving and Powerpoint presentations. I use clickers in large enrollment classes (e.g. Chem 120). This makes transparent the level of understanding of a given concept so that I know where gaps in comprehension are occurring. When most clicker answers are wrong, I ask the students to discuss their rationale with neighbors and re-run the question, which never fails to yield more correct answers.

I aim at presenting thought-provoking ideas or activities (e.g., a cartoon, video, or demonstration) to increase the appetite for the day’s lecture and reset the attention clock every 15 to 20 minutes. For example, in APSC 640, I began a teaching unit by showing a textbook figure of a membrane protein that had a feature violating an important biochemistry principle and asked students to identify the error. This exercise catches their attention, helps them retain concepts, and introduces the next topic, in this case parameters affecting the stability of membrane proteins in the complex environment of biological membranes.

I am committed to creating a positive learning environment, which encourages students to interact cooperatively, self-motivate and actively engage in their learning. On the first day, I stress that mutual respect is paramount in my classes and we are a community of learners. I remind students about the importance of valuing diversity and tolerance, as well as multiple viewpoints.

Assignments
Each of my classes features a term assignment that exposes students to emerging research in the field. After performing literature searches, students organize, analyze and explain ideas in their own words. This requires them to refine their skills as critical thinkers, who use their knowledge to evaluate the quality of the information. I believe this is learning in its highest and best form: students have transferred and applied knowledge to a new area, enhancing their capacity to utilize critical thinking and analysis tools to a wide variety of situations. Catalyzing this type of learning is one of my greatest satisfactions as a teacher: several students have shared with me their excitement, sense of empowerment, and increased independence as a result of learning through this modality, as shown by statements from student evaluations.

For example, in my graduate class titled “Membrane Proteins: Structure, Function, and Biomedical Research”, I create opportunities for students to interact with leaders in the field. Before the scholar’s visit, they read articles from her/his group. Once s/he is on campus, s/he gives a departmental seminar and does a class visit to expand on some topics and let students ask questions. In 2017, we hosted Dr. Tim Cross (NHMFL), Dr. Michael Wiener (University of Virginia), and Dr. Klaus Gawrisch (NIH).

In the Principles of Chemistry class that I taught at Hamilton College, I used a term assignment that I titled "biomimicry" in which students learn about biomaterials in the context of the chemical principles that underlie biological function and the physical methods used to characterize materials. As part of this class component, students got to interact with a leader in the field of biomimicry when s/he came to campus to give a seminar, share meals with the students, and do a class visit.

In the Biophysical Chemistry undergraduate class that I created at Hamilton College, students explored physical chemistry concepts and methods using the work of a scholar as a common thread. As a term project, they wrote a research proposal that they presented to the scholar. In 2014, this course component was selected for funding by a college endowment that I used to support the visit of Dr. Ken Dill, a member of the National Academy of Sciences. I created this course to be an alternative for Biochemistry and Molecular Biology (BMB) majors to the Physical Chemistry class. This course was successful in attracting more students to the BMB major. In 2009, there were five BMB majors graduating in the spring. In 2012, there were 11 students graduating as BMB majors and by the time I left in 2016, there were consistently 11-13 BMB majors graduating every year.

My teaching also demonstrates my dedication to experiential and discovery-based learning. For instance, I developed at W&M an interdisciplinary capstone ("COLL 400") course entitled "Directed Research in Medicinal Chemistry and Structural Biology of Bioactive Marine Compounds." Using concepts and methods from structural biology, medicinal chemistry, and physics, students investigate structure-function relationships in novel bioactive marine compounds relevant to the immune system of marine species living in the nearby Chesapeake Bay. Students learn how to perform liquid chromatography, circular dichroism, and high-resolution SS-NMR experiments on their samples. To help them considering the ramifications of their research on our local environment, I convene round-table meetings with local experts on marine science and coastal policy. At the end of the semester, students prepare a poster that they present to a scientific audience. In 2018, they contributed to a poster that they presented at the national Experimental NMR Conference in Orlando, FL.

Jason M. Crawford
Chemistry
Yale University

Introduction. Since graduate school, the PI has been dedicated to developing an academic research program focused on finding chemical solutions to biological problems. Why does the PI teach and run a chemical biology lab? Simply put, he very much enjoys teaching, mentoring, and sharing his excitement for chemical research and cannot imagine a more rewarding career. The PI has assembled an excellent team of undergraduate, graduate, and postdoctoral students to bridge chemistry and biology, solve problems at the interface, and begin to apply these chemical insights to medicine. The PI takes a hands-on approach to teaching while fostering an open discussion forum, not only to develop a sound basis in classroom theory, but also to tackle complex problems in the lab. Because he personally learns best by visualizing the chemical applications, he teaches in the same manner, using experimental demonstrations, teaching at the bench, and invoking hypothetical scenarios that could occur in the real world. Naturally, his course materials are influenced by on-going research in his lab. Specific examples about the PI's educational contributions to the chemical sciences are briefly highlighted below.

Teaching & Scholarship (Undergraduate, Graduate & Postdoctoral Education). Organic chemistry is the unifying theme in all of the major courses the PI has taught at Yale, which include Chemical Biology (a course cross-listed for graduate and undergraduate students), Organic Chemistry of Biological Pathways (undergraduate), Organic Chemistry of Life Processes (undergraduate), Fundamentals of Organic Reaction Mechanisms (graduate), and Bacterial Determinants of Pathogenesis (graduate section: Small Molecules Produced by Bacterial Pathogens). The PI's courses have been very well received (e.g., Chemical Biology received an average 4.4 out of 5 anonymous student rating). The students often pass along very appreciative remarks in the end-of-term student evaluations. In one anonymous evaluation, for example, the student said that the PI's Chemical Biology course was "Easily the best science course (if not overall course) I have taken at Yale."

There are two philosophies to teaching organic chemistry in the PI's research discipline: 1) synthetic organic and bioorganic chemistry are distinct and should be taught separately; and 2) synthetic organic and bioorganic chemistry can be viewed as one in the same at the mechanistic level. Generally, the PI views the underlying organic concepts as one in the same with differing reaction vessels – the round bottom flask versus the cell – and quite distinct methods at the bench. His courses often compare and contrast round bottom reactions with cellular reactions. Some students struggle at first with the differences, but they emerge from the course(s), having a deeper understanding of general organic chemistry, as evidenced by their improved performance on cumulative final exams.

As a teacher and lecturer, the PI firmly believes that students engage subjects better with active participation. Therefore, he always provides instruction beyond the lecture and includes time for discussion. These discussion sessions provide an added layer of interactive teaching and serve as a useful gauge to identify the concepts students have mastered and to focus on the concepts that require additional instruction. For example, as part of his undergraduate courses ("Organic Chemistry of Biological Pathways" and "Organic Chemistry of Life Processes"), he builds upon his lectures by having the students design an artificial biosynthetic pathway using their preferred biosynthetic engineering "parts." They then work together through the organic mechanisms of their artificial systems and construct their theoretical molecules. The students are blown away when they see that similar strategies have actually been carried out in leading laboratories around the world to diversify complex small molecules, such as the erythromycin antibiotics. Thus far, teaching with this combined theoretical and practical approach has been a success. Students have stated that while his undergraduate courses have had a "greater" workload relative to other classes at Yale, the students have still had very positive things to say.

The PI has been a strong proponent of supporting undergraduate research at Yale. He has officially mentored >10 undergraduate students in the lab over the last five years. Two female students have since graduated, moving on to graduate school (California Institute of Technology) and medical school (Albert Einstein College of Medicine). These undergrads have been integral members to several projects in the lab. For example, these students contributed to Molecules and J Biol Chem publications, providing the first mode of action support for N-acyl-D-Asn prodrug motifs in nonribosomal peptide antibiotics and structurally illuminating a stereoselective epoxidation process in polyketide antibiotic detoxification, respectively. Two additional male students matriculated as medical students (Yale School of Medicine). The rest have similar aspirations of going to graduate or medical school after graduation.

Of the four postdoctoral students to come through the Crawford lab, two are now Assistant Professors at top European Universities (University of Lausanne, Switzerland, and Aarhus University, Denmark) and two have secured their desired positions in Pharma. Current postdocs are on similar trajectories (~50/50 academia/Pharma). Of the ten graduate students currently in the lab, the PI's first two excellent students are on track for a 5-year PhD, a typical timeline for chemical biology graduate students. The PI initiated and currently runs a multi-departmental Research In Progress seminar series to nucleate research ideas among graduate, undergraduate, and postdoctoral students in the broader chemical biology sciences at Yale. All of the PI's lab members participate, and the successful series regularly draws strong faculty turnout.

The PI has also contributed to the mentorship of Yale freshman, as a volunteer Yale Freshman Faculty Advisor, including the mentorship of African-American groups, where he similarly encourages and fosters engagement in the broad sciences at Yale. He views this voluntary service as a vital duty to develop professional relationships with students who are underrepresented in STEM. As a volunteer Freshman Faculty Advisor, he is often the first faculty member beyond their college Dean that they meet upon arrival to Yale. He helps them with course selections and provides them with opportunities to meet with him throughout the year. He has served this role four out of the five years that he has been at Yale. Feedback to these students early on is critical, as one incorrectly matched class can sometimes derail a student from the science tracks completely.

The Crawford lab has also significantly contributed to mentoring the Yale iGEM team (Internationally Genetically Engineered Machine competition). The iGEM team consists of a group of undergraduates with an independent research lab on campus that develops and implements a synthetic biology project each year for competition. The team initially conducted experiments in the PI's lab until their dedicated space was available, and now Crawford lab members continue to mentor these students in the iGEM dedicated space. The Crawford lab, led by two key graduate students, has trained over a dozen team members. For many students, this was their first undergraduate lab experience, and through iGEM, the lab enabled them to conceive and execute quality research that has led to publications. In addition to this research component, iGEM emphasizes human impact and outreach. Accordingly, they have mentored the development of numerous outreach projects, such as "coffee shop" presentations on synthetic biology and genetically modified organisms, both on and off campus. Due to participation by the PI and the Crawford lab, synthetic biology at Yale maintains chemical rigor.

Chemical Science Outreach (High School Education). In addition to promoting undergraduate, graduate, and postdoctoral education in the chemical sciences, the PI is also a supporter of enhancing pre-college student exposure to the sciences. To this end, the Crawford lab runs a summer short course through the Yale Pathways to Science Program (Pathways), a formal partnership between Yale University and the New Haven Public School district. The lab's Pathways course ("Microbial Magic: Harnessing the Power of Bacteria") is geared toward local, urban high school students. Again, the course is related to the lab's research efforts and falls in the primary subject areas of chemical biology and biomolecular engineering. The program specifically focuses on introducing bacteria's power and utility as a chemical factory for the production of a large array of useful molecules. The lab poses questions like, "What are bacteria?"; "What makes bacteria such a useful resource?"; "How do scientists manipulate bacteria?"; "What are the limitations?"; "What are biocatalysts?"; "Are microbes dangerous, helpful, or both?"; "How does antibiotic resistance arise?"; and "What can we do to help slow the spread of resistant organisms?" By tackling these questions, students' misconceptions about bacteria are clarified. Instead of viewing all bacteria as harmful, students emerge from the course understanding the many benefits of bacteria, and can begin to appreciate the diverse chemistry of microbes. They can also appreciate the harm that some bacteria can cause to humans and animals. Students also enjoy conducting experiments throughout the course (for example, manipulating bacteria to fluoresce), and these rewarding hands-on experiences shape their trajectories toward advanced STEM degrees. Additionally, the lab frequently participates in the Yale Young Global Scholars program and the New Haven Science Fair program to more broadly impact young students. Overall, these activities provide enhanced awareness and enthusiasm of the chemical sciences in the community.

Kelling J. Donald
Chemistry
University of Richmond

My core teaching commitments at the University of Richmond (UR) include lecture and laboratory courses in Introductory Chemistry and Physical Chemistry. Our primary physical chemistry courses cover thermodynamics and kinetics in the fall semester and quantum mechanics and spectroscopy in the spring.

The fundamental tenet of my teaching philosophy is that teaching is leadership. My role is to guide, support, advise, and mentor my students as we build towards a deep and a broad knowledge of our subject. That goal is achieved by an engagement with my students in an active learning environment that weaves discussions, problem solving, and discovery into insight and understanding. Beyond the learning of facts and concepts, I want my students to appreciate the value of the material that we are studying. I want each class to be transformative in some way, and I have been fortunate to have students and colleagues who acknowledge and appreciate those aspirations. In recognition of my efforts in education (in the classroom, in research mentorship, and in the community), my peers nominated me in 2011 as UR's candidate for the Rising Star Award of the State Council of Higher Education of Virginia, and awarded me in 2014 the Distinguished Educator Award – our institution's highest recognition for teaching.

Teaching Innovation and Contributions to the Curriculum: In 2012, I developed an elective course in chemical bonding, which I taught for the first time in 2013. The course opens with an introduction to quantum mechanics that moves into discussions of molecular orbital and valence bond theories, and the theory of atoms in molecules (AIM). Metal-metal multiple bonding, the electronic structure of d- and f-block organometallic complexes and relativistic effects in chemistry are some of the topics covered in the second half of the course. I introduced this elective on bonding into the curriculum because a number of the topics just mentioned (AIM and relativistic effects, for example) are not explicitly discussed in standard organic, inorganic, or physical chemistry textbooks or courses. I wanted to give our students a chance within the undergraduate curriculum to encounter those ideas. The elective provided me as well with additional opportunities to employ new modes of instruction, and I welcomed that challenge. The course featured, for instance, project assignment options for students to (i) interview, by skype, phone, or e-mail, a scientist who has contributed in some way (broadly defined) to a topic covered in the course or (ii) work with a classmate (who would serve as the opponent) in an open debate of a controversial topic in chemistry. I taught the course again in the fall of 2015, and Clarke Landis (University of Wisconsin, Madison), E. D. Jemmis (Indian Institute of Science, Bangalore), Roald Hoffmann (Cornell University, NY), and Theresa Head-Gordon (Berkeley, CA), were some of the academics selected and interviewed by the students. We had only one debate forum that semester, with two students from the class taking opposite sides of the resolution: "The Bohr model should be eliminated from the chemistry curriculum." The basic flaws of the Bohr model are well known, but its pedagogical advantages are championed by some such that it remains (to the displeasure of others) in certain modern textbooks and courses.

Curriculum Development and Vision: During the first year of this award, I will propose a second elective for our curriculum. It will focus on mathematical methods for chemists and will address common areas of weakness in mathematics for majors in chemistry (such as vectors and matrices, for example). The course will be distinguished from regular mathematics courses by incorporating systematically chemical examples throughout, while illustrating the predictive and explanatory power in chemistry of mathematical analyses. I am reviewing candidate texts currently for the proposal for that course. I served for four years (2009-2013) as a member of our department's curriculum committee. My decision to offer these electives was encouraged by my experience on that committee as a junior faculty member. Along with strengthening my vision of what our curriculum could be, it allowed me think more clearly and meaningfully about how we prepare our students to engage with the world as rational thinkers and problem solvers.

Contribution to the Literature: "How do I teach chemistry to a mind that will gain access to significant influence and power?" Put another way: "How might my chemistry class inform the social consciences of my students?" My reflections on this question and an introduction to Jeffrey Kovac at the University of Tennessee, who had been interested broadly in ethics in science for some time, led us eventually to a joint publication on "The Scientist's Education and a Civic Conscience." in Science and Engineering Ethics.1 The article offers educators in the sciences some perspectives on seeing what we do in the classroom as an ethical engagement.

Contribution to Praxis: I have served on the Responsible Conduct of Research task force in my department as well. The team organizes seminars (which are required for seniors and juniors) in which students are engaged in a Socratic dialogue with faculty on ethics in science. We follow a discussion format that is supported by short readings and short videos on aspects of the responsible conduct of research, addressing issues such as authorship, plagiarism, confidentiality, and data manipulation. I have had the privilege of leading a number of those seminars.

Teaching in Research: A lot of teaching and learning is needed for success in undergraduate research. Undergraduates at my institution typically start research in their freshman or sophomore years, a semester or more before they have done any physical chemistry. I prepare students, therefore, by holding special tutorials and weekly group meetings each semester. During the ten-week summer research period, we have weekly meetings as well in which I give brief talks on relevant topics in chemistry and students report on their own research, papers from the literature, and on special reading assignments following a pre-established rotation of topics. My research students are trained in making oral and poster presentations and in writing scientific reports, and student co-authors on manuscripts that are in preparation are involved throughout the publication process, as well, from helping to write the first drafts to editing the proofs.

Chemistry in the Community: In the past five years, I have hosted over 100 high school students (in small groups, twice each spring) for hands-on experimental work in our chemistry laboratories. I have also invited, hosted, and trained 13 students from area high schools (a number of whom are now first generation college students) for 5 week internships in my research group. Both of those initiatives are parts of the College Outreach Nurturing Teens in the Sciences (COUNTS) Program that I developed in 2012 with the support of a National Science Foundation (NSF) CAREER award. A central educational goal of the COUNTS program is to encourage students from groups that are traditionally underrepresented in the sciences to learn more about the sciences and to consider pursuing science degrees in college.

Since starting at UR, I have had the privilege of being invited twice by the Osher Lifelong Learning Institute at the university to give talks for general audiences aged 50 and better. The talks that I have given so far have focused on (i) great theories of bonding in chemistry and (ii) the magnificent history, logic, and utility of the periodic table. I have already been asked to give another talk and I hope to do so in the next academic year. It's invigorating for them and for me!

---

(1) "The Scientist's Education and a Civic Conscience." K. J. Donald and Jeffrey Kovac Science and Engineering Ethics. 2013, 19, 1229.

Aaron P. Esser-Kahn
Institute for Molecular Engineering
The University of Chicago

A continuing trend in education is to decouple the practice of acquiring and generating new information from the memorization of that information. Put another way, no scientist ever discovered something from reading a textbook. UC, Irvine (UCI) is no exception, with undergraduates fixated on textbook knowledge and unable to make the leap to synthesize new information. However, unlike 20 years ago, students today are awash in information. It is easier than ever to synthesize new ideas and students understand and seek new information in ways that previous generations did not. Despite this pronounced shift, the undergraduate chemistry curriculum has remained largely unchanged for 30 yrs. Consequently, many of our undergraduates are failing to merge their digital/millennial learning styles with traditional curriculums. To better prepare our students, I am developing several pedagogical improvements that help students learn to read, write, speak, and think like a research scientist. The goal is to make it fun, by making it accessible. My approach preserves the rigor of traditional chemistry training, but exposes students to new learning modalities including guided lines of inquiry, and digital learning and thinking. Rather than develop a new set of specialized courses, I am leveraging our existing curriculum – merging new learning modalities into existing coursework - strengthening and improving the curriculum. These fall into three distinct goals: (1) Develop guided research curriculum around "Challenge Set" Concept, (2) Develop first "Flipped" organic chemistry course at UCI, (3) Gamification of Organic Chemistry - Chiral - A game to teach chirality.

Goal 1: Develop guided research curriculum for solving open-ended challenges. I teach UCI's undergraduate polymer chemistry course. The course places a heavy emphasis on fundamental reactivity, polymer kinetics, and current synthesis techniques. Traditionally, this left little time for teaching students to "think" like a polymer chemist and develop new ideas. The goal of any active research program is to identify unsolved problems, apply knowledge with a bit of creativity and develop a solution.

To teach students how to develop and solve new ideas, I instituted a new type of homework – challenges sets. A challenge set is "an open-ended research question. [Students] job is to work together using whatever resources they can find (Internet, Textbook, Scifinder, Reaxsys, etc.) to answer the question. Discussion sections are dedicated to solving these open-ended questions."

To ease students into this style of thinking, the challenge sets increase in difficulty throughout the quarter - guiding students toward independent knowledge generation. To increase generality, I developed guidelines for challenge sets, but the examples are from polymer chemistry:

(1) Modification of a known process - Students develop a synthesis of fluorinated Kevlar®. The synthesis and process for Kevlar® manufacture are already worked out, but the students must design fluorinated derivatives using online tools. Then, they explain how fluorination influences the rate of polymerization – teaching them Carothers equation, and polymer processing. (2) Competing techniques - The goal of this challenge is to have students integrate the first lesson, but then to compare, contrast and advocate for desirable physical properties of their polymer. Split into two teams, each team designs a drug delivery system and outlines the cost/benefit of their approach. (3) Develop a new chemistry and concept, Students design a new self-healing material using a chemistry of their choosing. To increase the difficulty, both the polymer chemistry and the application are open ended. At this point, students have integrated all three pieces necessary to construct new ideas: research, creativity, and knowledge. Now, they must self-direct. (4) Design your own research project: Students identify the challenge, gain approval from me, and apply what they have learned.

Student Comments: "Proposals that help students think like a researcher and sift through primary articles… every student should take a class like this as an undergraduate. Original ideas take time to generate… This class gave [us] valuable practice with it."

Goal 2: Develop a model for a "flipped" classroom for introductory organic chemistry. I teach UCI's 10-week introductory organic chemistry course. This class is focused on chemists and science majors, with ~200-400 sophomores enrolling per section (5) per year. It's a big class that covers complex topics from chirality to reactivity and kinetics. My goal in flipping this staple classroom is to teach student how to think and talk like organic chemists by solving problems alongside them. A flipped classroom is one where a portion of the lecture is dedicated to problem solving. Students watch some lectures prior to attending class. The goal is to go from being the "sage on the stage" - a tradition lecture where information flows only from Prof. to student to the "guide on the side" where information transfer becomes a conversation – helping students with the language and philosophy of organic chemistry.

Video lectures can be edited, polished, and rerecorded - becoming shorter and to the point. Using in class rapid testing (clickers), I determine areas where students falter, and use this information to focus the discussion on missed concepts. I can then devote time to helping students explore problem solving during class time through: experiential exercises, team projects, problem sets, and activities that were assigned as independent homework. In particular, students can receive direct input from me on the material that is the most difficult and ambiguous.

In 2014-2015, I implemented a hybrid flipped classroom devoting ½ of my lectures slots to problem solving and ½ to traditional lecture. While not quantitative, the results were noticeable. In 2014, the course received a 3.5/4 and in 2015, a 3.7/4 (Ch51a average for the 2015 was 3.0/4), while I improved in my evaluation from a 3.4/4 pre-flip to a 3.7/4 and 3.8/4 after flipping.

Students commented, "He is very helpful during class when we work out problems, he explains important concepts clearly, willing to answer questions, approachable, funny" "Promoting student involvement. Makes the students really think…the in-class problems makes us comfortable enough to ask questions" "I felt prepared for the exams with practice problems during class"

Goal 3: Gamification of Organic Chemistry - Chiral - A game to teach chirality. People learn more with a smartphone than any other knowledge transfer device in history. Coincident with this, people play more games than anytime previously. Recently, I saw the intersection of these phenomena while struggling to teach chirality in my introductory organic chemistry class. More than 50% of my 400 students typed on a tablet or phone during the lecture, some took notes, some not, but one-way or another they all learned. These students struggled to see enantiomers, but ask them to defeat the 50th level of Angry Birds, and they had no problem. The purpose of Chiral is to "gamify" the teaching of chirality. In the past year, with the support of the Cottrell Scholars program, we have developed an initial version of Chiral that is available on the App Store. https://itunes.apple.com/us/app/hiral/id989856029?mt=8

Chiral Description: Molecular visualization in 3D made easy - by making it fun. I believe understanding 3D elements by matching enantiomers to each other is an inherently rewarding experience. Chiral speeds up this process by iterating chirality comparisons. Points are awarded for a correct assignment, time of recognition, and the number of hints/mirrors required. These design elements push/pull the student to make a mental picture of the molecule and manipulate it rapidly. They will understand chirality by conceptualization mental models of the structures.

Francesco A. Evangelista
Chemistry
Emory University

1. Overview Students see the power of chemistry every day, from driving cars to cooking. The impact of theoretical chemistry on everyday life, while profound, can be harder to appreciate. Since I started at Emory, I have challenged myself to design physical chemistry courses that help students see chemistry through the lens of quantum mechanics, while also potentially preparing them for theoretical research. I have developed an undergraduate quantum chemistry course that integrates elements of computational chemistry and scien-tific computing. This course combines mathematical rigor with a range of in-class demonstrations, from real-time quantum chemistry computations to graphically-rich exercises based on *Mathematica*. Within our department, I am also contributing to the development of *Chemistry Unbound*, our new chemistry curriculum. We are rewriting the *entire* undergraduate chemistry program and creating new classes that break down barriers between traditional disciplines.

Mentoring students has been one of the most rewarding aspects of my work at Emory. Every year I have a chance to recruit undergraduate students interested in doing research in my lab. Many of these students become curious about theoretical chemistry through my quantum chemistry course, like Junchu Zeng and Xiaobai Li, who joined my group in their junior and senior year, respectively. As many undergraduates, Xiaobai faced challenges mastering the theory behind computational chemistry, but developed a genuine interest in the discipline and is now pursuing a Ph.D. in chemistry at Yale. The first student to graduate from my group with a Ph.D., Wallace Derricotte, was awarded an NSF Graduate Research Fellowship and was hired as an Assistant Professor at Morehouse College, an HBCU in Atlanta, Georgia. My group currently consists of one undergraduate, six graduate students, and one postdoc.

I have also been involved in several outreach activities. In 2014, I organized the meeting of the Southeast Theoretical Chemistry Association at Emory University. This is a regional meeting that emphasized graduate student participation via contributed lectures (1/3 of all talks) and poster prizes. I have also contributed to Decoding Nature's Puzzles, an event for middle- and high-school students that promotes the participation of women in STEM fields. In my talk, I introduced students to the idea of simulating physical laws with computers. I drew from everyday examples and explained how the trajectory of birds they see flying in a game like Angry Birds are computed by integrating Newton's equations of motion.

2. Computational chemistry and scientific computing in undergraduate physical chemistry
In my opinion, computational modeling is not only a powerful research tool, it also offers a way to teach that can both spark interest and render abstract concepts more accessible. When I started at Emory, I was given the opportunity to teach CHEM331, a course on the quantum mechanical foundations of chemistry. Traditionally, such courses focus heavily on analytical derivations and require students to have a working knowledge of calculus and higher-level mathematics-subjects that many undergraduates struggle to master.

In designing my course, I wanted to find a synthesis of traditional physical chemistry with a modem approach, using computational chemistry to reinforce basic principles of quantum mechanics. In addition to traditional calculus-heavy exercises, I also wanted students to learn how to solve problems using com-puter programming and numerical methods. Based on my experience when I first taught this class, in my second year I paired analytical problems with homework problems based on the computational software *Mathematica*. For example, when we discussed the harmonic oscillator-the simplest model of a vibrating diatomic molecule-students used *Mathematica* to approximate analytic integrals using numerical integration on a grid. Students were also able to use *Mathematica* to explore aspects of physical chemistry that are usually obscured by mathematics, like the difference between wave functions for identical bosons and fermions, and Pauli's exclusion principle (see Fig. 1).

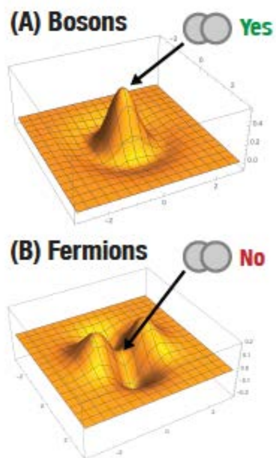


Figure 1. Exploring wave functions with *Mathematica*. Wave function for an excited state of 2 particles in a box: (A) Bosons can occupy the same region of space while (B) fermions cannot.

To introduce the basics of computational chemistry, I assigned research projects in which students used the software *Spartan*. For example, students predicted the energy of a hydrogen bond in the water dimer and in the hydrogen fluoride-water complex. To their surprise, students discovered that while the water dimer has several local energy minima, the water/hydrogen fluoride complex has no stable geometry of the type HO-H · · · F-H. Problems like this show students the power of combining experimental inquiry with computational chemistry.

During my third year, I have experimented with teaching physical chemistry in a flipped classroom format. Students were assigned video lectures to watch at home and a set of problems. In class, I would randomly select students to come to the board and present their solutions to homework problems. During this time I interacted continuously with students by asking and answering questions. I was positively surprised by the level of student engagement in the flipped classroom. Students have told me that coming to the board helped them with understanding some of the most difficult concepts covered in CHEM331. On the personal level, I found this approach very rewarding. Even with a class of 50 I had the opportunity to interact with, help, and get to know each individual student.

The last time I taught CHEM331, I integrated the insights from the previous three years and balanced lectures, student Q&A, group active learning activities, and small group homework projects drawn from computational chemistry and scientific computing. When surveyed about "What do you like the most about this class?," students replied: "It is applicable to my research," "I enjoy working through problems as a class + discussing them," "The material is very interesting and gives a good basis for a quantum understanding of chemistry," "The multimodal modes of learning is a plus," "Interesting new field, I had no previous knowledge about," "Learning how to use mathematica."

3. Decoding Nature's Puzzles: Simulating Chemistry with a Computer

Figure 2. A group of middle school students visiting Emory for *Decoding Nature's Puzzles*, an event organized by the group *100 Girls of Code*.

More recently, I have contributed at an outreach activity entitled *Decoding Nature's Puzzles*, which was organized by a local chapter of *100 Girls of Code* and the Emory chapter of the Association for Women in Science (AWIS). The mission of *100 Girls of Code* is to promote gender parity in STEM fields by introducing 10-18 year old girls to coding and computer engineering. In a one-day event held at Emory last September, I gave six 20-minute presentations entitled "Simulating Chemistry with a Computer" to these students. In this talk, I explained the objective and importance of computer simulations in science. I also emphasized the importance of com-puter programming through examples from my research and short demos (e.g., using Python to compute *pi* via Monte Carlo sampling). The collaboration with *100 Girls of Code* was quite rewarding and my group will seek other opportunities to be involved in their activities.

Alison R. Fout
Chemistry
University of Illinois at Urbana-Champaign

The Camille Dreyfus Teacher Scholar Awards Program has supported me in my continued efforts to become the *researcher, mentor, teacher,* and *advocate* I strive to be. One of the major reasons why I became a chemistry professor at a research institution was to inspire other talented scientists (especially females) that they too can achieve their goals. I have had exceptional mentors as a student, postdoctoral fellow, and as an assistant professor. It is these interactions that have shaped me as a scientist and it is these mentors that have taught me what it truly means to be a role model for other young scientists.

"Lessons Learned"

Over my time in academia I have learned a significant amount about teaching, running a research group, and mentoring. I have learned that students do not like power point presentations for teaching – they actually prefer notes on the board. I have learned that having both lecture and in class activities is effective and enjoyed by the students. I have also learned that sometimes less is definitely more.

I wanted to be a role model to female scientists, and I have been. Having two children pre-tenure has allowed students to see first-hand how I balance work and life – which at times can be very challenging. However, I think one of the most significant lessons I have learned is that managing students can be difficult and something I felt completely unprepared for. Each student is different and each student needs a slightly different mentoring style for success. I have also learned that graduate school is tough and that students are dealing with a lot – from struggling with their identity, to mental health issues, to the death of a family member. Each of these only adds a significant burden to an already stressful time for students. Helping students cope during these times is necessary and knowing who to turn to on campus to help them has been critical.

Danna Freedman
Chemistry
Northwestern University

Introductory chemistry for non-majors
My two fundamental pedagogical goals in the undergraduate classroom are to impart fundamental chemical literacy and generate enthusiasm for the chemical sciences. Teaching introductory chemistry to non-chemistry majors, as I have for five years, provides me with a tremendous opportunity to impact a large number of Northwestern University undergraduates—helping them not merely to survive the course, but to appreciate the relevance of its subject matter. Empathy is essential for increasing engagement with any population of students. One of the primary challenges I try to overcome in a large required course like introductory chemistry is students' perceptions they have enrolled in a "weed-out" course, an intensely competitive contest in which some designated quota of students will fail. On the first day of class, I briefly describe my own research, I explain that I choose to teach chemistry because I truly love the subject matter, and that it is my goal to persuade them to enjoy freshman chemistry, not to fail them. In an effort to communicate course goals clearly and to retain as many students in general chemistry as possible, I devote myself to refining my teaching skills and improving introductory chemistry by collaborating with Northwestern University's Office of Institutional Diversity and Inclusion, the General Chemistry Revision Committee, and the Searle Center for Advanced Learning and Teaching.

As one means to engross freshman new to university-level chemistry, I have incorporated primary chemical literature into the undergraduate curriculum in response to research indicating that students become more absorbed in scientific learning when it is related to research.[1,2] While holding a Searle Fellowship, an early-career program to develop teaching expertise, I reworked Northwestern's freshman chemistry curriculum to include real-time contemporary research topics, such as batteries, protein structure, and chemical synthesis. In one example, I included a series of cases from biological literature to appeal to the interests of what are at Northwestern mostly pre-medical students. I taught the students about how pKa influences protein structure and folding, and connected that to protein crystallography research and its impact on disease. I highlighted two protein crystallographers who won Nobel Prizes (Dorothy Hodgkin and Ada Yonath), and discussed current research on protein crystallography at Northwestern, highlighting my colleague Amy Rosenzweig. In a separate instance, I wove the Flint, Michigan water crisis into a three-week section on acid-base chemistry. We worked through challenging precipitation-related problems in the Flint crisis and I provided supplemental enrichment reading. I incorporated Flint-based questions into quizzes and exams, allowing the students to discover, as they solved the problems, how chemistry both caused the crisis and could have been used to prevent it.

In a separate prong of this research-focused approach, I encourage undergraduates to interact with graduate students to learn about ongoing research in the chemistry department. My students use clickers to vote on which of their ~30 teaching assistants (graduate students) should talk to the class about their path into the chemical sciences and current research program and to answer questions. Undergraduate students showed interest in the demonstrations and the research presented by the graduate students. Some undergraduates, realizing that their graduate student instructors spend their time conducting exciting scientific research, begin to model themselves on these TAs, who are far closer in age to the students than I am. Graduate researchers who speak to my classes demystify laboratory research and encourage students to consider a research career.

A parallel goal I pursue in teaching undergraduate chemistry is student retention. To lower the typically high dropout rate, I have collaborated with Northwestern's general chemistry educators to restructure the general chemistry curriculum to make completion attainable by more students. Over the past two years, we rearranged the course sequence, changed the material, and condensed the sequence from three quarters to two. The two quarter sequence occurs in the Fall and Winter, and we put into place a new "trailing" sequence, which begins with a problem solving course, and follows with the same Fall and Winter courses shifted to the Winter and Spring. Incoming students who struggle on the placement exam are placed into the three quarter sequence designed to acclimate them into the chemical sciences. (This Spring 2018, I will teach an entirely new third quarter curriculum I developed for the trailing sequence of students.) I created core learning goals for every chapter, incorporating material from the current chemical literature as examples, and added simple practice problems into my lectures. Further, I initiated a collaboration with our Office of Institutional Diversity and Inclusion to promote the success of underrepresented students in my class, as underrepresented students comprise the plurality of trailing sequence candidates. Increasing diversity in STEM is the best way to increase diversity of perspective and ensure that we are recruiting the top cadre of students. We developed interventions and team building activities to mitigate the perceived stigma of the trailing sequence, such as bringing in role models of similar backgrounds. The aggregate of these approaches led to my evaluations continuously improving over five years, and my receipt of invitations from my students to an annual faculty recognition dinner.

Graduate education in the chemical sciences
At the graduate level, my goal is to train students to question published science, propose alternate explanations for observations, and marshal scientific evidence to defend a point, three skills crucial for scientific success typically absent from formal graduate education in the chemical sciences. Towards that end, I designed a new course to connect physical property measurements, in particular magnetic measurements, to basic ligand field theory considerations. Throughout the class, I connected physical property measurements with current inorganic research topics, and engaged the students in discussion by asking questions about the meaning of the data they see. The most notable feature of my course is the incorporation of structured scientific debates, an exercise in which pairs of students debate a modern scientific question—again, preparing emerging scientists to propose, critique, and effectively argue ideas.

Chemical education outside the classroom
I choose to build campus community and to facilitate student-faculty interactions by serving as a faculty fellow in Northwestern's Public Affairs Residential College, one of the topically-focused undergraduate living groups on campus. Faculty fellows eat lunch at the student dining hall and attend house social events. In one such event, I led an interactive fireside chat with a group of 25 undergraduates about the impact of magnetism on renewable energy. I also

spoke at an event for international students preparing for the 2017 March for Science. Students made posters and discussed the impact of science funding with invited faculty.

In a collaboration between Dr. Patricia Ward, director of science and technology at Chicago's Museum of Science and Industry and Northwestern's Materials Research Science and Engineering Center, I developed a public museum exhibit on the impact of materials in society. First open in March 2015, the exhibit recently moved to its permanent home for display, O'Hare International Airport. My laboratory's research into magnetic materials features prominently (Figure 1), presenting my description of the requirements for new magnetic materials and how those ideas drive my laboratory's research. Dr. Ward's team and I also designed an interactive periodic table representing different categories of magnetic properties; visitors are invited to design magnets for different purposes.

Figure 1. Photograph of our magnetism exhibit at O'Hare Airport, with a video of me in the top left.

To serve the broader community, and generate opportunities for graduate students to disseminate their research and interact informally with faculty, I take part in organizing conferences and symposia. As an example, I organized a one-day Chicago Regional Inorganic Colloquium (CRIC) to gather scientists from Northwestern, University of Illinois at Chicago, the University of Chicago and other regional schools. We modeled CRIC after the semiannual Boston Regional Inorganic Colloquium, featuring a mixture of student and faculty presentations. For the Chicago area event, Northwestern's Graduate School awarded me a Catalyst Grant designed to facilitate graduate education.

(1) Krontiris-Litowitz, J.; Using Primary Literature to Teach Science Literacy to Introductory Biology Students J Microbiol Biol Educ. 2013, 14, 66–77.
(2) Hoskins, S.G.; Stevens, L. M.; Nehm, R. H. Selective use of the primary literature transforms the classroom into a virtual laboratory. Genetics 2007, 176, 1381-1389.

Juliane L. Fry
Chemistry
Reed College

Teaching chemistry is a joy because it involves responding to innate human curiosity and helping students to gain insight into the way the natural world works. Nothing beats the experience of seeing a student reach the moment of illumination when a new concept becomes clear. My overarching teaching philosophy is to lead by example in my enthusiasm about the material and its relation to real-world problems and the cutting-edge questions scientists are pursuing. At all levels, I endeavor to teach students to think analytically and critically and develop the problem-solving skills and confidence that support their engagement with scientific ideas.

My teaching at Reed has focused on four main areas: the introductory chemistry sequence (100-level), Environmental Chemistry (200-level), an interdisciplinary environmental studies course (300-level), and mentoring upper division students with independent research in the laboratory. This has required me to think about how to best teach at all levels, as well as how to motivate learning for diverse student populations, from science majors to interdisciplinary Environmental Studies majors to students simply taking Introductory Chemistry to fulfill the college-wide requirement of a year of lab science. I have enjoyed the challenge of developing pedagogical strategies for each context. For many of the students I interact with, in our large introductory chemistry course, my goal is to help them become a scientifically literate, skeptical, informed citizen. For students I have the opportunity to teach at higher levels, our goal is to learn the tools of the trade, become conversant in the environmental issues of our day and to learn to use quantitative scientific models to understand them. The activities I have developed for each course reflect my efforts to serve these diverse goals.

The introductory Chemistry course sequence (Chem 101/102) is taught in keeping with Reed's philosophy that students should not be tracked by academic ability or major, so the majors and non-majors are combined in two lecture sections (60-75 students each) and a unified set of lab sections. Since the College has a requirement of one year of lab science, we have a large population of non-majors in this course, while also trying to recruit Chemistry majors. Given the annual number of chemistry graduates, we seem to be successful in our recruitment!

In Fall 2009, I developed a new course, Chem 230 (Environmental Chemistry). My content goals for this course were to survey the "spheres" of the environment, from atmosphere to hydrosphere to lithosphere, and overview the natural chemistry and pollution influences on each. Given my field of expertise, the emphasis is somewhat heavier on atmosphere and climate, which best serves students who plan to do research in my lab. The field/lab project which I include each year teaches students about planning and executing field research and exposes them to state-of-the-art mass spectrometric analytical techniques, and has consistently been rated highly by students (as well as providing a fun growth opportunity for me, since I vary it each year). The three first class projects developed (ICP-MS measurement of heavy metal in soil samples, GC-MS measurement of biogenic and anthropogenic volatile organic compounds) were described in a talk I presented at the 2013 Association of Environmental

Studies and Sciences annual meeting, and I have since developed additional projects employing GC-MS to measure bisphenol-A leaching from plasticware and brominated flame retardants in couches. If we are able to increase department staffing, I would like to eventually develop these labs into a separate laboratory course.

In Spring 2013, we premiered the new ES300 (Environmental Studies Junior Seminar) course. Chris Koski (Political Science/ES) and I developed the course together in Summer 2012. We incorporated class discussions of journal articles, short problem sets and climate modeling assignments using David Archer's online climate models, GIS activities, a midterm paper assignment, a "Carbon field trip", and a class project including data collection and policy analysis conducted in collaboration with the City of Portland's Bureau of Planning and Sustainability, culminating in the students presenting their report in writing and orally to the City BPS. In Spring of 2014, our class project assessed the carbon implications of converting the Boardman coal fired power plant in the Columbia River Gorge to torrefied agricultural waste as a feedstock. The students find the course stimulating and rewarding, so we have continued with this course model in subsequent years, with a varying project focus each year.

All students at Reed must complete a year-long thesis project in the senior year in order to graduate; I have had the privilege of mentoring 18 theses and 21 summer and independent study projects. I consider senior thesis and independent project advising to be among the most important teaching I do at Reed, as I mentor students in their first independent research endeavor. I relish the challenge of figuring out the best motivational structure for each student, and work hard to help each student select a project that they can wake up every (or at least most!) mornings excited to work on. During the summers, we have weekly group meetings during which in alternate weeks I work through literature papers with students, or ask each student to present a figure to the rest of the group. This encourages collaboration among the students – I invite them to ask questions and help one another out with experimental roadblocks – and also gives them valuable practice presenting their work orally. For similar reasons, during the academic year, I alternate between individual thesis meetings with each student one-on-one, with group meetings on the off weeks.

In thesis mentoring, I maintain a high degree of flexibility in allowing diverse topic areas among students who work with me. I am glad to learn a new area of environmental chemistry in order to mentor a unique thesis project, but I make it very clear to the student that I will be learning with them in that case and be able to offer less guidance on the details of their project. Thus far my experience has been that the students who choose to pursue something outside of our group's traditional expertise after hearing these caveats are those with the right attitude and tools to make such a project successful. A list of thesis titles is shown below to illustrate both "typical" projects in atmospheric chemistry and those slightly out-of-the-box theses, which have been a pleasure for students and advisor alike.

- 2009, Jessica D. Tobin, Satellite measurements of NOx and aerosol over the West Coast
- 2009, Anna Stonestrom, FTIR measurements of Portland aerosol chemical composition
- 2010, Tara Cass, Measurements of silver nanoparticles in the environment
- 2011, Caleb Arata, Ozonolysis of α-pinene: A chamber study
- 2011, Claire Remington, Some Concrete Chemistry: The Effect of Sound Walls on Benzene Concentration

- 2011, Lisa Schomaker*, The Ozone Effect: Measuring physiological stress indicators in Pseudotsuga menziesii

* Advisor: David Dalton. Ozone exposure experiments were conducted in Fry lab.

- 2013, James Bianconi (ES-Chemistry), Monitoring The Ozonolysis Of α-Pinene Using GC/FID
- 2013, Danielle Draper, NO_2 effects on nighttime secondary organic aerosol (SOA) formation
- 2013, Laura Krause, A Quantitative Analysis of Ambient Organic Aerosol Composition by FTIR with Meterological and Gas-phase Oxidant Characterization in the Columbia River Gorge
- 2013, Kathryn Sackinger, Synthetic Models for Second-Generation Monoterpene Chemistry in NO_3-Influenced Aerosol Formation
- 2014, Hannah Allen, The air you breathe: A chemical characterization of the inorganic gas-aerosol system in the atmosphere above Portland, OR and Centerville, AL
- 2014, Chris Cogell, NO_x de Plume: A Spatial Analysis of Nitrogen Dioxide Plume Near the Brooklyn Railyard in Southeast Portland, Oregon
- 2014, Alan Tuan, Observational Study of Brooklyn Rail Yard and its Effects on Air Quality in Portland
- 2015, Hyungu Kang, Size-Dependent Molecular-Level Characterization of Secondary Organic Aerosol from NO_3 Initiated Δ-carene Oxidation using Nanospray Desorption Electrospray Ionization High-Resolution Mass Spectrometry
- 2015, Natalie Keehan, Detecting Organic Nitrates Using Thermal Dissociation Cavity Ring-down Spectroscopy (TDCRDS)
- 2015, Eve Mozur, The Composition of Secondary Organic Aerosols at an Urban Site
- 2016, Makoto Kelp, Tropospheric particle formation in forests: global modeling of secondary organic aerosol production from reaction of NO_3 radical with speciated monoterpenes
- 2017, Annelise Hill, Source Apportionment of Airborne Heavy Metals at the Brooklyn Rail Yard in Portland, OR

Amelia A. Fuller
Chemistry & Biochemistry
Santa Clara University

My educational efforts have centered on my commitment to: 1) integrating research experiences into the organic chemistry laboratory courses to advance and enrich student learning, and 2) promoting and facilitating these laboratory curricula as educational best practices. Below, I will detail my ongoing work both to develop courses at Santa Clara University (SCU) and to champion and disseminate curricular change. This work complements my commitment to mentoring student researchers in my independent lab at Santa Clara University and my teaching in introductory and advanced organic chemistry lecture courses.

Motivation
I have focused much of my curriculum development efforts on integrating discovery-based experimental work into the introductory organic chemistry laboratory. This type of curriculum reform has been advocated by the President's Council of Advisors on Science and Technology (PCAST) as a way to reform STEM education in the first two years of college. [1] The organic chemistry laboratory is the natural venue to contextualize lecture concepts through hands-on work. I am also compelled by the studies that provide evidence that research-based curricula are an effective way to deepen student understanding of scientific concepts, enhance student confidence for future experiences, and better equip students to think independently. [2] In my experience, students are highly motivated by the applications of their work, and the research framework gives special significance to learning basic experimental techniques. Additionally, their engagement in open-ended discovery experiments teaches students the creativity of scientific pursuit. [3] This approach to problem solving teaches skills transferable to any field—how to form and evaluate hypotheses, test reproducibility, troubleshoot, and develop resiliency.

I strive to exemplify the teacher-scholar model, and research-based laboratory courses are an ideal venue to integrate teaching and scholarship and share my deep enthusiasm for chemistry and discovery. While simultaneously advancing student learning, I recognize an opportunity to advance and complement my independent research program; I design projects that benefit from the large results sets generated.

Laboratory Curriculum Development in Introductory Organic Chemistry
To date, I have developed two, 10-week academic quarter laboratory courses to provide an authentic, discovery-based research experience for 12-18 chemistry and biochemistry majors annually. I have also developed a multi-week experiment for all organic chemistry laboratory students.

Quarter 1: Drug discovery laboratory (for majors). Both the students and I are inspired and motivated by the drug discovery process, which is frequently initiated by screening large compound libraries for desired biological activity. Because of the large number of students involved, introductory organic chemistry students can meaningfully contribute to the diversity of potentially bioactive molecules available. In this course, each student prepares a small, six-compound combinatorial array through multi-step synthesis on solid support. In the four times I have taught this course, students have prepared three different scaffolds, all derived from the "arylopeptoid" general structure,[4] and I have reported one of these experiments in the Journal of Chemical Education.[5] Although robust methods to prepare some arylopeptoid analogs have been detailed in the literature, our examples have never been reported in the chemical literature. Following their synthesis, the inhibition of bacterial growth by these molecules is evaluated in my own research laboratory or via collaboration with a free screening entity, the Community for Open Antimicrobial Drug Discovery (CO-ADD).[6] Moreover, the results obtained in these experiments contribute to a deeper understanding of the chemistry employed; as a class, we examine differences in substrate reactivity to identify trends. This course structure thus simultaneously adds valuable compounds for evaluation and accelerates reaction optimization of these analogs.

Quarter 2: Organic research projects laboratory (for majors). Following their introduction to research ideas in the previously described laboratory, students prepare compounds relevant to ongoing research in faculty laboratories at SCU. For example, a student group may be tasked with any (or all) of the following over the quarter: preparing a critical synthetic intermediate via multiple steps; optimizing new reaction conditions for a given synthetic transformation; examining the substrate scope of a given reaction. Learning objectives include solidifying basic synthetic and analytical experimental techniques, adapting literature procedures safely and effectively, design of new experiments, and troubleshooting experiments. This is a new course—I am offering it currently for the first time, and it represents a substantial expansion of the research opportunities for students in the curriculum over previous years.

Research experiments for all organic laboratory students. I have developed a three-week experiment for inclusion into the laboratory course taken by all students in the organic chemistry course. Studies have indicated the value of these experiences in retaining diverse students in STEM fields,[7] making this a valuable expansion direction. In this experiment, each student executes a multi-step synthesis to prepare a single new molecule for future biological evaluation. Across the class, multiple analogs are prepared.

Assessment. As I initiate and expand curriculum changes, I am committed to assessing student learning outcomes. In their responses on simple surveys, students are highly enthusiastic about the research-based approach and they self-report gains in conceptual understanding and in their confidence.5 Moving forward, I intend to leverage on-campus resources, including assessment experts, to develop thorough and meaningful assessment mechanisms.

Disseminating and Championing the Integration of Research into the Curriculum

I strive to become a visible leader, champion, and facilitator for others to incorporate research-focused curricular innovations at their own institutions. To this end, I have disseminated my educational efforts broadly: I have published research-based experiments in the Journal of Chemical Education,[5] I have contributed to book chapters,[8, 8] and additional manuscripts addressing novel chemical and biological outcomes of this work are in preparation. In addition, I actively present this work at international meetings. In particular, I highlight my participation in a workshop at the University of Havana, Cuba in October, 2016, and in a symposium at the spring, 2017 national meeting of the American Chemical Society. Lastly, I am actively engaged with a community of leading teacher-scholars who share my commitment to promote and facilitate inclusion of research experiences into the undergraduate curriculum. With a group of fellow Cottrell Scholars (awarded by the Research Corporation for Science Advancement), I am contributing to a practical guidebook for new practitioners to adopt similar curricular modules (in preparation with expected publication summer, 2017).

---

1. President's Council of Advisors on Science and Technology. Report to the President Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics. 2012
2. Weaver, G.C., Russell, C.B., and Wink, D.J. Inquiry-based and research-based laboratory pedagogies in undergraduate science. Nature Chemical Biology, 2008, 4, 577-580.
3. National Research Council. Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering. Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research. S. Singer, N.R. Nielsen, and H.A. Schweingruber (Eds.). Board on Science Education, Division of Behavioral and Social Sciences and Education. 2012. Washington, DC: The National Academies Press.
4. Hjelmgaard, T.; et al. Improved solid-phase synthesis and study of arylopeptoids with conformation-directing side chains. Tetrahedron 2012, 68, 4444.
5. Fuller, A. A. Combinatorial Solid-Phase Synthesis of Aromatic Oligoamides: A Research-Based Laboratory Module for Undergraduate Organic Chemistry. J. Chem. Educ. 2016, 93, 953-957.
6. Community for Open Antimicrobial Drug Discovery. www.co-add.org. Accessed March 23, 2017.
7. Eagan, M.K., et al. Making a difference in science education: The impact of undergraduate research programs. American Educational Research Journal, 2013, 50, 683-713.
8. Heemstra, J.; Waterman, R.; Antos, J.; Beuning, P.; Bur, S.; Columbus, L.; Feig, A.; Fuller, A.; et al. Throwing away the cookbook: implementing course-based undergraduate research experiences (CUREs) in chemistry. In ACS Symposium Series: Educational and Outreach Projects from the Cottrell Scholars Collaborative. 2017. accepted
9. Scott, W. L.; Samaritoni, J. G.; O'Donnell, M. J.; Dounay, A. B; Fuller, A. A.; et al. Ernest Eliel Workshop – US and Cuba Collaboration in Chemistry Education and Neglected Disease Drug Discovery. chapter in ACS Book: Stereochemistry and Global Connectivity: The Legacy of Ernest Eliel. 2017. accepted

John D. Gibertson
Chemistry
Western Washington University

One of our primary duties as a faculty member at Western Washington University is to be a teacher and a research mentor to undergraduate students. I am an inorganic chemist, and during my tenure at WWU I have taught classes that range from the very first chemistry course our majors take (Chem 121, General Chemistry) to our senior capstone lab course (Chem 464/ 465, Physical/Inorganic Lab), as well as electives. I truly appreciate the wide spectrum of students that I get to interact with in both teaching and research, and am humbled by the growth and maturity displayed by them throughout their careers. I have compiled a description of my efforts in education in the chemical sciences below.

I have taught at least one quarter of CHEM 121 every year since I arrived at WWU, which is not common for tenured or TT faculty. It is by far my favorite class to teach. Chemical demonstrations and class participation are integrated throughout my class in order to foster collaboration and discussion. I am involved in instituting student-centered learning practices (worksheets, videos, response systems, student "coaching", etc.) into my classes as part of WWU's Change at the Core (C-CORE) institutional transformation project. The C-CORE model is being implemented across STEM classes at WWU to transform them from teacher-centered classes to student-centered learning experiences. Our 12X (General Chemistry 1-111) series is in need of streamlining and I am a member of the General Chemistry Task Force, assembled to restructure general chemistry to provide students a better basis for molecular understanding and more rigor. This task force has meet weekly for the last year in order to develop a set of learning progressions to reorganize the general chemistry curriculum to align with those progressions. We are piloting an atoms-focused curriculum in the Fall of 2017 which includes instituting a new atoms-focused textbook.

I developed our current Advanced Inorganic Chemistry course (CHEM 441) upon my arrival in 2008. There were no lecture notes or slides (or even a book for that matter) for me to inherit when I started teaching 441. I developed the entire course from scratch and have taught it every year (except while on sabbatical). I am very proud of the work I have done in that course to bring it into the 21st century with common inorganic principles and themes, and the students appreciate it. I rely heavily on demonstrations and class participation to foster a safe, exciting learning environment and have begun the process of instituting C-CORE practices in to this course as well. Some of my favorite comments in the senior exit interviews are "why don't we have more inorganic chemistry?" or "I wish they wouldn't make us wait until our senior year to take inorganic chemistry."

I have invested substantial time and effort to upgrading the 464/ 465 labs. The inorganic portion of those two courses have had a complete makeover since I took over as the inorganic faculty member. I developed and added four completely new labs to the curriculum over the course of two years and was awarded a WWU Summer Teaching Grant to develop an "artificial leaf" lab (dealing with water splitting). I incorporated a great deal of electrochemistry and renewable energy topics to the lecture and labs which has brought those courses in line with modern inorganic chemistry.

I created the Bioinorganic Chemistry (425u) course, which did not exist before I came to WWU, and is always well enrolled. I also contributed to the creation of (and co-teach) the Chemistry of Renewable Energy (497) course with David Rider and David Patrick. In addition to our majors, these classes are typically enrolled by either MS students (425u), or students that aren't necessarily Chemistry majors (497).

I am also involved in Course-based Undergraduate Research Experiences (CUREs). During Dec. 2016 I attended a CUREs workshop hosted by Research Corporation Cottrell Scholar Collaborative outlining the integration of CUREs into the laboratory curriculum. I contributed to a chapter for a book and quick start guide describing CUREs. This book chapter is currently being assembled and edited for publication. These activities are being integrated into our 464/465 labs.

Science education doesn't stop at the undergraduate classroom. In an effort to educate students and the local public in the chemical sciences, I have created the video series titled "Scientist Citizen". These videos are meant to inform residents of Whatcom County, Washington of local scientific issues and the impact of those issues on the local populace:

https://cse.wwu.edu/chemistry/scientist-citizen

Scientist Citizen is a program aimed at educating the public about local scientific issues that are affecting the region. It also serves to provide a vital link between WWU and the broader community in Whatcom County.

Our unofficial motto in the Chemistry Department at WWU is that "research is teaching". In this regard I have a successful track record in obtaining external funding ($2,895,229) as either a PI or co - PI that has provided students not only in Chemistry, but Physics and Math as well, with multiple research opportunities over a wide range of different projects. Two of those grants have been for major instrumentation for research and upper division coursework (MRI for Single crystal XRD and MRI for 500 MHz NMR upgrade). I currently have three proposals pending (See CV). My current R15 submission to the NIH received an impact score of 26 and I have been informed that the proposal is within the funding range for this fiscal year, likely in time to hire students for summer research.

As a mentor and teacher I take diversity very seriously. 12 of the undergraduate students that I have mentored are "'women (44%) and nine are minority (33%), with six being underrepresented minorities (22%). Five of the six (83%) MS students that I have mentored are minority students, with three (50%) being underrepresented. I foster a safe, inclusive research environment in order to attract and retain students that might otherwise fall through the cracks. I am active in WWU's advertisements and recruitment efforts of students of all backgrounds from the Northwest.

Due to their positive experiences as students at WWU, almost all (except four) of the students that I have mentored have continued their studies in either graduate or professional schools. These include top chemistry programs such as the University of Michigan, University of Chicago, Yale, University of Washington, Penn State University, and the University of

California-Irvine (to name a few). Most of these students are/were the first ones in their families to go on to graduate school, and for some of them they are the first members of their family to attend college.

Lastly, in the regards to our "research is teaching" motto, students that graduate from the lab have a fundamental understanding of not only their research projects, but also the broader societal and scientific context in which those projects reside. I am a firm believer in teaching students to "learn how to fail" and not to be afraid to do so. This results in students possessing a developed sense of creativity, and they graduate as independent thinkers and problem solvers. My efforts in science education has assisted students to develop as young women and men, both professionally and academically, which helps them be productive members of society.

Randall H. Goldsmith
Chemistry
University of Wisconsin – Madison

The two most important vectors, or delivery agents, for an effective learning experience is unadulterated enthusiasm and placing the material in context with current research. These rules are especially important at the introductory level, where undergraduate students are still forming their opinions of chemistry. Enthusiasm is key to cracking Chemistry's perceived detached and sterile exterior and revealing the relevant and colorful science beneath. Letting students know that what they are learning is only a few steps removed from where the textbooks fail, that they really are close to the cutting-edge, instantly makes the material seem more relevant. Coupling this latter message to another realization, that their participation in the re-search enterprise at a top research university is within their reach, is another powerful tool.

How to Get a Research Job - Emphasizing that undergraduates can and should take part in research, even freshmen students, begins early in my classes. For the past four falls, 2-3 weeks into the semester, I hold a "How to Get a Research Job" seminar on an evening outside of class. Approximately 2/3rds of the class will attend. I begin by telling them that exciting research opportunities exist, that they (the students) are hot commodities, and that if they are willing to put in the legwork and tolerate a little bit of rejection, they will get a research position, all the while enjoying the looks of incredulity on their faces. I tell them some professors will not want a freshman student, but that many others will jump at the chance. I clue them into how a faculty member thinks about this, that undergraduate researchers require substantial investment of resources before they pay dividends, which makes getting in early, even as a second semester freshman, incredibly attractive. We discuss how research positions generally aren't advertised, that the impetus must come from the student. I tell them how they have to read every research description of each faculty member on the department website. We discuss writing a cover letter. I tell them to send out five emails to faculty members and expect some rejection (one will be emeritus, two will be too busy writing grants, one won't take a freshman, and one will be the perfect fit). We discuss waiting until classes feel under control to get a research job, that this may not happen until sophomore year. I declare to them that summers doing research at a university will be some of the best summers of their lives, and that scholarships are plentiful to make it work. Finally, I let them ask questions until everyone is saturated.

I get to spend the rest of the semester hearing the successes roll in. Matt M. is making nozzles for molecular beams. Mike P. is working with RNA in the biochemistry department (I tell him it's ok that he's not working in chemistry). Alex J. is doing theory. Sometimes I get email updates in later semesters,

> "Hello Dr. Goldsmith,
> I just wanted to check in and say thank you for your help regarding getting into research labs. It took me a while to get it together, but I followed your advice about sending out emails and applications and I did get a position working with a grad student in Laura Kiessling's lab! …I'm very excited to

> start, and I don't think I could've gotten an initial interview without your advice. It will definitely help me in the future as well. So thank you again!
> Lili"

I reinforce the excitement of research all through the semester. Electrochemistry begins with a brief discussion of electron transfer, molecular wires, photovoltaics and cellular respiration. After we learn the jargon associated with a topic, I put up research papers (less than five years old if possible) on the projector, and show them that these papers are using the same language they just learned. Molecular orbital theory ends with STM "pictures" of HOMO's and LUMO's in pentacene and phthalocyanine (everyone is astounded that molecular orbitals are not figments of a professor's imagination).

My emphasis on research in the classroom has resulted in tangible shifts in students' attitudes, as summarized by Dr. Cheri Rossi, "Randy has been a tremendous force in the department towards encouraging and inspiring undergraduate students. As the Undergraduate Research Director for the Department of Chemistry, I'm in a unique position where I get to talk to a lot of students about how they became interested in research, what type of research they would like to be involved in and how they become to be inspired to pursue a STEM degree. Since Randy started his position at UW, I have seen more students stopping by my office; without exception, these students inspired by Randy to purse a STEM degree always ask if Randy is taking more undergrads in his lab. This truly speaks to Randy's innate energy, his ability to inspire and his natural talent for resonating with undergraduate students on our campus."

Education at the Single-Molecule Level - Undergraduate chemistry students are asked to think at (and rapidly switch between) two dramatically different length-scales: the nanoscopic scale of atoms and molecules and the macroscopic scale of human experimental observation. One example of this dichotomy is the notion of a "dynamic chemical equilibrium," an outwardly unchanging system that hides the tremendous number of chemical changes occurring internally. Unfortunately, this concept is frequently misunderstood, with >70% of students using terms like "static," "at rest" and "not moving" to describe chemical equilibrium, as assessed by word-association tests. [1] It has been speculated that a significant cause of students' difficulty with this concept stems from the apparent disconnect between what is macroscopically observed, a seemingly unchanging mixture, and the rich dynamics occurring at the microscopic level. [2, 3] The majority of chemistry is inherently taught at the single-molecule level, including any lesson that entails discussion of chemical structure or mechanism. However, all laboratory activities are, by necessity, per-formed at the bulk level! This distinction places a cognitive obstacle between the themes taught in the classroom and the experimental observations that are ideally supposed to confirm those themes in the laboratory. Single-molecule experiments can cut through that obstacle by allowing students to directly spy on the behavior of molecules and see how bulk behavior organically derives from microscopic behavior.

I have developed an inquiry based approach to teaching equilibrium and kinetics incorporating observations of individual molecules. Students are shown single molecules blinking via a live-link to a microscope in my laboratory. They are then shown a fluorescent concentrated solution of the same molecule in a vial, which, of course, appears to be static. The students are then given an opportunity to discuss the origin of the apparent contradiction.

This is a critical time, as concepts such as the asynchronicity of changes will hopefully arise naturally, but can be helped along in a more guided-inquiry manner. The students' intellectual "struggle" here is the most important part of the inquiry-based experience. The equilibrium is then introduced as $\text{Molecule}_{BRIGHT} \rightleftharpoons \text{Molecule}_{DARK}$. Students are led to relate the equilibrium constant, KB/D, to the number of molecules in each state at a given instant. In this manner, the equilibrium constant is connected to something that is occurring at the molecular scale, but can also be directly counted. The "dynamic" nature of the equilibrium is apparent for all to see. An-other critical connection is that the time that the molecules are bright (dark) evolve from the rate at which they become dark(bright). I have implemented this exercise in lecture settings in my class and in those of my colleagues, as well as in smaller groups in my laboratory, including senior high school students from a series of rural Wisconsin science summer camps run by the Wisconsin Institute for Discovery.

An Integrating Sphere for Freshmen Chemistry - My work to bring tools of modern chemical instrumentation into the undergraduate experience extends to teaching labs. One activity entails assessing the luminosities of light sources (candles, LED's, incandescent bulbs, etc.) to determine efficiency. To enhance this lab, we developed a cheaply constructible integrating sphere suitable for undergraduate labs (see picture). The sphere is placed over the light source and luminosity is quantified on a detector. We have developed a production model, fabricated multiple copies, and are now acquiring several semesters of data on classroom use before submitting a manuscript to J. Chem. Ed.

An integrating sphere for the un-dergraduate lab with sensor

Honors - My dedication to undergraduate chemical education has been recognized with multiple campus-wide teaching awards. I have been nominated as University Housing Honored Instructor for the past six semesters and received a Distinguished Honors Faculty Award from the College of Letters and Science in 2015. Most recently, I have received the Benjamin Smith Reynolds Award for Excellence in Teaching Engineers, an annual award given by the College of Engineering that requires multiple student-written letters. This was the first time in ten years the honor went to a faculty member outside of the Engineering College.

Maskill, R. et. al., Int J Sci Ed, 1989, 11, 57-69. 2Kind, V.: Beyond Appearances: Students' Misconceptions about Basic Chemical Ideas; 2 ed.; Royal Society of Chemistry, 2004. 3Gussarsky, E. et. al., J Res Sci Teach, 1988, 25, 319-333

Robert R. Knowles
Chemistry
Princeton University

Undergraduate teaching and mentoring My primary goal in chemistry education at the undergraduate level is to entice the best and the brightest young minds to pursue careers in the molecular sciences. To do so I stress how fundamental advances in chemistry have enabled our current quality of life, including the development of modern agriculture, the invention of life-saving pharmaceuticals and antibiotics, the myriad applications polymers and plastics, and the lithium batteries that power our devices and vehicles. But even more importantly, I emphasize that in coming decades chemists will need to invent and discover new solutions to many problems of increasing societal concern, including the development of sustainable energy technologies, renewable materials, environmental remediation strategies, and continued advances in our understanding of human health and disease. Basic research in the molecular sciences will undoubtedly be central to these efforts and convincing young people to devote their minds and careers to these causes is our most important role as educators. Even for those we cannot recruit to our ranks, it is critical that we instill an appreciation of the role of chemistry in modern life and the critical importance of basic research in the chemical sciences.

I have been fortunate to have a large stage from which to promote this message through teaching CHM 304, the second semester organic chemistry course for undergraduates at Princeton. This course is mechanism-based survey of many of the major reaction classes and aims to provide undergraduate students with a firm understanding of the foundations of chemical reactivity. Real-world applications are heavily emphasized to demonstrate the central role of organic chemistry in medicine and human health. In the future, I am interested in incorporating more active learning features into the undergraduate organic chemistry curriculum and exploring the possibility of 'flipped' classrooms for teaching introductory organic chemistry courses.

Along with these classroom activities, I am deeply committed to providing research opportunities for undergraduate students. Since 2011, I have served as a research mentor to 17 undergraduate coworkers. In addition to basic laboratory skills, my goal has been to teach them to think like scientists and to develop the ability to independently analyze data and generate testable hypotheses. I am proud to say that I have published seven original research papers with undergraduate co-authors (five in J. Am. Chem Soc., one in Nature, one in Science). In all cases these students made meaningful experimental and intellectual contributions to the projects, and played a key role in getting them across the finish line. I have also mentored six students in writing a senior thesis. Of this group, one just began her graduate school in chemistry at Scripps, one is pursuing an MD/PhD at Caltech & USC, and two have gone on to medical school.

Graduate teaching and mentoring Since 2011 I have mentored 14 graduate students and 4 postdoctoral researchers. In my view, successful chemical education at the graduate level teaches students to recognize the frontiers of their discipline and to look beyond traditional methods for new solutions. As such, facilitating a broad, interdisciplinary, and progressive chemical education is a central element of my approach to mentoring. In my view this is best done through frequent and in-depth conversations about the state of the field and critical appraisal of the current research literature. To this end, our research group holds two weekly literature meetings. In the first, three recently published papers are chosen by the students and discussed by the entire group. The relevant background material is presented as a means to contextualize the advance and the students lead a free-form discussion on the merits and impact of the work. From these discussions students learn not only the mechanics of putting together a well-written research paper but also how to assess and articulate what differentiates important breakthroughs from routine incremental advances. The second meeting is an in-depth 'topic' meeting, wherein one student presents a formal hour-long talk on a specific research focus. This provides students the ability to take time away from lab to explore interests in areas of chemistry far removed from their thesis topic, and provides additional training in organizing, creating, and presenting a formal lecture.

With respect to classroom teaching I have been involved in teaching three different graduate-level courses in organic chemistry during the first five years of my appointment. In particular I am proud of developing a new course here at Princeton (together with my colleague Paul Chirik) in Physical Organic Chemistry (CHM 532). This course is designed to provide detailed coverage of many essential topics relating to the study and understanding of reaction mechanisms, including kinetics, isotope effects, linear free energy relationships, catalysis, bonding, non-covalent interactions, and photochemistry. This class is now become an integral part of the graduate curriculum for students in organic chemistry, chemical biology, organometallics, and inorganic chemistry. Students are provided with more than 180 pages of original notes and leave the course with the ability to methodically design and interrogate mechanistic questions in their own research projects and to critically read mechanistic proposals in the current research literature.

I have also taught both semesters of our graduate organic synthesis sequence. The first semester course (CHM 530) is designed to give incoming graduate students and advanced undergraduates a strong background in methods for the construction of complex organic molecules. Particular emphasis is placed on understanding the basis for achieving chemo-, regio-, diastereo- and enantioselectivity in the reactions of complex, polyfunctional substrates. In lieu of a textbook, students are provided with over 350 pages of original class notes outlining the development, scope and strategic use of many of the most important classical and contemporary reaction technologies. Primary literature sources are also emphasized, and students are provided with a curated collection of more than 250 original papers that describe many of the most significant advances in the field over the past four decades. Synthetic students are provided with a firm foundation to enter into upper level courses on advanced topics while students in other disciplines leave the class with a firm theoretical knowledge of how to devise syntheses of molecules necessary for advancing their own research projects. The second semester course (CHM 536) is intended to give students specializing in synthetic organic chemistry an overview of most significant advances in catalytic chemistry the field over the past 10-15 years. Special emphasis is given to modern catalytic and enantioselective methods, including research topics that remain at the forefront of the discipline. Selected topics include cross coupling, olefin metathesis, metal-catalyzed hydrogenation and related metal hydride technologies, C-H activation, aryl amination, photoredox catalysis, and organocatalysis. Special emphasis is placed on the mechanistic features and design principles that led these technologies to become standard methods in the field.

Jane M. Liu
Chemistry
Pomona College

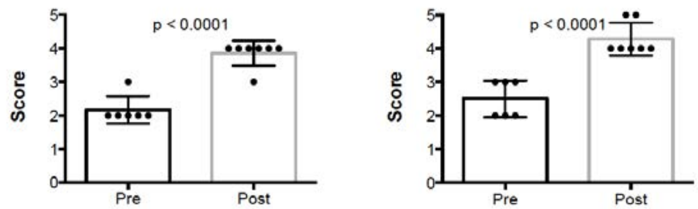
My goal as an educator is to teach students the skills and vocabulary necessary to appreciate scientific methodology, to understand the products of science research, and to think critically and create their own ideas. Below, I present two specific activities that represent my accomplishments as a teacher at Pomona College in the past few years.

Activity 1 – A new course on understanding science research and how to read science literature

Consistent with my goals to increase scientific literacy and to make science feel more accessible to students, in Spring 2017, I created a new course aimed specifically at second-year students. The impetus was that I wanted to reach students that I do not usually see in my upper-level Biochemistry and Chemical Biology courses. In particular, I wanted to work with students who were perhaps still a bit apprehensive about chemistry and science research – either because they felt like they had trouble understanding it or they thought that they were not capable of "doing science". It has been suggested that: "Many students do not have a sense of how scientific knowledge is generated, how research projects progress over time, or how scientists think about and actually do research". [1] I wanted my new course to help students bridge the transition between introductory and upper level courses, and to also provide a gateway to independent research experiences. In the course, I focused on two questions: What is science research? Who does science research? Specific scientific content was secondary to these two questions, but throughout the course, the students were exposed to and learned about chemistry ranging from the structure of nucleic acids, non-covalent interactions, binding affinity, thermodynamics, molecular cloning and directed evolution.

My course, CHEM 112: Analyzing Scientific Literature – Demystifying the Approach and the Science, was centered on the C.R.E.A.T.E. (consider, read, elucidate hypotheses, analyze and interpret the data, and think of the next experiment) approach to teaching scientific literature. [2-4] The C.R.E.A.T.E approach has been successfully implemented at a number of colleges to teach science content, to expose students to the progression of science research, to demystify the process of reading a scientific article, and to humanize scientists. The course centered on guided investigation of a set of related journal articles and students were given the opportunity to develop their ability to decipher figures, interpret findings, and propose and defend further experiments to test their own hypotheses and questions. While most of the papers were selected by myself, the students also searched the literature to find an article that interested them and presented that article at an open poster session as part of the Spring 2017 Chemistry-Biology Student Symposium. We also spent time in class discussing grant writing and funding mechanisms, the process of publishing a journal article, and the challenges and opportunities of being a scientist. Each student also reached out to a scientist who had authored one of the papers we had read to ask a series of questions. Many of the scientists responded and we spent the last day in class discussing their answers.

I was absolutely thrilled with how well this new class went in its first iteration (and it has since been offered a second time, with similar outcomes). I felt that I successfully met my intended learning goals. And perhaps most importantly, the students left feeling more confident about approaching science literature and their understanding of the scientific process (see figure, right).



How confident students feel in ability to read and analyze scientific journal articles (1, zero confidence; 5, extremely confident)

How much students feel they understand the scientific research process (1, don't understand at all; 5, understand it very well)

Activity 2 – An authentic research experience for second-semester organic chemistry
Over the past few years, I also developed and implemented a laboratory module, the Antimicrobial Peptide Lab, in Second-Semester Organic Chemistry. This laboratory experience provides an opportunity for students to explore the process, nature, and limitations of science. By including this exercise in Second-Semester Organic Chemistry, a course taken by many students, not just chemistry majors, the potential impact of this activity is high; thus far, >300 students have already performed this laboratory exercise.

The main idea of this exercise is for students to have the opportunity to design and synthesize a molecule that could have antimicrobial activity. After reading a primary scientific paper on antimicrobial peptides, students synthesize their own peptide that they hypothesize will have antimicrobial activity based on its chemical structure and potential interactions with the bacterial membrane. The students characterize their products by analyzing liquid-chromatography mass spectrometry (LC-MS) and antimicrobial bioassay data collected for their peptide (by the TAs and instructors) to evaluate whether they synthesized the correct molecule and whether their initial hypothesis was valid. Students completing this exercise gain hands-on experience with solid-phase chemistry, a widely-used technique in the chemical sciences, while also developing hypotheses and executing experiments of their own design.

Through a variety of assessments, I found that the laboratory exercise largely met my intended learning outcomes, which included improving student knowledge of peptide chemistry and characterization of synthetic products by LC-MS analysis. Through a self-designed survey on student attitudes toward the Second-Semester Organic Chemistry laboratory experience, I also learned that compared to the other labs they completed during the course, a higher percentage of students: strongly agreed that the peptide lab helped them understand experimental organic chemistry, strongly agreed they enjoyed the lab, and strongly agreed that the lab provided useful preparation for subsequent lab courses. Working with Prof. Katy Muzikar, Prof. Tom Vasquez, Prof. Deb Mashek and Cristina Saldaña (PO '15), the development, implementation and evaluation of this laboratory was written up and published as a peer-reviewed manuscript in the *Journal of Chemical Education.*

1. Hoskins, S. G., Stevens, L. M. & Nehm, R. H. Selective Use of the Primary Literature Transforms the Classroom Into a Virtual Laboratory. Genetics 176, 1381–1389 (2007).
2. Hoskins, S. G. But if It's in the Newspaper, Doesn't That Mean It's True?" Developing Critical Reading & Analysis Skills by Evaluating Newspaper Science with CREATE: An activity to help students "decode the data. The American biology Teacher 72, 415–420 (2010).
3. Hoskins, S. G., Lopatto, D. & Stevens, L. M. The CREATE approach to primary literature shifts undergraduates' self-assessed ability to read and analyze journal articles, attitudes about science, and epistemological beliefs. CBE-Life Sciences Education 10, 368–378 (2011).
4. Gottesman, A. J. & Hoskins, S. G. CREATE cornerstone: introduction to scientific thinking, a new course for STEM-interested freshmen, demystifies scientific thinking through analysis of scientific literature. CBE-Life Sciences Education 12, 59–72 (2013).

Julius B. Lucks
Chemical and Biological Engineering
Northwestern University

I am deeply passionate about teaching the next generation of scientists and engineers. It is immensely rewarding to train these future leaders to responsibly develop solutions to challenges faced by our global society. My teaching in the chemical sciences has spanned course development, classroom instruction, undergraduate and graduate mentoring and development of international teaching environments. Philosophically, I aim to link subject fundamentals to the excitement experienced in cutting-edge research. By connecting students with the most stimulating research questions, I hope to inspire them to invest themselves in mastering the fundamentals.

Description of Educational Activities
<u>Excellence in undergraduate teaching.</u> I began undergraduate teaching as an Assistant Professor at Cornell University, prior to moving to Northwestern. At Cornell I taught the junior-level chemical engineering heat and mass transfer course four times. This was a particular challenge for me: prior to joining Cornell's faculty, I had never taken a ChemE course! This reality combined with classrooms of exceedingly smart and driven Cornell undergraduates kept me racing to use my knowledge of chemistry and physics to teach the students (and myself). But disadvantage turned to advantage: I began teaching the principles of heat and mass transfer from a hybrid chemistry-physics-chemical engineering perspective that gave students a deep understanding of the fundamentals and placed them in a real-world engineering research and application context.

Seeing students grasp these multiple perspectives to achieve 'aha' moments catalyzed me to pursue this multidisciplinary, research-context approach, which proved resoundingly successful. After year three, I received the Mr. and Mrs. Richard F. Tucker `50 Excellence in Teaching Award, the Cornell Engineering College's highest teaching honor. The most encouraging feedback came directly from students: "The professor was absolutely amazing. He was always eager to explain concepts and help the students obtain a better understanding of the material"; and "Professor Lucks was probably the best professor I've ever had at Cornell."

Teaching undergraduates gives me a way to help someone achieve a sense of true scientific understanding for the first time, while simultaneously enlarging my own scientific boundaries. Carrying this lesson forward, I am working with my colleagues at the Northwestern Center for Synthetic Biology on ways to transform the way we teach undergraduates the principles of synthetic biology. Through classroom teaching and undergraduate research experiences, I intend to create a framework for teaching quantitative principles of synthetic biology by describing biological phenomena using the core chemical engineering concepts of thermodynamics, kinetics and transport – a perspective which allows students to integrate and learn biological chemical principles without having to memorize, merely for its own sake, a mass of biological details.

Excellence in undergraduate research. The most influential aspect of my chemistry education at UNC Chapel Hill was my opportunity to conduct undergraduate research, where the challenge of research combined with the mentorship by professors made me thrive. As a result I have dedicated myself to giving undergraduates the same type of mentorship, and have witnessed some students go beyond what I thought possible. As I continue this tradition at Northwestern, I plan to reach beyond chemical engineering to integrate research opportunities for chemistry students, as well.

I have been fortunate to supervise 14 Cornell undergraduates (seven women) who have made significant impact, with four peer reviewed papers co-authored by four different undergraduates. Two have won NSF graduate fellowships, three are in top graduate programs at Stanford, UC Berkeley and Georgia Tech, three have landed coveted positions at biotechnology companies, and four have won research prizes.

However, these student achievements do not tell the whole story. *I believe the legacy of my lab will grow exponentially through the people I train, who, if I have done it right, will perpetuate a tradition of strong mentorship as they assume leadership in their own careers.* Borrowing a concept from my graduate mentor Dudley Herschbach (Harvard Chemistry), students in my group work *with* me, never *for* me. I tell students even before they join my group that one of my roles is to inspire them to be as excited about their work as I am. I have observed many undergraduates go from merely curious about research to consumed by a passion for discovery. Some have made breakthroughs: Tim Abbott (now at Stanford), obtained some of the first ever data on the structure of RNA molecules inside cells. Perhaps because of my philosophy, I now find I am known for my undergraduate research mentorship; undergraduates from around the country seek summer positions in my lab (opportunities for which I have budgeted Dreyfus Teacher-Scholar funds).

Advances and innovation in chemical education. In 2012, I was invited to co-create the first Cold Spring Harbor Laboratory Summer Course in Synthetic Biology (CSHL SynBio), a singular honor. For over 65 years, CSHL courses have marked a milestone in emerging fields by defining a research agenda and training researchers and teachers. Notable past courses include Max Delbruck's phage course, which helped crystallize molecular biology and led to several Nobel Prizes. The creation of CSHL SynBio marked a transition for synthetic biology, and, remarkably, has already helped nucleate a new teaching methodology for this area.

While a prestigious opportunity, the task of conceiving and running CSHL SynBio was not easy. In fact, it fell on me and my three co-founders to create the entire course, a process which took several years. Inspired by my earlier experiences, I led the team to emphasize teaching through research. This is a principle that is still carried forward in the course, as instructors bring research projects from their labs to teach students concepts while immersing them in the thrill of discovery. This has been a resounding success, with even a publication with students from the course (Takahashi et al. ACS Synth Biol, 2015, 4:503-515) outlining a research breakthrough and our development of a research-based synthetic biology teaching tool. In addition, the course has enabled me to be a teacher of teachers, which has further disseminated my teaching strategies – one of the star students of the course was a professor at Middlebury College, who is now bringing synthetic biology to his undergraduate curriculum.

Summary My past teaching success has made me more committed than ever to education in the chemical sciences because of the enormous, amplified impact great teaching and mentorship can have on the next generation of leaders. Support from a Camille Dreyfus Teacher-Scholar award will enable me to chart new directions for teaching synthetic biology from a chemical sciences perspective, and to increase my use of immersive research experiences to train undergraduates from around the country.

Thomas E. Markland
Chemistry
Stanford University

My enthusiasm for integrating the latest developments in education and research into my teaching is something forms the basis of my approach to chemistry education that I am continually striving to build on. At Stanford I have developed and taught three courses: an undergraduate course introducing freshman students to research, a majors course in the undergraduate physical chemistry series, “Statistical Mechanics, Transport and Kinetics”, and a graduate course I introduced on molecular modelling. My teaching developments at Stanford have placed particular emphasis on the introduction and integration of molecular simulation and visualization into the physical chemistry program. When I began at Stanford in 2011 none of the physical chemistry series of courses utilized molecular simulation, and now all courses in this stream incorporate the MATLAB-based experiences that I have developed in my undergraduate and graduate courses. This and my other teaching achievements led to me being awarded Stanford’s Humanities and Sciences Dean's Award for Distinguished Teaching in 2015 (only the third time this had been awarded to any Chemistry department professor in the past decade).

I have also been involved more broadly in teaching and advising at Stanford by acting as pre-major advisor and have been actively involved with Stanford’s Center for Teaching and Learning (CTL) activities to exchange ideas with other faculty and to make myself aware of all the developments in education research ranging from the use of technology in the classroom, to understanding student motivation. As detailed below, I also organized and lectured at CECAM schools on path integral quantum mechanics to introduce graduate students from across the world (participants from 14 countries) to the techniques of this advanced topic that is not typically covered in graduate courses. In addition, I have also hosted high school teachers in my lab to develop teaching aids for local schools.

Undergraduate education: In my undergraduate teaching I have taught the physical chemistry course “Statistical Mechanics, Transport, and Kinetics” (Chem 175). In this course I have added new topics with emphasis on interacting systems, dynamics and structure of liquids, classical statistical mechanics and Marcus theory of electron transfer because they play a major role in understanding modern chemistry but are not typically included in undergraduate courses. One of my major developments is to introduce molecular simulation into the course, where the students use and create MATLAB programs to visualize the structure and dynamics of molecular systems. This allows me to cover topics which are not as amenable to analytic treatment but form a vital part of chemistry such as interacting molecules, dynamics and structure in liquids, and chemical reactions. Rather than just creating standalone simulations, my approach has been to create simulation tools that can be used at multiple different levels of the curriculum where additional complexity is revealed to students as they progress in their studies. For example in earlier courses they watch molecules collide and exchange energy and change properties via a graphical user interface and in later courses they edit the code to extract new properties and add new functionality. These represent a different direction to many other developments in this area by providing a tool that can be used at multiple different levels of education and removing the black-box aspect present in many other simulation tools (e.g. PhET simulations).

I have taken advantage of many of the resources at Stanford to constantly improve my teaching and knowledge of chemical education. To develop my undergraduate courses, I attended Stanford's Course Design Institute, where I spent a week working with educational specialists from Stanford's Center for Teaching and Learning along with other young faculty who were developing their own courses on completely remaking all the course materials and significantly changing and updating the content. This experience was transformative to the way I think and approach my teaching, as it introduced me to the latest developments in educational research and various methods for motivating students. As such, I base my course around understanding, at a molecular level, which chemical product one will get in a reaction, and how this can be controlled by equilibria or kinetics. I do this by posing chemical reaction outcomes that might at first seem counterintuitive and then showing how molecular level concepts allow one to address these questions. I also frequently show simulation videos of research currently taking place at Stanford to aid in the integration of computational active learning components in the course. By doing this, even students whose primary interests are not in physical chemistry have appreciated how the course content fits into their understanding of chemistry as a whole. This has been reflected in end of course evaluations, where the students' rankings of their "ability to engage" with the course material have averaged 4.4/5 during the years I have taught the course (4=Very Good and 5=Excellent), and are echoed in the student's written comments with words such as "approachable" and "engaging" appearing frequently. Perhaps my biggest satisfaction comes from the fact that each year a number of students approach me about taking graduate courses in statistical mechanics and computational modeling (that are not required for the chemistry major), as they have become so enthused by the experience.

Graduate education: I introduced a Stanford graduate course: "Topics in Molecular Modelling." In this course I introduce the important role of simulation in modern chemistry by highlighting the interaction and impact that simulation has with all areas of chemistry. Emphasis is placed on understanding the statistical mechanics and quantum mechanics underlying these areas, so students can appreciate when these methods can (and cannot) produce accurate elucidation or predictions of chemistry. To encourage students to think about the role all forms of simulation have in their work, part of the course assessment is a simulation proposal and practical where students research existing simulations for a system of their choosing (with the idea that it is related to their area of research) and then propose and perform a calculation of it. This is combined with analytic as well as practical questions based on MATLAB, where they get the opportunity to see and edit the code, as well as with using codes such as OpenMM and Gaussian for more advanced calculations.

Other chemical education and teaching outreach: Outside of Stanford, my teaching has catered to both advanced graduate teaching in the form of lecturing at CECAM schools on path integrals quantum mechanics and also local high school educational developments.

In particular, I organized a week long CECAM school on "Path Integral Quantum Mechanics: Theory, Simulation and Application" in June 2016 which brought together students, postdocs and experienced researchers wishing to learn the basics and recent developments in real and imaginary time path integral quantum mechanics methods and start setting up their own projects. The school was organized as a series of introductory pedagogical lectures given by experts in the field each morning followed by computational practicals on topics covered by the lectures each afternoon, thus providing broad hands-on experience supervised by expert researchers. I was also a lecturer at the CECAM School on “Path Integral Molecular Dynamics” in June 2012 where I gave 3 hours of lectures to graduate students on how to implement and use path integral methods.

I also hosted a local high-school teacher in my lab during the summer to develop high school lesson plans that extend the molecular visualization tools I have developed in my graduate and undergraduate teaching. This led to the development of two new guided inquiry computational labs: one on visualizing ice nucleation from liquid water and another on the structure of ionic crystals that can be downloaded from the Stanford Chemistry Outreach website. These are being used throughout a network of local high schools.

Future Developments: I am currently working with the Chemistry department lecturers and faculty to extend chemical simulations and visualization into earlier courses in the chemistry series. We are achieving this by providing a graphical user interface to the MATLAB codes that I have developed for my more advanced courses and also by integrating them into Jupyter notebooks. Our objective is to use the same MATLAB codes across multiple courses so that students obtain a deeper knowledge of the code as they proceed into more advanced courses. As this approach has already been proven to be highly successful across the physical chemistry courses, I believe this extension to earlier courses will be very beneficial to students. I am also developing a computational chemistry course for undergraduate students.

John B. Matson
Chemistry
Virginia Polytechnic Institute and State University

In joining the faculty at Virginia Tech, I was able to maintain my vision of becoming not just a scholar, but a teacher-scholar. In short, my goal is to create innovative, evidence-based learning environments in my classes at Virginia Tech and to encourage others to employ evidence-based approaches in their classes. To this end, my efforts focus mostly on the development of a very large flipped classroom. I have used some of these techniques in other classes, but I will focus here only on my undergraduate organic chemistry class.

Background and benefits of a flipped classroom

First described in 2000 in a college setting by Lage, Platt and Treglia, [1] the flipped classroom is a teaching method that implements video lectures to deliver content and uses time in class for problem solving—the opposite of a traditional classroom. It has several advantages over traditional classrooms. First, students can gain more from video lectures than traditional lectures because they can pause a video lecture to seek clarification from a textbook on points confusing to them. [2] This video lecture approach effectively prevents delivery of content too quickly for students to keep pace. Second, students benefit from working problems in the classroom under the guidance of a professor rather than working problems alone for the first time on a homework assignment. This immediate feedback accelerates learning but is often absent in the classroom. [3] Third, students can talk in class to their peers, who may be better able than professors to explain concepts that they have just learned. [4] The goal in most introductory college chemistry classes is to cover the first five levels of Bloom's Taxonomy on a topic (the highest level, Creating, is typically reserved for advanced or capstone classes). In an effective flipped classroom, students achieve mastery in Remembering and (to some degree) Understanding at home before class and tackle higher level skills (Applying, Analyzing, and Evaluating) during the class period. In contrast, a traditional classroom addresses these higher level skills mostly via homework problem sets. [5]

The benefits of a flipped classroom are realized most readily in small classes (<50 students) where the instructor can communicate with each student in nearly every class period. [6] When flipping very large classrooms (>150 students), several additional challenges arise. These challenges include 1) the rigid classroom structure available for most large classes (desks usually can't be moved in large lecture theatres); 2) providing an incentive for students to prepare before each class; and 3) the wide range of students' abilities in large classes.

Developing materials for a flipped classroom

My first experience with a large undergraduate class came in spring 2014. I taught Chem 2536 (Organic Chemistry II for non-majors) to 163 students and implemented a flipped classroom. I had never taught a large class before, so I sat in on several classes in the spring of 2013 to observe different teaching styles used by my colleagues. One instructor in particular caught my attention. Professor Rich Gandour, who had taught Organic Chemistry in a traditional lecture format for over 25 years, had begun experimenting with flipping his classroom in 2002. When I observed him in 2013, students spent most of the time in class working problems on worksheets that he had prepared. I was impressed by their attentiveness and focus; however, I also observed that students who did not grasp the basic concepts struggled because the class lacked effective content delivery. I spent the summer and fall of 2013 making animated video lectures to supplement the worksheets, and together Prof. Gandour and I refined the in-class worksheets through weekly meetings to ensure consistency with the videos and improve logical flow between concepts. I used these worksheets and approximately 70 videos of 4–8 minutes each in spring 2014-2016. Prof. Gandour and I continue to refine these materials to improve our classes, and we have shared these materials with other professors in our department who have used them to implement flipped classrooms themselves.

Approach to teaching organic chemistry using a flipped classroom

Even with the needed materials, the challenges listed above remain for teaching a large class using the flipped classroom approach. Overcoming these challenges required careful planning of how the class would be carried out, with a goal of maximizing learning for each student in the class. To accomplish this, I use several specific strategies:

First, I deal with the problem of classroom structure by including 2–3 undergraduate TAs (UTAs). UTAs encourage collaboration among students, motivate reluctant students to try problems, and answer students' questions. I encourage collaboration and interaction among students, UTAs, and me to make the class feel smaller.

Second, I encourage students to prepare before class by making the preparation as concise and straightforward as possible. Before each class students are asked to watch 2–3 video lectures and complete a short reading assignment. In my videos, I strive to be concise, using animations and edited scripts to reduce long explanations and keep students interested. I have received comments that students appreciate the length and conciseness of the videos. Several students have mentioned that they share them with friends in other sections of Chem 2536. Prof. Gandour also uses my videos in his major's section. In end-of-semester surveys that I conduct each year, >90% of students typically agree or strongly agree that the videos are helpful.

The third challenge of varied student abilities appears in every large class. I address this challenge using the in-class worksheets mentioned above. They are specifically designed to step students through a series of problems of increasing difficulty. For example, if the topic is a new reaction, the first question might ask the students to draw in only curved arrows in a pre-printed mechanism. The second question would then ask them to draw the entire mechanism for slightly different substrates, and the third might ask students to predict the products of a series of reactions. The fourth could be a multi-step synthesis that uses the reaction under discussion. I allow students a few minutes to work through each problem and then ask for a volunteer to show his or her answer (students receive extra credit points for volunteering). I correct any mistakes and take questions before moving on to the next problem. I have found that these worksheets, in combination with this classroom format, keep most students engaged and keeping up. The best students work ahead and volunteer for harder problems.

Survey results from 2016 class

To monitor how students respond to my flipped classroom approach, I ask them to complete a survey near the end of the semester. This survey is distinct from the end-of-semester survey administered in all classes and has just a few questions along with an opportunity for students to make suggestions. In general, students like this model. My most recent survey in spring 2016 (52% response rate) shows that:

- 93% of students spent some time preparing for class, with 49% spending at least 20 minutes preparing before each class meeting.
- 98% of respondents strongly agreed or agreed that they were more engaged during class than they would have been in a traditional lecture style version of this class.
- 93% of respondents strongly agreed or agreed that the flipped classroom helped them learn the material much better or better than in a traditional classroom.

Dissemination of flipped classroom model

I have attended several campus workshops with goals of improving my flipped classroom and sharing my experiences with other professors. These include "Learnability – What It Is and How To Get It" (a half-day workshop), "Read, Reflect, Connect: Examining Our Lectures" (a month-long online class) and "Using Active Learning Strategies to Transform your Lectures" (a half-day workshop). While each workshop has taught me something about flipped classrooms and active learning, I have also found the workshops successful for encouraging other professors to consider flipping their classrooms.

I also presented this model in summer 2016, along with Prof. Gandour, at the Virginia Tech Conference on Teaching Large Classes. Rather than simply describe our method, Prof. Gandour and I used this opportunity to actively engage conference participants. We put ~25 participants (most of whom were not chemists) through an example class, including a 5-minute video lecture and a 20-minute worksheet. We then described our experience with this approach, the challenges we aim to address in the future, and took questions from participants. Overall the response was quite positive.

Broader impacts

The broader impacts of the flipped classroom approach in organic chemistry are substantial. I frequently hear from top students in my class that they struggled in the first semester of organic chemistry. Based on these anecdotes, I conclude that a flipped classroom takes the fear out of learning organic chemistry, and by association, chemistry in general. This may lead to doctors, dentists, nutritionists, and other professionals who have a better understanding of the natural and unnatural organic compounds that we encounter every day, and therefore provide better treatments to their patients. Perhaps more importantly, considering the breadth of students in non-majors organic chemistry classes, these efforts may help to reduce 'chemophobia' among adults. Achieving this difficult goal, considering the current public distrust of all things deemed to be 'chemicals,' may avoid more crises due to chemophobia such as the current anti-vaccination movement. The public must have a better understanding of both the risks and the benefits of the chemicals that they touch, eat, and inject every day. This can only occur though effective, evidence-based teaching methods tailored to student learning.

---

(1) Lage, M. J.; Platt, G. J.; Treglia, M. Inverting the classroom: A gateway to creating an inclusive learning environment J. Econ. Educ. 2000, 31, 30.
(2) Bergmann, J.; Sams, A. Flip Your Classroom: Reach Every Student in Every Class Every Day; 1st ed.; International Society for Technology in Education, 2012.

(3) Knowing What Students Know: The Science and Design of Educational Assessment; Pellegrino, J. W.; Chudowky, C.; Glaser, R., Eds.; National Academy Press: Washington, DC, 2001.
(4) Lasry, N.; Mazur, E.; Watkins, J. Peer instruction: From Harvard to the two-year college Am. J. Phys. 2008, 76, 1066.
(5) McGivney-Burelle, J.; Xue, F. Flipping Calculus PRIMUS 2013, 23, 477.
(6) Freeman, S.; Eddy, S. L.; McDonough, M.; Smith, M. K.; Okoroafor, N.; Jordt, H.; Wenderoth, M. P. Active learning increases student performance in science, engineering, and mathematics Proc. Natl. Acad. Sci. U. S. A. 2014, 111, 8410.

Kang-Kuen Ni
Chemistry and Chemical Biology
Harvard University

1. Curriculum Development for Chem 160 ("The Quantum World")

Since arriving at Harvard, I have been fortunate to have opportunities to interact with both grad-uate and undergraduate students in the classroom. A major educational goal for me in the last 3 years has been new curriculum development. This concerns the course of quantum mechanics for undergraduate chemistry students, which is a required course for all chemistry concentrators. The traditional way of teaching quantum mechanics that focuses on analytical problem solving to gain physical intuitions has tremendous value. However, from my own experience, when I face a realistic quantum problem for my research, I do not necessarily know how to solve it from the quantum courses I took both as an undergraduate and as a graduate student. In many cases, I have to resort to different textbooks or literature searching for numerical approaches to which I was never introduced. Learning to solve problems numerically helps further solidify my own understanding of quantum mechanics concepts. For this reason, my colleague, Alan Aspuru-Guzik, and I introduce numerical approaches and numerical homework exercises. Another benefit of this approach is that chemistry students will have a formal opportunity to learn to program and to use computers for scientific applications. Learning to program is not only a useful skill in this modern world, but also great training for logical thinking. Last, and probably the most exciting aspect is that introducing programming and including computers for coursework make it easier for students to visualize quantum mechanical wavefunctions. Concepts such as quantum tunneling and superposition can be illustrated further by animating the time evolution of the wavefunctions. This approach makes the chemistry curriculum more coherent because many students in their prior chemistry classes, organic and inorganic chemistry, were exposed to a pictorial emphasis to gain "chemical intuition." I would say the traditional analytical and the new pictorial approach are complementary. Ideally, students will be exposed to both approaches. In reality, students can choose between the more traditional approach offered by the physics department or the more pictorial approach offered by the chemistry department.

To summarize, to engage students in our undergraduate "quantum mechanics for physical chemistry" course, we are developing a new approach that integrates quantum mechanics, chemical physics, and computational science into one course. We use different quantum degrees of freedom of molecules to illustrate different "analytical" solutions of quantum mechanics problems. We then want to solve more realistic problems that often cannot be solved analytically. With the advance of computational power, we can address those questions on computers. Students are introduced to these exercises through homework problem sets to be completed on their laptop computers. At the same time, utilizing computers, we can illustrate non-intuitive quantum concepts through animations. Students can visualize properties of molecules through 3D graphing software (for example, graphs of molecular orbitals). My hope is that this new approach will motivate students to learn, and to want to dig deeper. Quantum mechanics is fundamental in chemistry and is something that we can all build our "chemical intuition" on.

The feedback that I got from the students going through this course in the last 3 years has been increasingly positive. Many students who initially started with no programming experience and with a lot of fear, went away with confidence and a sense of accomplishment that they were able to complete these programming exercises. Our focus on helping them with problem sets that tightly connect to key concepts illustrated in lectures enhance their learning over what otherwise would be an exam-based course.

Asking students what they have learned and what is the most effective aspect of the class through a mid-semester survey this semester, a couple example answers are below: "1. I have learned how to use Python to model concepts that we are learning. 2. A building up of quantum mechanical behavior from a single particle in 1D to chemical reactions that occur in 3D space. 3. How to apply these concepts to the real world through real-life examples." "(The most effective aspect is the) Python exercises, as we got to apply what we have learnt in lectures to practical issues. Also we got to experience a taste in coding."

Seeing these positive responses, I could not be happier. Tremendous amount of time and effort have been put into designing this modern curriculum. If it is assessed as successful, I believe this could be adapted to other universities and provides and complements quantitative training for a new generation of chemists.

For myself from teaching, I really enjoy the challenges that the students raise during lectures or office hours and seeing them understand new concepts after putting in a lot of effort. I continue to strive to be a better teacher.

2. Undergraduate Research

My lab welcomes 2-3 undergraduate students to perform research per academic year. I especially encourage freshmen to join and get excited about research as early as possible. Undergraduate students in my lab work on a range of hands-on projects from designing and constructing electronics and mechanical parts to optics. The first paper that was published from my group was first- and second-authored by undergraduate students. [1] With an outreach program at Harvard, I will bring a female undergraduate from outside of Harvard per year to come in for summer research. Being a female scientist myself, I understand the challenges working in the hard sciences where the fields have predominately male scientists. An important focus that I have been pursuing is to develop a positive culture and work environment for everyone in my group.

---

[1] W. G. Tobias, J. S. Rosenberg, N. R. Hutzler, and K.-K. Ni, "A low-temperature external cavity diode laser for broad wavelength tuning," Review of Scientific Instruments, vol. 87, no. 11, p. 113104, 2016.

Eranda Nikolla
Chemical Engineering and Materials Science
Wayne State University

The involvement with educational and outreach programs in chemical sciences has been one of my top objectives and a source of inspiration for the pursuit of an academic career. My interest in teaching stemmed early on from my interaction with high school students from the Detroit Area, while I was an undergraduate student at Oakland University in Rochester Hills, MI. While at OU, I was actively involved with the DAPCEP (Detroit Area Pre-College Engineering Program) program on campus. The program's main objective was to teach and inform underrepresented high school students from the Detroit Area regarding programs in sciences and engineering. DAPCEP was designed to promote problem solving and critical thinking skills among underrepresented high school students and inspire them to pursue careers in science and engineering. I was involved with designing problems and activities that helped promote these skills. This experience was inspirational and it contributed significantly to my desire to pursue a PhD in chemical engineering, so I could have opportunities in the future to impact the education and careers of science and engineering students, especially those from diverse backgrounds.

My teaching philosophy focuses on integration of cutting-edge research ideas and projects into student learning as an effective way of engaging them in the classroom and training them for the jobs of the future. I strongly believe that, in addition to teaching students the fundamentals of a particular subject, it is also very important to incorporate research-related projects and activities to get them engaged and able to apply the principles learned in class. For the first time at Wayne State University, I organized a Chem-E-Car team for the undergraduate students, in order to get them engaged in teamwork and to apply principles leaned in their kinetics, thermodynamics and engineering classes. The students designed a car that started, ran and stopped based on chemical reactions. The team was very successful in designing their car, and they competed for the first time in the 2015 regional competition organized by the American Institute of Chemical Engineers (AICHE).

In addition, I have developed, along with 4 other faculty members at WSU, an undergraduate Certificate Program in Nanoengineering (funded by National Science Foundation (NSF)), which is based on integration of teaching and research across chemical sciences and engineering disciplines. This is the first training program in nanoscience/nanotechnology in the Metro Detroit and surrounding areas. We have developed four new courses. One of these courses is a Capstone Design/Research Experience in Nanoengineering, which engages students with research in one of the faculty laboratories. I have mentored over 10 undergraduate students as researchers in my laboratory, and they have highlighted the research experience as a very instrumental part in advancing their learning. The program has been successfully running for approximately two years and has been implemented as part of the undergraduate curriculum at WSU.

One of the true pleasures of an academic career is the complementary balance between teaching and research. While research efforts (e.g. proposal writing) often require considerable time to bear fruit, teaching offers immediate feedback from students, and immediate satisfaction when it is done well. For example, as I was finishing up my Fall semester work teaching "Advanced Reaction Kinetics", I was thrilled and energized to receive this note from a student in my class: "You are the best Professor I have ever come across in my life till now. I learnt a lot from your class, which I never understood in my undergraduate. This mail is my gratitude to you for being such an awesome guide and a wonderful human being. Thank you."

I am also a strong believer that providing inspiration and guidance to students early in their educational path is critical toward building their desire to pursue higher degrees in chemical sciences and engineering. This is particularly important for female students. One of the challenges that women experience when it comes to careers in chemical sciences and engineering is an environment lacking the appropriate diversity. It is my firm belief that a diverse core group of students creates an environment that promotes the desire to learn and excel as well as fosters a more communal and cooperational, problem-solving atmosphere that benefits all students. Below, I discuss a number of strategies that I have implemented to reach out to students at the local K-12 Detroit and surrounding areas and local community.

Activities with K-12 students: I am actively involved with the Gaining Options-Girls Investigate Real Life program (GO-GIRL) at WSU since 2011, when I joined WSU. GO-GIRL was launched through funding from NSF and has served over 700 adolescent girls from the Metro Detroit area by engaging them in science, engineering and medicine. The program targets a diverse population of girls, with participants from a wide variety of racial, ethnic, and social economic backgrounds; the urban demographics of Detroit ensure a large population of African Americans. Last summer my research group and I organized and hosted the GO-GIRLs Keeping in Touch Workshop "Material Girls Get Energetic!". The event hosted approximately 50 female students, with diverse backgrounds, from the local K-12 Detroit schools. This workshop began with a presentation on energy systems followed by a hands-on lab activity where students built their own electrolytic cell to power an LED. The workshop was very successful and inspired over 50% of the female students to consider careers in chemical sciences and engineering. Another workshop of a similar nature is planned for 2016.

I have begun independent collaborations with local high schools - Pontiac and Bethune Alternative Academy High Schools, University Liggett School, and Troy High School - to develop activities and projects to engage their students with chemical sciences and engineering. This is especially significant for Pontiac and Bethune Alternative Academy High Schools, which are predominantly populated by African American and Hispanic students with very low rates of college enrollment. I have visited the schools and given a number of presentations. I work closely, and keep in touch, with teachers from these schools to develop activities to enhance students' desire to pursue a higher degree in STEM fields. I have also hosted two high school students as researchers in my laboratory.

Outreach activities with the local community: In order to reach out to the local community, I have developed a partnership with the Michigan Science Museum. My group took part in the "Ask the Expert" series, where we talked about "Energy and Environment" along with hands-on demonstrations. Participants were local students and their parents. The objective was to increase awareness of the local community regarding energy and environment and the role of chemical sciences in these areas. I have also built an independent partnership with the Balkan American Community Center, a local non-profit organization that reaches out to first generation Americans and helps them with successful integration in the educational/social system. I have given a number of presentations to encourage and inform first generation Americans from disadvantaged backgrounds, many of whom are prospective first-generation college students, potentially seeking higher degrees in chemical sciences and engineering. My research group has also hosted a number of laboratory tours for these students to inform them regarding research and career options in chemical sciences.

Research activities with undergraduate students: During my years at WSU, I have made significant efforts in involving undergraduate students from underrepresented groups in research through the Initiative for Maximizing Student Development (IMSD) and The Michigan-Louis Stokes Alliance for Minority Participation (LSAMP) Programs. These programs focus on stimulating and facilitating the progress of a diverse group of students interested in pursuing graduate study and careers in research related to chemical sciences. In addition I have worked closely with the Society of Women Engineers (SWE) at WSU to recruit undecided women undergraduate students to work in my laboratory. These efforts have led to a number of female undergraduate researchers (Lisa Schalm, Enxhi Xhafa, Monty Diaz, Brunna Souza, Suzana Meira, Mariana Souza, Samarah Novas, Isabela De Souza, Bruna Araujo, Marisa Leney) working in my laboratory. The undergraduate students have been paired with graduate students and assigned research tasks with realistic goals that could be completed within a clear time line. A number of these students have presented their work at national meetings of the AICHE, and several have also published with me peer-reviewed journal articles.

Michelle A. O'Malley
Chemical Engineering
University of California, Santa Barbara

As the first female Assistant Professor in the Department of Chemical Engineering at UC-Santa Barbara, I strive to serve as a role model to encourage women & underrepresented groups in STEM. Of equal importance to me is to bring research experiences to every undergraduate student – either by training them in my lab, or by bringing cutting edge research into to the classroom. Below I detail some examples of my commitments.

UG Research Training and Scholarship Development. During my time at UCSB, I have found fulfillment by mentoring several undergraduate research projects in my laboratory. To date, I (and members of my lab) have trained 26+ undergraduate students, including 13 women; many of these students are also participants in minority strengthening programs (INSET, SABRE, RISE) on campus. In the past two years, all graduating seniors from my group have gone on to attractive positions in industry (Merck, Genentech, Baxter), or to graduate programs (Princeton, Stanford, Delaware) – many have also earned co-authorship on prominent research manuscripts from my lab. I consider this an incredibly positive experience on both sides.

In addition, I have also worked to strengthen the pipeline of UCSB Chemical Engineering students who transition to the biopharmaceutical industry. For example, Amgen is a major potential employer of our students in California. Two years ago, through a grant proposal, I established an Amgen Scholars Program in the Chemical Engineering Department at UCSB. Under this program, an Amgen Scholar is selected by the department to conduct summer research in a ChE laboratory, and the scholar is also invited to network with Amgen employees at their headquarters in Thousand Oaks. Both Amgen Scholars trained to date (Erich Brodbeck & Charlotte Abrahamson) are now thriving in graduate research, and have extensive contacts at Amgen that they can draw from as they negotiate for future industrial positions. In subsequent years, I plan to work with Amgen to increase the number of scholarships awarded, and to use this opportunity to model additional industrial partnerships that can benefit our students.

Bringing Undergraduate Research into the Classroom. I have a passion for involving undergraduates in research, as it broadens their technical skills and provides them with an understanding for how basic science leads to innovation. However, due to the sheer volume of students seeking research opportunities, and the limited space in laboratories on campus, it is very difficult to accommodate all students. For this reason, I have taken a new path – to bring undergraduate research into the classroom. This past spring, I was excited to develop a new graduate/undergraduate course entitled “Omics-enabled Biotechnologies”, which involved a strong, collaborative research component that was carried out by students in the class. The course is the first of its kind at UCSB, and focuses on merging approaches in genomics, transcriptomics, proteomics, and metabolomics to tackle pressing issues in systems & synthetic biology. Together, students analyzed the sequences of 4 novel genomes from biotechnology-relevant strains of archaea; materials & sequencing supplies were generously sponsored by an educational grant that I submitted to Illumina. Through a series of collaborative meetings and classroom instruction, the students combined bioinformatic approaches in Illumina's BaseSpace and DOE's Kbase platforms to analyze the content of the genomes, with special emphasis on annotating the metabolic pathways that lead to methane production by the microbes. This effort resulted in the first full genomes sequenced on the UCSB campus, and revealed an unexpected, novel mechanism of methane biosynthesis in one of the strains. A manuscript authored by all of the students has been submitted to BMC Genomics (currently in revision), and initial reviews were incredibly positive. Overall, several undergraduates without prior research experience were able to see what it is like to work on an open-ended research problem, and witness their efforts translate into a scientific manuscript.

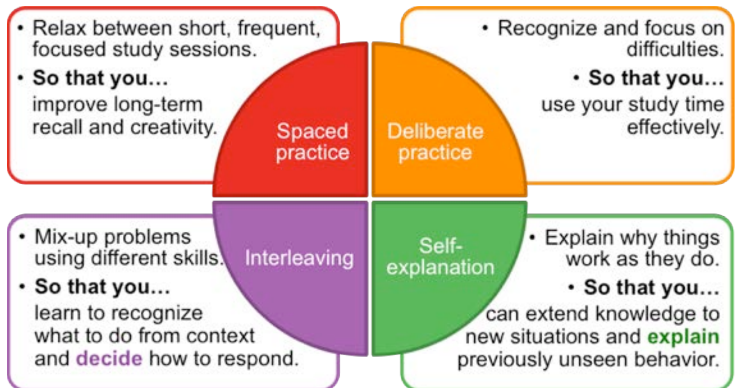
Overall, the strategy to involve undergraduate students in classroom-wide research is scalable – it does not require new facilities or one-on-one training, but rather engages students in research through collaborative mentorship and teaming. Another strength of this approach is that it is multi-disciplinary by nature. Initially, I piloted the "omics" course with 11 students from a diverse cross-section of campus, including students from Chemical Engineering, Mechanical Engineering, Materials Science, Marine Sciences, Earth Science, and Chemistry. I found that this mixture of educational backgrounds perfectly suited the goals of our study. For example, students who were strong in biochemical metabolism educated those who were experts in physiology; students who were proficient in redox chemistry collaborated with students who sought to verify strain phenotypes in the literature. Research communication skills were also put into practice as each student composed a research proposal based on tailored "omics" techniques that applied to their own research, and many students actually submitted these proposals via their associated PI. For many students, this was their first experience in grant proposal construction & for the undergraduates, it was also their first foray into research. I plan to extend this strategy in future years as a forum to scale the experience to 10+ UG students per class, and will collaborate with other professors to extend this model of education to other special interest topics in the chemical sciences.

Commitment to Outreach. Research pertaining to gut microbes is a natural pivot point to engage public interest in science and engineering. As such, we have established a partnership with the local Santa Barbara Zoo to strengthen outreach activates for children, adults, and families who visit the Zoo. For example, in the past year, my lab developed a 1-week science activity for ages 5-10 called Whose Poop is It? that teaches children the differences between the digestive system of ruminant and non-ruminant herbivores by dissecting fecal materials. This activity also highlights the role that ruminant herbivores have in carbon cycling and methane release. These types of experiences are critical tools to communicate scientific research to non-technical audiences, rather than the limited audiences reached by high-impact journals. Connecting with the public increases awareness and enthusiasm for science, which benefits all of us across the world. Given the nature of my research on anaerobic microbes, research from my lab has already been featured in the LA Times, BBC News, Newsweek, and Forbes among other sources, which I consider helpful in this regard. I plan to expand on these activities by participating as a speaker in an adult science night at the Santa Barbara Zoo, called At the Watering Hole, which features scientists and conservationists from the Central Coast region. The topic of discussion will be Microbes in Our Environment – to focus on the synergy we have with microbes, their role in carbon cycling, and the differences between pathogens and the non-infectious microbes studied by my research team.

Leadership & Student Involvement in Professional Societies. In the past several years, I have actively taken on leadership roles in several professional societies, with a keen interest in advancing undergraduate participation in these groups. For example, for several years I served as the faculty advisor to the UCSB Student Chapter of the American Institute of Chemical Engineers (AIChE). Last year, I took on the major role of 2017 Programming Chair for the American Chemical Society (ACS) Division of Biochemical Technology (BIOT). In this role, I am responsible for organizing all technical programming at the national meeting, including the establishment of student awards, networking opportunities, and travel subsidies. This year, my commitment has been to increase participation of undergraduate students in the BIOT-sponsored poster session, as well as visibility of a fledgling BIOT undergraduate student group that seeks to engage with professional members of ACS. Through this type of networking, my goal is to connect talented undergraduate students with professionals that can hire them in diverse industries across the chemical sciences.

Katherine E. Plass
Chemistry
Franklin and Marshall College

Research-supported learning principles have been shaping how I teach chemistry over the past few years. Informed by the literature on the learning sciences[1] and interactions with the Franklin & Marshall Faculty Center, I have been teaching students to organize and contextualize information, use self-explanation and testing as a way to achieve deeper learning, and develop their meta-cognition and intentional use of study techniques (scheme 1). This has resulted in past and on-going alterations to all of my courses, some of which are described below. These insights have also altered how I craft student research experiences.



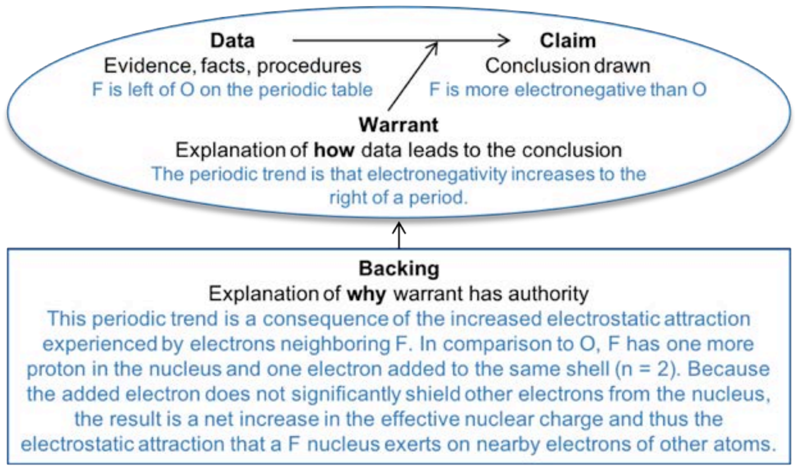
Scheme 1: Research-supported[1e] learning techniques I teach to students and organize course content to support.

General chemistry – Self-explanation, recall testing, and context

My sections of General Chemistry (1) have been revised to provide more opportunities for self-explanation and interleaving. Self-explanation is the construction of a story that explains "why"—why a problem is solved in a particular way or why a fact is true. It is not only a useful study skill, use of a theoretical model as the basis for self-explanation is a fundamental scientific skill that allows one to build a framework for new information and rationalize or predict experimental outcomes. It is the one study technique that enables students to better transfer knowledge and, for example, answer exam questions that are significantly different than those seen previously.[1e] Students are asked to give explanations for behavior in small groups in class and in homework, and this is modelled in class. Further revisions to homework and lectures support interleaving –the process of working on a mixture of different problem "types" during a study session. This technique encourages useful knowledge organization by teaching students to recognize when to apply what they have learned and its relationship to other concepts. Cues like chapter titles or problem order are being removed from many problems to allow practice with recognizing when to apply different concepts or problem-solving skills based solely on the problem content. This encourages deeper understanding of topics and makes it more likely that information will be retained longer and can be applied in different situations.

Inorganic chemistry – Argumentation

In "Inorganic Chemistry: Structure and Stability," my efforts have focused on the role of argumentation in predicting and rationalizing chemical behavior—an activity that strengthens the self-explanation and contextualization necessary for deep learning. Toulmin's argumentation scheme[2] (scheme 2) was introduced as a framework for distinguishing explanations that merely describe how one arrived at an answer from explanations that are



Scheme 2. Toulmin's argumentation scheme applied to the question "Which is more electronegative, O or F? Why?"

logically tied to a fundamental physical basis. Since implementing interactive lectures and student practice focused on generating logical and in-depth explanation, I have noticed that my students present better arguments and have an easier time extrapolating theories to new situations. I have also seen improvement in laboratory skills and written reports. Students better cite data, explain it's meaning, and logically describe how that data supports a conclusion compared to previous years.

Materials chemistry – Learning outside formal education

After graduation, students need to be able to learn outside of a classroom context and to recognize what they need to learn and how to do so independent of a teacher. My senior capstone course, "Materials Chemistry," used project-based learning techniques to help students achieve independent learning and improved meta-cognition. Two types of collaborative, project-based assignments are used to accomplish these goals. In the first, students read a paper, identify key concepts necessary to understand it, and then find and read background material as necessary. Students become progressively more independent in their ability to understand current chemical literature, the synthesis and characterization of solid-state materials, and how to find answers outside a classroom context. This process is repeated with four or five different papers over the semester. This repetition allows scaffolding such that early in the semester students have help distinguishing important questions and identifying the best resources to answer. The second project is preparation of an hypothesis-based scientific proposal in which students must recognize important scientific questions and craft experiments to address them. This assignment requires students to read the chemical literature critically, identify gaps in understanding, and formulate a hypothesis and plan to test it. Many assignments throughout the semester are devoted to helping students think critically about this process and to get feedback from their in-class writing group—a support group to help them through the writing process, other students who serve as "external reviewers," and me.

Undergraduate research (Summer research and CHM 390/490) – Scientific leadership

The goal of my research is not only to advance the field of nanochemistry, but also to train students to be leaders in their fields. A solid scientific background is necessary but not sufficient for this; students must also develop necessary supporting skills (schematic 3). Research students are asked to plan their lab work each week, reserving instruments and sharing goals on an electronic calendar. For each experiment, students are asked to plan carefully how it will be carried out and identify what questions will be answered in their collaborative electronic laboratory notebooks. This has proven to be useful for scheduling as well as an excellent context for discussing how to set goals and plan to achieve them logically and accurately. It has accelerated the transition from faculty-planned work to student-planned work. Peer-mentoring relationships are made explicit among more and less experienced students; more experienced students participate in the planning for new student training and work with the newer student on a very similar project. Focuses on planning and mentoring strengthen skills and make mentoring 4-5 undergraduates feasible. Effective visual and written communication is taught through preparation of sequenced research reports and preparation of research posters and presentations. Research reports are written in stages throughout the semester (CHM 390) or year (CHM 490), starting with guided literature reading, preparation of an introduction section, crafting of figures that clearly communicate the meaning of the data presented, and finally results and discussion sections that justify conclusions in detail. All research students now incrementally prepare posters with continuous feedback through biweekly group meetings where we focus on one figure's meaning and design.

Scheme 3:. Supporting skills required to be a scientific leader.

---

(1) Accessible secondary literature that I have found useful for myself and for students includes:

a. Brown, Peter C.; Roediger III, H. L.; McDaniels, M. A. Make it Stick: The Science of Successful Learning, 2014, Belknap Press.
b. Ambrose, S. A.; Bridges, M. W. DiPietro, M.; Lovett M. C. Norma, M. K. How Learning Works: 7 Research-Based Principles for Smart Teaching, 2010, Jossey-Bass.
c. McGuire, S. Y. Teach Students How to Learn: Strategies You Can Incorporate Into Any Course to Improve Student Metacognition, Study Skills, and Motivation, 2015, Stylus Publishing
d. Oakley, B. A Mind For Numbers: How to Excel at Math and Science (Even If You Flunked Algebra), 2014, Tarcher Perigee.
e. Dunlosky, J.; Rawson, K. A.; Marsh, E. J.; Nathan, M. J.; Willingham D. T. "Improving Students' Learning With Effective Learning Techniques: Promising Directions From Cognitive and Educational Psychology" *Psychological Science in the Public Interest* **2013**, 14, 4 – 58.

(2) Kulatunga, U.; Moog, R. S.; Lewis, J. E. "Argumentation and Participation Patterns in General Chemistry Peer-Led Sessions" *Journal of Research in Science Teaching* **2013**, 50, 1207 – 1231.

Corinna S. Schindler
Chemistry
University of Michigan

My current and future educational goals described herein rely on my previous experiences of leading regular outreach activities (FEMMES and Michigan Math and Science Scholars) for elementary and high school students and teaching four different courses (one undergraduate level and three senior undergraduate/graduate level) since starting my independent career at the University of Michigan (U-M). The overarching goal of my educational efforts is to spark and sustain an interest in STEM research areas across a range of ages, educational levels, and socioeconomic and cultural backgrounds.

"Ace 210" – Creating Active Learning Environments in Large Undergraduate Organic Classes
Personal Teaching Objective: To create an active learning environment in large introductory organic classes to improve informative feedback about students' progress and enable successful STEM learning experiences. Recent studies hold the traditional teaching practices common to the STEM fields partially responsible for the low success and retention rates of undergraduate science majors. More effective teaching strategies are "active learning interventions." Failure rates of students in traditional lectures increase by 55% over the rates observed in classes embracing active learning environments. In other words, a student in a traditionally taught class is 1.5 times more likely to fail. Importantly, active learning interventions were found to be effective across all class sizes and improve achievements for all students while disadvantaged and underrepresented minority students benefitted the most. However, successful implementation of active learning interventions in the context of large introductory science classes is often particularly challenging, as the prevailing perception is that adopting such practices in large classes is detrimental to lecture content.

U-M's introductory organic chemistry course, Chem 210, is taught in a traditional manner consisting of 4 lectures and an additional open discussion session per week. 10 graduate student instructors each hold 6 additional weekly discussion sessions. Due to the large enrollment and diversity of the students (~1400 students/semester), the course offers a tremendous opportunity to educate the next generation of scientists and implement strategies to retain students while promoting critical thinking and problem solving techniques. I taught this class for the first time in the Fall of 2015 and came to know students' struggles and frustration first-hand, mainly the lack of informative feedback about students' progress in learning and understanding of the course material. Problem sets to accompany each lecture did not exist and grades were exclusively based on students' performance in a total of 4 exams. Unfortunately, students did not realize gaps in their understanding until taking the timed exams, which caused difficulties in catching up with the class materials. Additionally, the quality of the graduate-student-led discussion sections varied significantly which caused additional frustration among the undergraduate students.

In the Fall of 2016 I taught Chem 210 for a second time and implemented two major changes resulting from my previous teaching experience. Specifically, I helped the graduate students structure their discussion sections into a 10-minute review that covered the key points of the past week's lectures and a 30-minute problem solving session. I provided the graduate students with a weekly summary of key points to review and problem sets with a range of difficulty. This change gave the graduate students confidence in their teaching abilities, resulted in better evaluations of our graduate-student-led discussions and increased attendance. The second change impacted the undergraduate students directly. I developed 35 problem sets with matching answer keys that were uploaded to Canvas after each lecture and covered the course material discussed that day. The problems also varied in difficulty to bridge the gap between the examples covered in class and the actual exams. Importantly, these problem sets were available to all students enrolled in all four sections of Chem 210. The feedback from the undergraduate students at the end of the semester was overwhelmingly positive ("I went in to organic chemistry thinking it would be a nightmare. However, it ended up being my favorite course." – This is a direct quote from a Chem 210 student in the Fall of 2016). Motivated by this experience, I am currently working towards implementing a program which I termed "Ace 210" as an online learning tool and an active learning strategy into Chem 210 (Fig. 1). Students will receive personal and immediate feedback about their level of understanding and progress in Chem 210. Similarly, the instructor will obtain regular information about their students that will guide mid-course adjustments when necessary. This online study tool is inspired by "Problem Roulette," a successful and well-received cloud-based study resource developed by faculty in the U-M physics department. Together with Prof. August Evrad (Michigan Center for Theoretical Physics) and the U-M Library, I am currently working towards converting the Chem 210 problems into weekly online problem sets consisting of 3 multiple-choice problems. Although students won't be graded on these virtual problem sets, based on my personal experience, I expect that the incentive of working with "Ace 210" to get detailed answer keys and explanations relevant to the course material will be high. The course instructor will obtain detailed statistics and reports on student performances using the easily available Google-based system already implemented for the physics "Problem Roulette." This information will be used to plan and

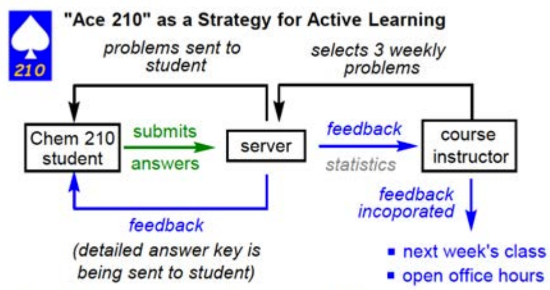


Figure 1: "*Ace 210*" - Functional view of the weekly online problem set. 3 problems will be selected weekly by the course instructor and send in a multiple-choice format to the students.

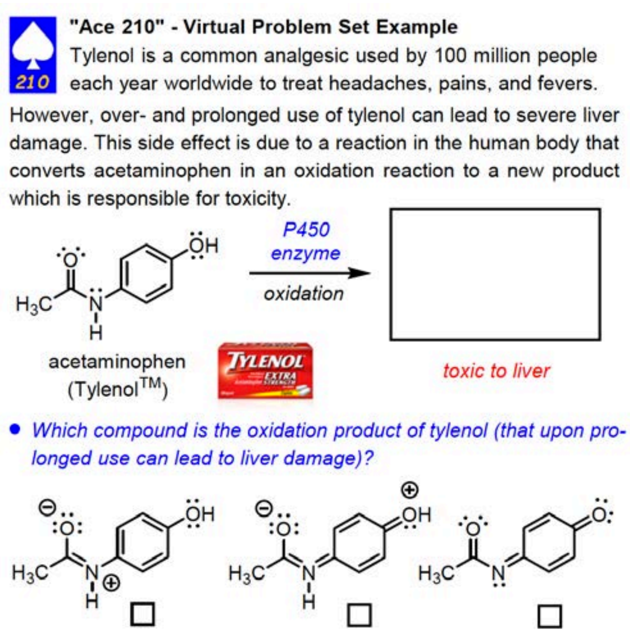


Figure 2: "*Ace 210*" - Example for a virtual multiple-choice question that relates an important synthetic organic problem to human health.

structure the following week's review session, as well as lectures and office hours. "Ace 210" will be the first step to creating a more active and engaging learning environment for students enrolled in introductory organic courses at the University of Michigan.

"Natural Products in Bloom" – Changing the Public Perception of Synthetic Chemistry
Objective: To develop an active learning strategy in an advanced synthesis class that aids students in activating prior knowledge to enhance learning in the classroom as well as help create and reinforce a positive public perception of synthetic organic chemistry. Plan of Procedure: Chem 541 is an "organic synthesis" class for senior undergraduates and first-year graduates (~25 students) which aims to teach retrosynthetic strategies to enable the construction of complex and important molecular structures from commercially available materials. This class is one of the most crucial, especially for students pursuing careers in the pharmaceutical industry, yet also the most frustrating for students; it requires students to predict products of chemical reactions while globally dissecting the ultimate target structure into easily accessible synthetic fragments. The frustration felt amongst even the most advanced students leads to lack of interest in the field of organic synthesis. Teaching this course for the first time in the Winter semester of 2016, I noticed that students particularly struggled with accessing prior knowledge, previous knowledge obtained in organic, physical organic, and mechanism-based named reaction classes. Recent studies suggest that linking new knowledge to prior knowledge provides more effective learning strategies. Based on my experience in Chem 541, I developed the "Natural Products in Bloom" program in collaboration with U-M's Matthaei Botanical Gardens to help students connect prior knowledge to new course material while demonstrating the importance of synthetic organic chemistry to the general public. Students in Chem 541 research specific natural products isolated from plants, with a focus on biological activity, ease of isolation, biosynthesis, and successful synthetic strategies that are presented to the class. Additionally, they create and display "infographics" at the botanical gardens that showcase the chemistry associated with the natural products and the importance of organic chemistry to life-saving medications (Fig. 3 - infographic example we developed for Taxol). The program impacts are two-fold: 1) these active learning interventions help students recognize and correct for inappropriate and insufficient prior knowledge which is essential to succeeding in class, and 2), this collaboration aims to generate a positive

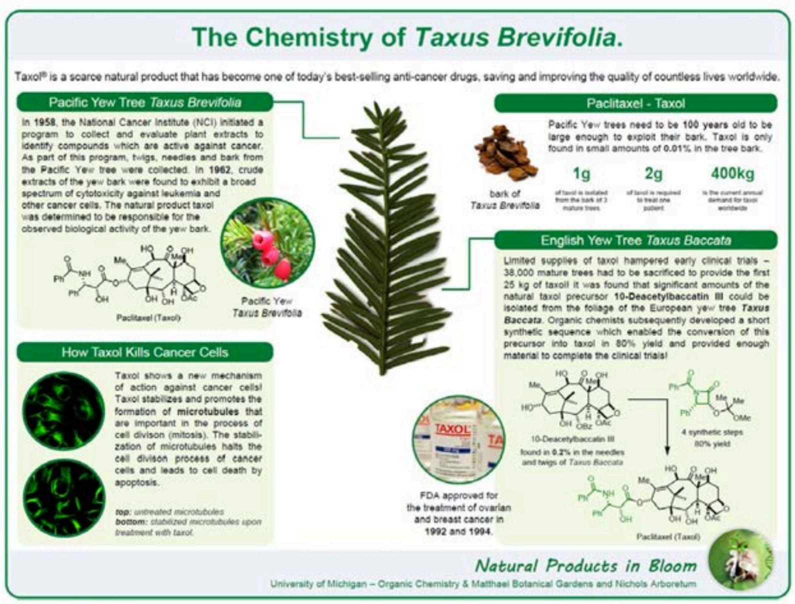


Figure 3. Example of an infographic developed by us for the "Natural Products in Bloom" Program with the Matthaei Botanical Garden.

perception of synthetic organic chemistry in the general public through infographics that relate the importance of organic chemistry to life-saving medications.

"Engaging Future Generations of Scientists"

My research group has been involved in two outreach programs since the Fall of 2013 aimed at elementary school girls (FEMMES) and high school students ("Michigan Math Science Scholars" MMSS). We have developed a two-week chemistry course to excite high school student for a career in chemistry and have hosted this course 5 times over the past 3 years.

Mohammad R. Seyedsayamdost
Chemistry
Princeton University

One of the main reasons I have decided to pursue an academic career, aside from the thrill of chemical discovery, is academic teaching. Formal teaching provides a logical context for research, which in turn informs and stimulates classroom teaching. As such, teaching and research go hand-in-hand and, in training the next generation of scientists, it is paramount that we provide both classroom (or theoretical) and laboratory (or practical) education. Bidirectionally connecting classroom and laboratory training has been my teaching philosophy at Princeton, a mindset very much in line with that of the Camille Dreyfus Teacher-Scholar Awards Program.

Classroom Teaching

At Princeton, I have taught two graduate-level chemical biology courses and experimented with different styles of didactics. In one course, a broad survey course of the various methods employed in chemical biology (CHM538), I used PowerPoint slides to convey the lecture material. In a second course, which focuses on the discovery, functions, and biosynthesis of secondary metabolites (CHM541), I have presented exclusively in a chalk-talk format. Both styles have their merits, and by experimenting, I have learned what types of lectures warrant which kind of presentation style. I have also found that, in addition to a deep knowledge and understanding of the topic of discussion, a passion for teaching and communication of knowledge in an interactive style is the best way to convey the course material. Passion is a common denominator for success in teaching and research. Therefore, choosing what topics one is passionate about in the laboratory and the classroom, is the first step in being a successful Teacher-Scholar.

Naturally, one of the most important indicators of my performance as a teacher is student participation and evaluation. As such, I have eagerly read student evaluations and treated them as constructive criticism to improve my didactic techniques. Over the past five years, I have accumulated an overall evaluation score of 4.5 out to 5.0, one of the highest in the department, which suggests that while there is room for improvement, I am on the right track.

My courses have been primarily attended by graduate students, on average ~75% graduate and 25% undergraduate students. Seeking an opportunity to engage in undergraduate education, I recently proposed a new course, which was approved by the department, and will be offered in the Fall of 2018. This course, in my view, proverbially kills two birds with one stone. On the one hand, I had felt that our department would improve its curriculum by offering an undergraduate biochemistry course. I was the beneficiary of two fantastic biochemistry/enzymology courses taught by Prof. Stubbe at MIT and Prof. Hedstrom at Brandeis University, and I wanted to create a similar course at Princeton. At the same time, I also sought to experience the joys of teaching at the undergraduate level. As part of the Dreyfus Teacher-Scholar award, I look forward to creating this course to enhance our department's curriculum, and to engaging undergraduates in biochemistry/enzymology, while at the same time honing my teaching skills. To foster an interactive style of learning, I plan to include student presentations, in-class problem sets, and mid-semester evaluations. I hope and expect that this course will be a mainstay in the Princeton Chemistry curriculum in years to come.

Laboratory Teaching

As mentioned above, I believe that classroom and laboratory education is linked, and I have enjoyed training undergraduates, graduate students, and postdoctoral fellows since my arrival at Princeton. I have especially enjoyed training undergraduates. I have worked side-by-side with all undergraduate students in my group because I would like to instill, at an early stage, the right way of conducting experiments and the importance of using proper techniques in the laboratory. The most valuable asset an undergraduate brings to a research lab is a sense of enthusiasm and wonder, and by working directly with the students, I hope to nurture and stimulate that mindset. Three of the four undergraduates that conducted their theses in my laboratory have published in leading, peer-reviewed journals. For the other, a paper is currently in preparation. I have also trained, or am training, twelve graduate students. Three have graduated with PhDs and multiple first-author publications. Finally, I have also mentored five postdoctoral fellows.

Mentoring students in the laboratory requires a different set of skills, one that is not really taught during the course of our education. I have therefore spent a fair amount of time learning managements skills both in practice and by completing online workshops. My approach has again been driven by passion: I view one of my chief roles in matching the 'right' project to each student. When students are passionate about their projects, their level of engagement remains high throughout their tenure. Of course, every student is different and there is no recipe that applies to all. Learning to work with each student and observing the personal and scientific growth and maturation in each individual, is one of the most rewarding aspects of a Teacher-Scholar. I hope to continue to witness this growth both in the laboratory and the classroom while working with undergraduates, graduate students and postdoctoral fellows alike.

Benjamin M. Swarts
Chemistry and Biochemistry
Central Michigan University

Teaching through undergraduate chemical biology research at a PUI. As a faculty member working at a predominantly undergraduate institution (PUI), undergraduate research is an essential component of my teaching activities, and I believe it should likewise be an essential and inspiring part of any chemistry major's education. CMU is the only public university in Michigan to have a required thesis-based capstone research program for every chemistry and biochemistry major, and I have been fortunate to mentor a diverse group of about 40 undergraduate students in independent research, including CMU students and students from local community colleges through my outreach program. Because our lab's mycobacteria-focused chemical biology research is inherently interdisciplinary, students' projects integrate a breadth of concepts and techniques from different fields. The projects are designed to engage students on several levels:

1. Chemical biology research encourages students to identify difficult-to-solve biological problems—of which there are many in the field of mycobacteriology—and approach them from a creative, interdisciplinary perspective that centers on chemistry;
2. Our research focus, the mycobacterial cell wall, is replete with fascinatingly complex chemical structures arising from biochemical pathways that are singular to mycobacteria, allowing students to build on their classroom chemistry studies in a unique way;
3. All projects are applicable to a major pathogen predominantly affecting developing countries, which challenges students to think critically about the role of basic science in global health, as well as how political, economic, and cultural conditions can contribute to human health and disease.

Our research projects expose undergraduates to a variety of chemical and biochemical techniques, ranging from chemical and chemoenzymatic synthesis to protein characterization and cellular studies. While some students may focus on developing a particular skillset, all students are exposed to a range of techniques and project design approaches through participation in group meetings featuring research presentations and relevant literature reviews. Our research is feasible in a PUI setting because we focus undergraduates' projects on small-molecule synthesis and evaluation of probes in model mycobacterial species that are fast-growing and non-pathogenic. In all, each of our projects is interdisciplinary, and students are typically exposed to a variety of chemical, biochemical, and microbiological concepts and techniques that are combined to solve problems related to the mycobacterial cell wall.

Incorporating a global perspective into undergraduate chemistry teaching. I believe that students should be challenged to learn by contextualizing and disseminating their education outside the boundaries of campus. Toward this goal, I have implemented in-class projects and a way-out-of-class study abroad program to help students develop global perspectives in their scientific pursuits. While study abroad programs have long been used to provide undergraduates with new cultural experiences, relevant opportunities for science majors are scarce, and the notion of disrupting a highly prescriptive curriculum leads many students to regard travel abroad as untenable. I developed a science study abroad program at Stellenbosch University, a top-tier teaching and research institution in South Africa. This program enables CMU students to stay on track with their coursework in a new and diverse setting while participating in a rich cultural exchange. The program has been designed to not only provide suitable science courses, but also to provide opportunities to do research with Stellenbosch faculty mentors and participate in a service learning program. In addition, the program has been set up to maximize interactions with South African students and to provide regular excursions to sites of South African historical and cultural significance.

William A. Tisdale
Chemical Engineering
Massachusetts Institute of Technology

Chemists and Chemical Engineers are well-equipped to address problems in nanoscience & engineering, and an important part of my educational mission at MIT is to show students how their training in the chemical sciences has already equipped them to address grand challenges in this field.

Like many other tenure-track faculty at MIT, I maintain an active research group employing a large number of students. Over the past six years, I have mentored 12 Ph.D. students in Chemical Engineering and Physical Chemistry, 7 Master's students, 22 undergraduate researchers, and 8 postdoctoral associates.

However, my greatest contributions to undergraduate education at MIT have been through classroom teaching. Each fall, I teach 10.302 "Transport Phenomena" – our junior-level core subject in heat & mass transfer – to approximately 75 undergraduate Chemical Engineering majors. Heavy in partial differential equations and broad in scope, 10.302 is widely regarded by our students as the most difficult subject in our undergraduate curriculum. However, through my involvement in the class over the past five years, many students now note in our senior exit surveys that it was also their favorite.

In my third year at MIT, I was honored to receive the 2014 Everett Moore Baker Award for Excellence in Undergraduate Teaching. The Baker Award is considered to be the most prestigious undergraduate teaching award at MIT. It is given annually to one MIT faculty member – of any rank, in any department – in recognition of his or her "exceptional interest and ability in the instruction of undergraduates." It is the only teaching award in which the nomination and selection of the recipients is done entirely by students. Student testimonials included such statements as "[Tisdale is] the best professor I have had at MIT so far," and "literally the greatest teacher I have had in my 15 years of schooling." The following year, I was selected by the undergraduate students in Chemical Engineering to receive the 2015 Department of Chemical Engineering Undergraduate Teaching Award (and again in 2017).

In addition to my teaching in 10.302, I have also served for five semesters as a project leader in 10.26 "Chemical Engineering Projects Laboratory" – a junior-level undergraduate lab subject focusing on project management and oral and written scientific communication. In 10.26, students are split into teams of 3, and each team is given a different project that they work on over the entire semester. My goal in 10.26 has been to give the students projects that incorporate aspects of my independent research program. I take care to clearly define a problem, but also to give the students freedom to propose their own solution – even if it means experiencing failure. Over the past five years I've led projects on organic solar cells, patterning colloidal quantum dot films, synthesis and stabilization of organic-inorganic perovskite nanomaterials, and thermal transport in nanostructured battery electrodes.

Due to extensive contact with the undergraduate students during the fall and spring semesters of their junior year, I am frequently approached for advice and mentorship as they consider post-graduate options, which I am always happy to provide. Some of them decide to pursue graduate degrees in Chemical Engineering or related disciplines. In total, I have written letters of recommendation for 36 different undergraduate students applying for graduate school admission or prestigious international fellowships, including one Rhodes Scholar (Anisha Gururaj, 2015) and one Schwarzman Scholar (Kelsey Jamieson, 2016).

Finally, in 2015, I piloted a new technical elective subject, 10.51 "Nanoscale Energy Transport Processes." Rather than a survey course, the class is a technical subject designed to equip students with the knowledge and mathematical tools to quantitatively address problems in nanoscale heat, mass, charge, and exciton transport. In particular, we looked at the many ways in which continuum approximations break down at short length scales and fast time scales, and developed alternative computational (kinetic Monte Carlo) and statistical mechanical (Boltzmann Transport Equation) frameworks for handling nonequilibrium transport phenomena. 26 students enrolled in the class, including 8 upper-level undergraduate students.

Moving forward, I am eager to continue devoting significant time to the teaching and mentorship of undergraduates at MIT, beginning with a complete re-design of our sophomore thermodynamics subject, 10.213, in spring 2019. The Camille Dreyfus Teacher-Scholar Award has provided flexibility in how I spend my summer months, and additional funds for educational initiatives in the chemical sciences at MIT.

Matthew T. Whited
Chemistry
Carleton College

Course-Based Research and the Undergraduate Learning Trajectory

I believe that we are in an exciting time for STEM education. As questions continue to arise about the role and value of higher education, we as educators are being equipped with numerous tools to aid instruction (both as a result of technological advances and research into evidence-based methods for effective teaching) and challenged to ask critical questions about what our goals are and how to achieve them. We have the opportunity not only to train a more diverse and representative workforce of graduates for STEM-related fields, but also to educate the next generation of leaders who are not professional scientists but understand and articulate the role of science in society (including its limitations) and can bring an integrated approach to problem solving to a variety of careers. My work as an educator has touched on a number of areas, but here I will specifically address efforts to bring research into the classroom.

My entry into science education started in the laboratory, and I firmly believe that the characteristics of the research laboratory (broadly defined) — dealing with real and sometimes messy data, incorporating many different methods to solve problems, collaborating on difficult work as a team — offer some of the best ways to attract a diverse group of students, including those from traditionally underrepresented backgrounds, and challenge them to become independent thinkers and problem solvers. In the laboratory, where answers are unknown but postulated and often of interest beyond the walls of the institution, teacher and student are co-learners working together to tackle difficult problems. These mentored research opportunities are undoubtedly an important part of my teaching and lead to significant gains for students. However, they are also inherently limited in scope to the few students whom I can support through mentored research apprenticeships.

As a result, I have worked to expand research experiences to a number of Carleton students through the upper-level laboratory curriculum, specifically the Laboratory in Advanced Inorganic Chemistry (CHEM 352). The areas receiving special attention so far have been novel inorganic synthesis, techniques for microscale glove box synthesis, and small-molecule X-ray crystallography. For instance, I modified an existing gram-scale experiment preparing organometallic molybdenum complexes to be carried out on 100-mg scale in a glove box. The modification allowed students to pursue previously unknown synthetic targets (the old prep only made a single, well-known product). Since the products were new, students were faced with fully characterizing and purifying unknown targets, along with the possibility of failed syntheses— an important goal in itself. The procedures proved quite general and were only made possible by the use of special small-scale glove box techniques. I published the lab experiment in the Journal of Chemical Education, along with extensive instructions about how to implement glove box synthesis in undergraduate teaching labs.[1] I have also shared the procedures with additional comments about using and implementing glove boxes with undergraduates through the Virtual Inorganic Pedagogical Resource (VIPER).

The work described above led to a significant effort to incorporate and subsequently expand the use of X-ray crystallography in advanced labs at Carleton. A collaboration with Prof. Daron Janzen (St. Catherine University) led to publication of four new structures in three papers with a total of ten undergraduate co-authors. [2] As we generated new datasets, many that were not published were incorporated into a crystallography laboratory allowing students to work with unpublished crystallographic data related to the experiments they were conducting. Now, our findings about incorporating crystallography into the undergraduate curriculum[3] are serving as the foundation for further work I am undertaking using a single-crystal X-ray diffractometer purchased in part with Dreyfus funding. Students are being exposed to the molecular world in a new way with unpublished data using an important modern technique that is often neglected in the undergraduate curriculum. Furthermore, I am planning to develop experiments engaging high-school students in crystallization and crystallography after the instrument is installed.

My current work with course-based research has moved significantly beyond its largely crystallographic beginnings and has most recently involved development of an entirely new course for the Carleton catalogue, CHEM 300: Chemistry Research. Students in the course, many with very little background in inorganic or organometallic chemistry, work together on problems related to my research, and the structure afforded by this regular course offering allows me to measure the impact of the research experience on students' mindsets and problem-solving skills.

I have collaborated with Carleton's Science Education Resource Center (SERC) to develop instruments for understanding how students develop adaptive expertise through course-based research experiences. This work has involved development of detailed rubrics to help students understand and chart their own progress. Our early findings indicate that one of the first changes for students involves the formation of a self-critical mindset that allows them to situate themselves and their work better within the field. We are hoping to continue using the outcomes from research experiences of students in my laboratory as vehicles for understanding how we can structure research opportunities, and particularly feedback during them, to help students gain problem-solving skills that can be applied across a range of problems both inside and outside chemistry. Looking forward, I am eager to learn about best practices for my own benefit and to help other faculty at Carleton and beyond develop effective ways to use research as a teaching tool for undergraduate students.

---

(1) Whited, M. T.; Hofmeister, G. E. J. Chem. Educ. 2014, 91, 1050.
(2) (a) Whited, M. T.; Hofmeister, G. E.; Hodges, C. J.; Jensen, L. T.; Keyes, S. H.; Ngamnithiporn, A.; Janzen, D. E. Acta Crystallogr., Sect. E: Struct. Rep. Online 2014, 70, 216. (b) Whited, M. T.; Bakker-Arkema, J. G.; Greenwald, J. E.; Morrill, L. M.; Janzen, D. E. Acta Crystallogr., Sect. E: Struct. Rep. Online 2013, 69, m475. (c) Whited, M. T.; Boerma, J. W.; McClellan, M. J.; Padilla, C. E.; Janzen, D. E. Acta Crystallogr., Sect. E: Struct. Rep. Online 2012, 68, m1158.
(3) Janzen, D. E. "Benchtop Diffractometers: Implementation of an X-ray Crystallography Consortium of Undergraduate Institutions Based at St. Catherine University" American Crystallographic Association National Meeting, Albuquerque, NM; 2014;

Douglas D. Young
Chemistry
The College of William & Mary

The Dreyfus Foundation's commitment to teaching significantly aligns with my passion for undergraduate chemical education. Over the past 6 years, I have found W&M to be an ideal environment to flourish, both as an educator and as a scholar. The college is somewhat unique in its mission to equally strive for excellence in both teaching and in scholarly work, truly training undergraduate students for careers in the sciences by facilitating hands-on learning through research experiences. While I experienced pressure to take positions at more research-intensive institutions, I believe I have found my perfect niche at W&M. It is here that I am impacting scientific research through the extensive training of undergraduate researchers, effectively preparing the next generation of scientists and leaders. This has been accomplished via two primary approaches: the engagement of undergraduates in independent research, and the development of novel courses and laboratories to optimize the undergraduate experience.

Undergraduate Research

My deep appreciation for the value of undergraduate research was instilled early in my tenure at the University of Puget Sound, as I began participating in undergraduate research during my sophomore year in the lab of Dr. Eric Scharrer. In retrospect, I recognize this experience to be one of the most transformative of my life, as I discovered my passion for science and truly developed as a researcher. I often draw upon this experience, now in the mentoring position, and value it as a fundamental mechanism to advance scientific education and effectively prepare the next generation of scientists. Consequently, I have elevated the undergraduate research experience to one of my top priorities at W&M. I hope this is illustrated not only in the number of undergraduates that I have mentored since coming to W&M, but also in the number of undergraduate researchers involved in publications in high impact journals (in many journals which I never dreamed would be accessible when teaching at a primarily undergraduate institution). During my 6 years at W&M I have had 37 undergraduate researchers work in my laboratory, and 4 M.S. students. This translates to roughly 16 students/academic year, with 6-9 students working full time in the summer. Moreover, I find it astounding to consider the sheer volume of research these students were able to accomplish in this time. To date, my lab has published 19 manuscripts and 2 book chapters (with all but 2 having undergraduate authors). There are a total of 21 unique undergraduates listed as authors, with a total of 33 cited undergraduate authors, as many individuals have multiple publications. I strive to ensure that the undergraduate research experience provides a strong foundation for each and every student, and thoroughly prepares them for their future careers. Gratifyingly, this appears to be illustrated in their successful post-baccalaureate outcomes. Of the 15 students that have graduated, 4 students are enrolled in medical school, 10 are in Ph.D. programs for chemistry or biochemistry, and 1 has found employment within industry. Many of the students enrolled in Ph.D. programs entered W&M as pre-health students, but through their participation in research, altered their career direction to attend highly ranked Ph.D. programs. Additionally, I have been fortunate enough to mentor 3 Beckman Fellows, and 2 Goldwater Fellows, demonstrating the powerful influence undergraduate research has had on their professional careers. Hands-down, the most rewarding aspect of my job is being able to witness the evolution of these students throughout their 4 years of undergraduate studies into highly competent and brilliant scientists and individuals. This is my true impact on science, as a domino effect is created with so many new scientists primed to have their own unique influence on science, aligning with the Dreyfus vision and the ultimate purpose of the Henry Dreyfus Teacher-Scholar program.

Efforts in the Classroom
My primary teaching responsibilities at W&M have been General Chemistry I and Biochemistry. These two courses offer a unique juxtaposition, as they bookend the undergraduate experience and afford unique opportunities to engage students in chemistry. General Chemistry I is a large lecture based course consisting of a mix of first and second year students. The challenge of the course is managing the large size (~150 students) and the wide range of experiences in chemistry. Many students enter this course as their introduction to science at the college, and are initially apprehensive about the subject. I strive to convey to the students the utility of the knowledge and make the course both relevant, and potentially even fun. I have come to recognize that it is a privilege to teach this course, as it becomes my responsibility to excite impressionable students about the field of chemistry, and convey my enthusiasm for the subject. In fact, a recent report in Inside Higher Ed, noted the importance of engaging and enthusiastic professors in introductory courses as they serve as gatekeepers to the subject, significantly affecting the major selection process (Jaschik 2013). I take this role very seriously and attempt to provide the best introduction to the material possible.

I also teach Biochemistry to mostly juniors and seniors in a much smaller setting (~60 students). The challenge of this course is distilling very complex material to its essentials and making the dense material manageable. Moreover, I believe this is the optimal time in the educational experience to hone student's analytical skills. Biochemistry represents a course where it is feasible to develop critical thinking skills and truly force the students to apply their knowledge rather than simply regurgitate facts. I also attempt to introduce the students to the primary literature, and despite having large enrollments, cultivate their scientific writing skills through the incorporation of a semester long writing assignment that I developed.

In addition to the traditional role in the classroom, I have also been involved in several less traditional activities to enhance the undergraduate experience. During my tenure at W&M, the college instituted a new curriculum to better embrace the liberal arts experience, and afford a more thorough undergraduate experience. Consequently, I have developed a new course, Biochemistry at the Bar, which aims to both literally and figuratively put biochemistry on trial. This course examines the societal impacts that science has on economics, global health policies, and the law. Ideally, we attempt to recognize the important role that the scientist has in society and solidify the necessity for the responsible conduct of research and effective presentation of scientific knowledge to the general public. I have taught this course the last two years as an unpaid teaching overload, and thus far, it has been well received by the enrolled students.

Additionally, the Chemistry Department has recently also updated its curriculum, and I have served as a committee member helping to navigate through the curricular changes. I relish these unique opportunities as they facilitate the improvement of the undergraduate experience and help to develop well rounded scientists. Finally, I have also been involved in the development of several new laboratory experiments to update the curriculum as a means to make it more relevant and introduce skill sets that will make the students more viable job candidates. Toward this end, I received an internal Morton grant for the purchase of a CEM microwave reactor to be employed in the Organic Chemistry Laboratory course. Working with undergraduates, we developed new laboratory exercises to introduce microwave technologies to the undergraduate curriculum, culminating in a publication in a chemical education journal. I have also developed 3 other new laboratories for the Biochemistry and General Chemistry laboratories, integrating my unnatural amino acid research into the teaching lab, resulting in a publication in the Journal of Chemical Education. Finally, I am currently involved in transitioning the General Chemistry pre-lab lectures to a digital format that can be watched and assessed using Blackboard software, obviating the need for an additional "discussion" section, that has been problematic for both scheduling and attendance since I have been at the college.

Ultimately, I have a true passion for teaching and an appreciation for my role as a mentor to undergraduate students. This love of teaching has taken several forms, but ultimately is displayed through both my course development and my engagement in research with primarily undergraduates. The impact of these activities has far-reaching and exponential effects, as each student mentored is then able to influence numerous scientific fields in the future.

Guihua Yu
Materials Science and Engineering
The University of Texas at Austin

Building a Vibrant Materials Science Educational Program

As a materials chemist and professor of Materials Science and Mechanical Engineering, I view the teaching as an indispensable catalyst for students' learning. A good teacher should not only present a student with a clear pathway for comprehension, but also facilitate and promote students' intrinsic enthusiasm, self-motivation towards science and technology, and critical thinking. A good teacher shall remain accessible and active throughout the process of student's learning and training. I always believe that being able to teach and interact with college students is one of the most rewarding aspects of being a professor, and I always commit myself in continued curriculum innovation that best reflects the advances in scientific research to make the classes intriguing and full of excitement, and in seeking novel ways to connect with students and help prepare them for the future with the knowledge of how to approach a problem and address it.

From the start of my career as an independent faculty member in fall 2012, my teaching and education efforts in the chemical sciences, particularly materials chemistry and science, have been focused on building a strong and vibrant materials science program at UT-Austin from the undergraduate to graduate level. Below I will describe the multi-tier approaches and multifaceted activities I have undertaken to educate future-generation materials scientists.

1. *New Curriculum Development – Nanoscience for Sustainable Energy*

I have established a highly interdisciplinary research program with four integrated elements: chemistry, physics, materials, and energy. To tightly integrate my research and new advances in the rapidly growing field of energy science and technologies, I have developed a school-wide, multidisciplinary course for senior undergraduates and graduates, entitled "*Nanoscience for Sustainable Energy*". This course incorporated materials chemistry and device physics with current nanoscience research, with the emphasis on the synthesis and structure of materials for different energy devices. This new course is designed to culture beneficial experience for students from various backgrounds to communicate and interact with one another through the numerous presentations, discussions, and collaborations in the course.

2. *Encouraging Undergraduate Students in Materials Chemistry Research*

Undergraduate research is a key facet in my research laboratory. When I was a college student, I had the opportunity to work in a lab for almost three years, and co-published several research papers with senior graduate students. This early stage experience was truly invaluable in shaping my view of materials science research, and helping solidify my intention to become a professor. *When I joined UT-Austin, I knew that I would be significantly committed to ensuring that undergraduate students can benefit from the exciting research experience in my research lab.* I always encourage undergraduate students in my classes, especially those from underrepresented groups, to participate in research.

I firmly believe that no matter how complex the research topic is, there is always room for undergraduates to both learn and make meaningful contributions. Many of our published scientific papers have undergraduate students as co-authors, including a junior student who made the discovery as a sophomore. Note that Texas demographics are such that the undergraduate body at UT-Austin has a significant Hispanic representation (~16%). Such contacts and experience with minority students have also created a positive effect on the diversity of our graduate program.

3. *Fostering Materials Science Graduate Program*

I have been responsible for many aspects of the materials science graduate program as representative faculty in graduate admission and recruiting committee. In my own research group, I cross-train both my graduate students and postdocs, and encourage them to mentor at least an undergraduate researcher for at least a semester in my lab. My group also cooperates with '*Graduates Linked with Undergraduates in Engineering* (GLUE)' program at UT-Austin, aiming to provide undergraduates the opportunity to gain practical research experience in materials science by pairing with graduate students (mentors) in their majors. The goal is *to target specifically the female undergraduates for better retention of women students.*