

# Research Frontiers in the Chemical Sciences

A Dreyfus  
Foundation  
Teacher-Scholar  
Symposium

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The Camille & Henry Dreyfus Teacher-Scholar Awards programs recognize the country's most promising young scholars in the chemical sciences, based on their forefront independent research accomplishments. In addition, the Dreyfus Teacher-Scholars are leaders in innovative approaches to education in the chemical sciences. The following statements by the Teacher-Scholars summarize their initiatives and philosophies on educating the next generations of scientists.

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I am a child of two teachers, and education has always been an integral part of my life. Encouraged to pursue a career in science by my high school chemistry teacher, I understand and deeply appreciate the power of an educator to challenge and inspire students. I have sought out teaching opportunities at all levels of my training, beginning in high school when I taught chemistry and biology to at-risk middle school students. As a faculty member I have continued to demonstrate a strong commitment to education inside and outside of the classroom. My educational interests include curriculum development at the interface of chemistry and biology, expanding access to undergraduate research opportunities, and encouraging broader participation in science through both outreach and mentoring activities.

### **Curriculum Development at the Interface of Chemistry and Biology**

Biological phenomena are ultimately chemical in origin. Since joining the faculty at Harvard I have taught two courses that explore chemical transformations utilized in biological systems. I have developed a new graduate-level course called 'Biological Synthesis' (Chemistry 171). This class, which is a unique offering at Harvard, discusses chemical synthesis from a biological perspective. I designed the course to address two major questions: how do biological systems generate complex molecular scaffolds, and how can chemists use tools from biology for synthetic purposes? The first half of the class examines how organisms construct and manipulate complex natural products, introducing topics from both biosynthesis and enzymology. The second half of the course described how biological catalysts and organisms are used for small molecule production, covering very recent progress in the rapidly growing fields of biocatalysis and synthetic biology.

I have also redesigned an existing undergraduate course, 'The Organic Chemistry of Life' (Chemistry 27). A requirement for premedical students and life sciences concentrators, this large organic chemistry course explores the enzymatic reaction mechanisms utilized in central metabolic transformations. My lectures incorporate examples of enzymatic chemistry that impact important challenges in medicine (antibiotic resistance/infectious disease, obesity/metabolic disease). I also discuss reactions that relate to emerging areas of human biology (epigenetics) and my own research (human microbiome). Finally, I have developed new teaching tools that I use throughout the course, including 'YouTube-style' instructional videos. I also give a series of optional, supplementary lecture/discussion sessions for students that focus on the chemistry underlying current research in medicine and biology.

### **Expanding Opportunities for Undergraduate Research**

Nothing is more exciting and compelling to a young scientist than experiencing scientific discovery firsthand. Participating in original research increases students' enthusiasm and leads to greater retention in science during college and as a career. With this in mind, I have made it a priority to include undergraduates in my research lab. Undergraduates in the lab are initially closely mentored either by a graduate student or postdoc, but as they gain experience they pursue independent projects.

In addition to mentoring undergraduates in my laboratory, I am also seeking out additional opportunities to enhance our students' introduction to scientific research. I have developed a new freshman seminar that will engage Harvard students in research right at the start of their undergraduate studies. The course, entitled 'Discovering Chemistry From the Human Microbiota', pairs a small group of freshman with two of my group members and me. As a team, we will design an experimental approach for discovering new classes of either enzymes or small molecules from gut microbes. Over the course of a semester, the students will first test and refine their experimental plan and then begin to characterize their results. This project addresses a real gap in human microbiota research: a lack of understanding regarding the chemical functions carried out by these organisms. I anticipate that by having this opportunity to explore a timely

research problem and drive the direction of their research at a very early stage in their academic experience, participants in this seminar will be motivated to seek out further undergraduate research opportunities and will be inspired to pursue scientific career paths.

### **Encouraging Broader Participation in Science**

I first participated in science outreach activities in high school. The excitement and joy I gained from sharing my growing passion for science with others was an important motivation in my eventual pursuit of a career in academic science. As a faculty member I have continued to undertake outreach and mentoring activities with students at all levels of education, with an emphasis on groups that have been traditionally unrepresented in science. For the past three years my lab has participated in EXPLORATIONS, an outreach program that links Harvard scientists with Boston and Cambridge middle school students. Each fall we host visiting students in our lab for an afternoon, introducing them to a research topic, giving them the opportunity to perform an experiment, and talking with them about careers in science. I have also given talks to undergraduates at Harvard and beyond about both my research and advice for pursuing graduate work in science.

Finally, I am committed to mentoring future generations of scientists, with a particular emphasis on women. As a graduate student in synthetic organic chemistry, I had few female role models to emulate, both within my department and among the broader organic chemistry community. My own experience led me to recognize that I could play an important role in the careers of younger female scientists by serving as a resource and advisor. For the past three and a half years I have served as a mentor for the Harvard Graduate Women in Science (HGWIS) Mentoring Program. I currently serve as a formal mentor to two Harvard graduate students. We meet frequently throughout the year to discuss a diverse range of topics, including time management, goal-setting, writing and presentation skills, work-life balance, and networking. I also hope that by frankly discussing my career path and both the joys and challenges of academia with my mentees, I serve as both an accessible and effective role model.

## Shannon W. Boettcher

Chemistry & Biochemistry  
University of Oregon



### Convergence of Chemical Education, Outreach, and Research

I am passionate about my laboratory's research, and I do everything possible to make it of the highest quality with the greatest probability of positively impacting humanity. However, I also believe that the students I help to educate are an equally important output, and they are likely to have a larger cumulative positive impact on the world than the results of our research. I am therefore committed to advancing chemical science education at all levels, both inside and outside the classroom. Particularly, I have focused on developing and implementing new scalable models to provide hands-on, science-based problem-solving and research experiences to students.

**Outreach.** During my first year as an assistant professor, my group engaged in a variety of one-off outreach activities for local students at the elementary through high school level. While these activities engaged students successfully, I realized a systematic approach with a long-term vision was needed in order to significantly impact science education in our community. After meeting with local K-12 teachers and administrators to understand their needs, I started an outreach program in 2011 in collaboration with the Springfield School District. The goal was to provide enhanced science education for local underserved MS students and demonstrate a path from MS to high school (HS) to college. I worked closely with other UO assistant professors [Dr. Nazin (physical chemistry), Dr. Pluth (organic chemistry)]. By collaborating, we shared administrative burdens associated with planning and evaluating our program, which allowed us to reach more students and teachers and to increase the depth, intensity and impact of our outreach.

The program included three thrusts that synergistically connect MS and HS students to science research and create familiarity with college and practicing scientists: (1) 3-4 h laboratory-based learning activities for MS students on the UO campus take place during no-school and early-release Fridays implemented due to state budget cuts. The activities are run by undergraduate/graduate students, along with HS student volunteers who we recruit to serve as near-peer mentors from partner HS teacher classrooms. Select HS students earn summer internships in faculty research labs (I have hosted five HS students thus far).

Over the past years we recorded (per year) ~150 visits from MS students and ~8-10 events. Our school district collaborator manages student recruitment and transport. The program starts with an October recruiting event held at the MS, and culminates in June with a family-oriented on-campus event where students present and explain their work to their parents using hands-on demonstrations. Our effort has been featured in the Springfield Times and Eugene Register Guard newspapers, on the KEZI local news channel, and in Chemical and Engineering News (for links see <http://sciencefriday.uoregon.edu/press/>). The faculty collaboration and scale of the program allowed us to garner financial support from local companies. We are also grateful to the Dreyfus Foundation Special Grant Program in the Chemical Sciences, which funded a proposal to support the program. We quantify impact by surveys and have published the results (Pluth, Boettcher et. al., *J. Chem. Ed.*, 2015). One question asks whether the students "felt like a scientist today" – we typically receive ~75% positive responses. Parents also value the program. From the *C&E News* article:

Cynthia Nagao, whose foster son participates in the Furlough Fridays program, credits the outreach program with helping to plant the seeds of college in her foster son's mind. Before her foster son started attending the Furlough Fridays program, Nagao says, he didn't see himself going to college but could see himself going to prison. "After five or six months, there was a very clear turning point for this child where his conversations started being more about, 'When I go to college,' " Nagao says. "Somewhere, there was a shift in his thinking, and part of it is because he got to spend some time on a college campus."

A key feature of this program is scalability. Although it was significant work to start, it is now essentially run by undergraduate and graduate students. These students value the teaching experience and chance to

design and implement hands-on activities. Students in my group have developed activities on solar energy, batteries, nanotechnology, and materials chemistry. Our school district collaborators value the high quality content. Our long-term vision is to make this opportunity available to all the MS students in our county. We are institutionalizing the program by recruiting additional science faculty/students from other departments to support expansion.

**Undergraduate Education.** Although I have taught several courses (e.g. in semiconductor materials chemistry, electrochemistry, inorganic laboratory), I believe the largest impact I have in classroom-based undergraduate education is by teaching Honors General Chemistry. This course is taken by the top students from all science disciplines. For many of these students (e.g. those in geology or anthropology), it is their only exposure to college chemistry. My teaching philosophy adheres to the following goals. (1) To teach, with mathematical rigor, at a level that challenges the best students in the course while also emphasizing the qualitative understanding of microscopic electronic and molecular action to establish a “chemical intuition.” (2) To provide mentoring and support for all students to succeed. (3) To nurture a student mindset and class culture that values being “pushed” and learning “how to think” over memorizing equations and specific problem-solving algorithms. (4) To instill appreciation for the role of chemistry in solving past, current, and future challenges for humanity. The vast majority of students respond well to these goals.

While classroom education is important for scientific development, hands-on research experiences solidify concepts and promote confidence in research and problem solving. I prioritize making research experiences available to students as early as possible in their scientific education. During my 6 years at the UO, my group has hosted 31 diverse undergraduates and 5 high school students in substantive research projects. While I am proud of the accomplishments of these students so far, many science undergraduates still lack access to high-quality research experiences, or they engage research too late in their undergraduate career.

I am thus now working to implement a scalable program to increase the quality, depth, and quantity of undergraduate research at the UO. The program, which we call the *Research Immersion* (or RI) lab, emphasizes team-based training for undergraduates as they work together on open-ended research questions. The students earn replacement credit for freshman chemistry laboratory, so it doesn’t lengthen time to degree. The goal is to change the culture of undergraduate research from an activity that students might do as junior or seniors, to a core part of the undergraduate science experience that permeates the way all students approach coursework, develop their aspirations, and prepare for careers.

To date we have run two pilot research immersion labs, each with 10 freshman (roughly equally weighted between young women and men with diverse backgrounds). The students are typically split into two “pods”, each led by a graduate-student mentor. I work closely with these mentors to develop specific research questions that satisfy the following requirements: (1) the results will be publishable in a reputable journal and advance the thesis work of the graduate student, (2) the experiments are tractable by a guided team of undergraduates, and (3) the experiments connect to the general chemistry curricula. In the first year, one of the pods studied materials for oxygen electrocatalysis and the other the aqueous synthesis of metal hydroxide clusters. The concepts connect strongly with the traditional curricula including kinetics, thermodynamics, aqueous equilibria, and redox reactions. In the second year, the students synthesized and characterized a range of amorphous mixed-metal oxide thin films, which we aim to use as selective electronic contacts in solar devices.

The majority of students who participated have continued undergraduate research in their areas of interest (many unrelated to the research areas in the course). Three of them are working in my research group currently. While we have received exceptional qualitative feedback on the impact this course has had on some students, we now must analyze quantitatively how this course affected trajectories in undergraduate education relative to conventional laboratory courses. Another key issue is developing a financial model for the course that enables scalability. Undergraduate students from previous years are eager to assist the next batches of freshman as near-peer mentors, and this provides one mechanism to support the program growth. Graduate students volunteer to lead pods because they see it as excellent professional development that simultaneously accelerates their thesis research.



## Andrew J. Boydston

Chemistry  
University of Washington



My teaching experiences at the University of Washington have been some of the most fulfilling aspects of my career. Excellence in teaching is critical to the development of our students as future leaders and I am grateful to play a role in this process. As a member of the UW community, I enjoy the rich diversity within the student body and among faculty. This has provided an environment for me to collaborate, innovate, and adapt in ways that enhance the abilities of instructors and broaden opportunities for students. My primary teaching goals have been to inspire students to think critically and take ownership of their education. These have been central themes in my undergraduate and graduate level instruction, in the classroom and the laboratory.

### Undergraduate level instruction and curriculum development

Since arriving at the University of Washington in 2010, I have taught Introductory Organic Chemistry (Chem 237) each autumn quarter. After my first experience with this course I was motivated to increase student access to course materials and resources, and refocus my interactions with students toward the most challenging concepts and applications of organic chemistry. It seemed that establishing a more interactive learning environment might be challenging with large lecture courses (300 – 400 students), but the traditional lecture format did not appear to best serve the needs of the students. I was committed to redesigning my course and realizing more of my potential as an educator.

Piloting the Canvas learning management system revealed several opportunities to reach my objectives. For example, I made use of online “virtual” office hours to offer students a way to participate in live discussions remotely, which increased office hour attendance and student activity during the online sessions. Time in the classroom was also made more useful by incorporating online resources as part of the overall course materials. Using Canvas Modules to organize online learning activities, such as tutorials, mini lectures, and discussions, opened up the lecture period for active learning exercises. After focusing more of the lecture period on problem solving strategies, applications of concepts, and critical thinking problems I observed an increase in the average score on exam problems that tested for these abilities.

Enthusiasm for incorporating technology into teaching has grown within the Department of Chemistry and added to an already collaborative environment. This was fueled by recent participation in the Teaching Technology Fellows Institute, which provided guidance on how to implement and test our ideas for teaching. Working most recently with Prof. Stefan Stoll, Dr. Jasmine Bryant, and Dr. Colleen Craig, we established a team of instructors who actively evaluate new technologies, integrate promising platforms, and mentor other faculty members who are interested in teaching with technology. The team includes experts in different fields of chemistry who collectively teach classes ranging from 100-level undergraduate courses to 500-level graduate classes. This is an exciting development because the diversity of the team that has nucleated thus far is an indication of broadening impact and relevance throughout our department and beyond.

### Research opportunities and exposure for undergraduates

Being involved in undergraduate research with an enthusiastic and supportive mentor was a turning point that set me on a course toward my current career. It was simultaneously the most challenging, independent, and rewarding academic experience I had encountered. Since then, I have maintained a commitment to mentoring undergraduate researchers and have done so while earning my graduate degrees and now as an Assistant Professor. Since 2010, I have mentored 14 undergraduate researchers from various universities and diverse backgrounds. These talented students have included recipients of campus-wide awards such as the Mary Gates Research Scholarship and four were summer Amgen Scholars.

In my research group, undergraduate students are paired with a graduate or postdoctoral researcher who has expressed interest in mentorship. I work closely with them to help make the experience as successful as possible for all those involved, and to guide the transition toward independence for the undergraduate student. Projects are selected based upon the interests, skill set, and goals of the student and they are able to make unique contributions to larger projects. They share in group responsibilities, participate in weekly group meetings, present their research to the group, and are encouraged to take intellectual ownership of their projects. One undergraduate student, Candice Cooper, was also able to present her research at a National Meeting of the American Chemical Society.

While teaching introductory organic chemistry for the past five years, I have included a lecture that focuses on undergraduate research. Students provided positive feedback, and many had never had instruction on how to pursue research positions. That lecture has been recorded and is now also shared by other instructors teaching organic chemistry. To reach a broader spectrum of students, and inform them about my own perspectives in science, I also participate in The UW's Research Exposed - a seminar series featuring faculty in various disciplines. Collectively, these experiences give me a forum to disseminate details about my own research and focus intensely on the general aspects of research, lab membership, and career development that are important to undergraduates. This opened up another opportunity at the UW, which was participation in the Math Science Upward Bound program as an invited speaker.

One program that I was particularly inspired by was the Louis Stokes Alliance for Minority Participation (LSAMP) Program, which works in partnership with the College of Engineering's Bridge Program. The mission of the LSAMP Program is to increase recruitment, retention, and graduation rates of under-represented students in STEM disciplines. I had the opportunity to participate with the LSAMP and Bridge Programs by working with my graduate students to provide a two-week long Design Labs as part of the summer program for incoming undergraduates. This provided a unique opportunity for incoming students to experience what research is like at the UW and to make connections with faculty and graduate students in STEM fields. My group planned and directed experiments for seven undergraduate participants who synthesized poly(lactic-co-glycolic acid) (PLGA) with varying feed ratios of the comonomers via organocatalyzed ring-opening polymerization. The students also prepared poly(N-isopropylacrylamide) (PNIPAM) of varying molecular weights via radical addition polymerization. These polymers were selected because of their wide-spread use in nanotechnology and biomedical engineering, which piqued the interest of the undergraduate participants. Graduate students who helped in mentoring also gained valuable experience by teaching concepts and techniques of polymerization, experimental design and setup, and polymer characterization. The Design Labs culminated in a symposium where participants presented posters and seminars on their projects, and it was rewarding to see them taking such ambitious strides in just their first summer at the UW.

### **Graduate level instruction and curriculum development**

At the graduate level, I have taught Advanced Organic Synthesis (Chem 531) every year since 2010. This class focuses on reaction mechanisms, multi-step synthetic strategies, and common classes of functional group transformations. The class is fast-paced and the students must consume massive amounts of information. One of the caveats of this style of teaching is that students often do not get practice critiquing ideas, revising strategies, and putting their ideas through iterative feedback loops, which are critical skills to develop at the doctoral level. To serve this need, I took advantage of the Active Learning Classroom (ALC) capabilities in the Odegaard Library. The weekly lecture sequence was modified to include a traditional chalk talk lecture on Monday, in-class problems and lecture on Wednesday, and then active learning in the ALC on Fridays. Students submitted answers to challenging problem sets each Thursday evening and I would select examples from the pool to use during our Friday sessions in the ALC. The answers that I selected had correct and incorrect components to them, and the students would work in small groups to critique the answers, identify flaws, and offer improvements. Additionally, the students were pushed to identify alternative strategies to solving the problems and then we discussed some of the suggestions during the class. I noticed an almost immediate increase in the level of discussion that took place in the Monday and Wednesday lecture periods as a result of our activities in the ALC. Since scheduling in the ALC is challenging, we have successfully moved these activities online using Canvas

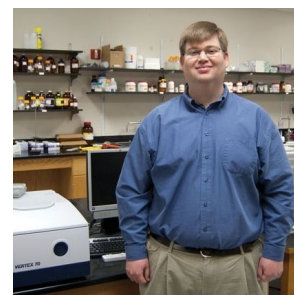
Discussion Boards and Modules to facilitate student interactions. The ability to use Canvas for this style of assignment may make it easy for other faculty member to adopt similar strategies.

Together with Assistant Professor David Masiello, I have developed a new graduate course (Chem 500) that focuses on scientific writing and grant preparation. We recognized the great potential of our incoming graduate students and were surprised to learn that many of them were unaware of and unprepared for opportunities to earn extramural graduate fellowships. Additionally, we knew that the technical writing and communication skills that are developed during the process of preparing a competitive proposal would be important throughout the careers of rising chemists. The course that we developed uses the National Science Foundation Graduate Research Fellowship Proposal as relevant framework for guiding students through the process of preparing a proposal application package. During the course, students draft their proposals and participate in rigorous peer review. We also facilitate a mock grants panel in which students have to debate the merit and relevant rankings of proposals in the pool. Although the course is open to all first- and second-year graduate students regardless of their fellowship eligibility, and no fellowship submission is required to receive full credit, we have celebrated a notable increase in the number of extramural fellowship awardees since the birth of this new course. This has helped to raise the profile of the Department, provide support for graduate research and outreach, and contribute to an ethos of success among the graduate student body.

## Scott H. Brewer

Chemistry

Franklin & Marshall College



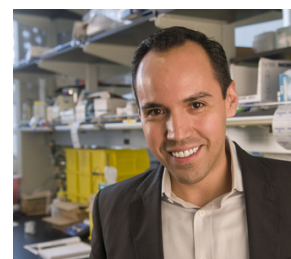
One of the courses that I commonly teach is the first course of the two-semester, upper level physical chemistry sequence at F&M that focuses on the mathematically rigorous development and application of the three laws of thermodynamics in addition to the development of mathematical models to describe chemical kinetics.

The lab portion of the course utilizes an inquiry-based lab curriculum. The students in the class are divided into several groups and each group is initially charged with extracting specific thermodynamic and/or kinetic information from a given chemical or biochemical system. The students must engage the primary literature to devise, optimize, and carry out an appropriate experimental procedure to achieve their objective. The students must then analyze their resulting spectroscopic data through non-linear least squares fitting. The students are then provided the opportunity to extend their project beyond the initial prompt, which is similar to previous work in the literature, to ask and potentially answer additional questions about the chemical or biochemical system.

The students then present their results in a written report in journal format and in an oral presentation where they must be able to defend their work. During the remainder of the semester, the lab groups provide their peers in the lab with their optimized procedures to provide an opportunity for each group to perform each lab project. The initial group is responsible for aiding other groups as they carry out their optimized procedures. This peer mentoring helps facilitate engagement of the students with their initial projects.

## Luis M. Campos

Chemistry  
Columbia University



Materials Chemistry is truly an interdisciplinary field. It involves collaborative efforts from chemists, engineers, biologists, etc. Moreover, it is a young field that began attracting attention in the late 1960's, but was not identified as materials chemistry until a couple of decades ago. In fact, only six years ago the International Union of Pure and Applied Chemistry (IUPAC) put forth a definition: Materials chemistry comprises the application of chemistry to the design, synthesis, characterization, processing, understanding, and utilization of materials, particularly those with useful, or potentially useful properties.<sup>1</sup> By virtue of this definition, materials chemistry is a collaborative science! Therefore, it is imperative to teach students to work in teams and communicate with each other at early stages of their development. Underlying the issue of collaboration, creating a diverse environment that attracts women and minorities (i.e., under-represented groups, URGs) to higher education will have positive impact to nurture collaboration and teamwork.

Among several issues contributing to the challenge of scientific cross-pollination and collaboration, there are three aspects that I am focused on changing: the tradition of clearly defining and segregating research disciplines,<sup>2</sup> the notion of the “uneven playing field,”<sup>3,4</sup> and our inability to train young scientists to communicate and collaborate at early stages of their education.<sup>2</sup> The approach that I am taking at Columbia is aimed at K-12 education, and undergraduate/graduate level teaching and research education in the chemical sciences. The pillars to target are: A) Interactive teaching/learning strategies; B) Peer-led mentorship and support; and C) Teaching/learning interdisciplinary research skills.

### A) Interactive Teaching/Learning Strategies

At the undergraduate level, I teach organic chemistry in a way that allows me to connect with the students. For this purpose, I have implemented the use of in-class worksheets as Teachable Tidbits, which I call “Working on Worksheets with Your Neighbors” (or, WoW your neighbors). Working in groups of 3-4 students, they are introduced to a topic and asked to fill out the worksheets, discussing answers with each other. Although there are ~200 students in the course, they manage to self-assemble and solve problems without prior knowledge of the subject covered. The key is to scaffold the worksheets so that the students arrive to conclusions on their own, by building from the questions posed in the worksheet or at the beginning of class. With this approach, the students are faced with a new concept for the day, and they learn by synthesizing the information based on the cues from the worksheet. The assessment of this activity comes in the form of a concept inventory<sup>5</sup> – a series of “quick-fire” multiple-choice questions administered during the midterms. Finally, I use the values-affirmation approach, which has been previously observed to yield positive results toward reducing achievement gaps among URGs in science.<sup>4,6</sup>

### B) Peer-Led Mentorship and Support

Graduate Level: While the active learning methods in the classroom are based on the widely successful concept of peer mentoring,<sup>7</sup> in the past decade I have been interested in peer-led mentoring practices for student recruitment and retention at the graduate level. As a graduate student, I founded the Organization for Cultural Diversity in Science, and as a Postdoc, I founded the Graduate Students for Diversity in Science. These are two groups running independently at UCLA (11 years) and at UCSB (8 years). The support groups have been widely successful. They are run by students and funded by independent sources. A similar chapter will start at Columbia next year.

K-12, Educational Outreach to Middle Schools in New York: Graduate students from the Campos group lead science demos for 7th grade students from Children's Zone Promise Academy 2, located in Harlem, NY. We work together with Ms. Cleo Hirsch to expose her students to graduate and undergraduate student life at Columbia. Each semester, 20-25 students visit our campus and our laboratories. They

receive safety training, lab coats, goggles, and gloves to do hands-on experiments that teach concepts in energy, lab protocols, and collecting data, among other concepts.

General Community, Science Exclamation Point: In this activity, the improv troupe Thank You, Robot, invites scientists to give short lectures in their fields of study. Following each talk, there is an exploration of the presented topic in the form of improv comedy. I have worked with the improv team delivering research talks at local bars. Additionally, a similar act was taken to Columbia University to my Organic Chemistry class, attended by approximately 200 students.

### C) Teaching/Learning Interdisciplinary Research Skills

I have an extensive track record of working in teams, tackling challenging research topics in device physics, engineering, and biomaterials. Collaborative research in the sciences has become a common ground for next generation leaders, especially in the chemistry of materials. Considering the multiple interactions that arise from interdisciplinary research in academia, national laboratories, and industry, students must be exposed to a diverse research environment to build marketable skills to earn placement in competitive research environments. Students in my group work with scientists in various fields and locations worldwide.

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**Neal K. Devaraj**  
Chemistry & Biochemistry  
University of California, San Diego



It is becoming increasingly clear that the next-generation of chemical biologists will be primed to make distinct and important scientific advances. However, a well-recognized issue is the lack of formal undergraduate training in chemical biology.<sup>1</sup> Since arriving at UCSD, I have strived to establish myself as a leader in the classroom by developing innovative new courses and outreach efforts at the interface of chemistry and biology. One of the privileges of being at UCSD is the ability to conduct cutting edge research while simultaneously having opportunities to teach the next generation of chemists how to think critically about science. UCSD has one of the largest chemistry undergraduate programs in the country, with an average of 1200 declared majors, and I believe it is poised to be a great incubator of future chemical biologists. Below I summarize my efforts to date in advancing chemical biology education at UCSD and the broader San Diego area, and outline my proposed educational efforts.

Since arriving at UCSD, I have developed two new courses to engage students interested in the field of chemical biology. The first course is an undergraduate and graduate (co-listed) course entitled “Chemical Biology” (Chem 116/216). This course covers current topics in chemical biology, historical advances, recent literature, major developments, and the mechanism of various tools that are frequently used in chemical biology studies (e.g. mass spectrometry and fluorescence microscopy). UCSD has a core strength in research at the interface of the chemical sciences and biology, and each year we recruit numerous graduate students interested in pursuing chemical biology research. However, when I started at UCSD, it was surprising that we offered no formal coursework that exclusively focused on the subject of chemical biology. Since development of the chemical biology course, it has quickly become our department’s most popular graduate course, and currently ~50 graduate students are enrolled. This includes students not only in the Chemistry and Biochemistry department but also students from Chemical Engineering, the Scripps Institute of Oceanography, Bioengineering, and several graduate students from the San Diego State University. The variety of academic backgrounds helps to enrich the multidisciplinary spirit of the course and serves to introduce and expose chemical biology related research and techniques to graduate students in the broader San Diego chemical sciences community. With an enrollment of ~25 undergraduate students, Chem 116/216 is one of the few undergraduate courses that exposes students to substantial primary academic literature, making the course highly relevant to those undergraduates that are concurrently pursuing research in chemical biology labs. I place a large emphasis on the preparation of our undergraduates for real world science by exposing them to the exciting breadth of research that is included in “chemical biology” and introducing the material in a way that promotes discussion and creative problem solving. I have been thrilled to hear from several undergraduates about the impact Chem 116/216 has had on their future professional and academic pursuits.

The second course I created is an undergraduate course for pharmaceutical chemistry majors entitled “Drug Synthesis and Design” (Chem 168). In recent years, UCSD undergraduates have shown increasing interest in the pharmaceutical sciences. This interest has been driven by a desire to understand the application of the chemical sciences to biological problems and the appeal of pursuing medicinal chemistry careers. An outcome has been a dramatic surge in the number of our pharmacological chemistry majors over the last 10 years. Today, UCSD’s pharmacological chemistry major is our department’s largest major, with an average of 450 students. Unfortunately, when I arrived at UCSD, there was only one core class associated with the major, which focused on pharmacokinetic principles. In response, I developed Chem 168 to fill this need. My course covers practical methods to make drugs currently in clinical use. We discuss small molecules, biologics, and hybrids such as antibody-drug conjugates. Topics include fragment-based screening, solid phase synthesis, directed evolution, and bioconjugation. Many of the students in this course have gone on to chemistry or pharmacy graduate school.

In addition to lecturing in the classroom, I have also engaged undergraduates with research opportunities in my lab. I have mentored 9 undergraduate research students through the UCSD undergraduate research program, many whom come from underrepresented backgrounds. Several of these students have become

coauthors on our group's publications. I am also an active participant in the Research Scholars program, having mentored multiple high school students in the lab during the summer months. One such student, Sampreeti Chowdhuri, recently had a first-author paper accepted in the well-regarded chemical biology journal, *ChemBioChem*, and she is now pursuing premedical studies at the University of Southern California.

Selection as a Camille Dreyfus Teacher-Scholar will help expand my current outreach efforts, which have extended to the development of extracurricular outreach activities in chemical biology that reach students in San Diego at the graduate student, undergraduate, and high-school level. It is extremely important at the K-12 level to foster student's interest in the chemical sciences, particularly those from underserved communities, preparing them for a postsecondary education.<sup>2</sup> To this end, I have been working with the UCSD Center for Research on Educational Equity, Assessment, and Teaching Excellence (CREATE) and have developed an educational component integrating our bottom-up synthetic cell research with an existing coordinated effort at UC San Diego to improve the STEM pipeline K-20 in San Diego. In particular, we focus on reaching populations typically underrepresented in STEM fields. Specifically, this coordinated effort links our lab's research interests and results in the chemistry of lipid synthesis with two efforts at the university: 1) the San Diego Science Project (SDSP), a K-12 professional development and teacher support organization training both UCSD undergrads and teachers to engage science content with secondary students and 2) the TRIO Upward Bound Math/Science Program (UBMS), a federally funded outreach program that aims to increase the number of underrepresented minorities and low-income youth that enroll in undergraduate education. Our goal is to stimulate the entry of underrepresented and low-income student populations into STEM fields, exposing a range of students and teachers to chemical biology.

I also plan to develop a new laboratory module to introduce undergraduates to the techniques of chemical biology. Although I have introduced chemical biology to undergraduates in the classroom, it is still lacking in the laboratory at UCSD. Studies have shown that students exposed to lab training gain better understanding of subject material compared to those in purely lecture-based classes.<sup>3</sup> By creating an interdisciplinary laboratory focused on chemical biology, I hope to be able to lower the barrier for students trained in one discipline, such as organic chemistry or biochemistry, to work with the skill sets required of the other. As part of our current advanced chemistry laboratory course (Chem 143), I will design a chemical biology module to give students hands-on training in the principles and critical thinking required of chemical biology. The laboratory project will center around our recently developed RNA-TAG labeling technology, and students will have an opportunity to synthesize nucleobase analogs bearing simple fluorophores and biotin, transcribe appropriately modified RNA, label transcripts, and perform gel and imaging studies to verify labeling. The goal will be to expose undergraduates to topical research practices in chemical biology. Since chemical biology is a topic of rising interest in the educational community, I will enable dissemination of this lab course through the planned submission of an article in the *Journal of Chemical Education*. Furthermore, the plasmids required for enzyme and RNA transcript expression will be made readily available, either by request or through depositing in a non-profit repository such as Addgene. Eventually, this module will be used to nucleate a laboratory course focused exclusively on chemical biology projects.

[1] Nat. Chem. Biol. 2015, 11, 900-901.

[2] X. Wang, Am. Educ. Res. J. 2013, 50, 1081-1121.

[3] A. Hofstein, V. N. Lunetta, Sci. Ed. 2004, 88, 28-54.



## Mircea Dinca

Chemistry

Massachusetts Institute of Technology



On the first day of my appointment at MIT, I was exhilarated at the opportunity to work with some of the best undergraduate and graduate students that our nation has to offer. I was also conflicted, however, realizing that the MIT student body is only a minuscule fraction of the nation's undergraduate population and that whatever I did, I may never be able to interact with students who are perhaps just as talented and deserving as our own students, yet who were not fortunate enough or did not have the proper counseling and support to be admitted to MIT. As such, one of my (admittedly, long-term) goals was to try to make MIT more accessible to others. This was a tangible goal given MIT's leadership in the development of online learning platforms with initiatives such as Open Courseware, a program that received one million hits monthly, and the newer edX initiative. Cognizant of the challenges that come with developing online classes that are effective, not least of which are making interactive problem sets, using real-time statistics to provide feedback to students, and rethinking curricula into shorter segments that can be matched in different sequences depending on the instructor or a student's personal progress, I chose to take the long road for making this transition. My teaching duties involved 5.04 – Principles of Inorganic Chemistry II in the Fall (an undergraduate inorganic chemistry class taught from 2010 through 2015), and 5.068 – Physical Methods in Inorganic Chemistry in the Spring (2012 through 2016). Whereas the curriculum for 5.04, an undergraduate class is somewhat rigid, 5.068 is a graduate class focused on discussing the various physical (spectroscopic or otherwise) methods of analysis of inorganic molecules and solids. The latter is particularly amenable to modular teaching approaches. In the last 3-4 years, I have rewritten the curriculum for MIT's course of Physical Methods in Inorganic Chemistry (5.068), with the aim to develop an interactive, web-based, and textbook-free course. My primary goal was to deviate from the monologue lecture style that has solidified over centuries of academia when information came almost exclusively from the professor, and when the only way of testing students was through homework assignments and periodic examinations. In doing so, I was inspired by the revolutionary results obtained with fifth and sixth graders in California's Los Altos School District, which recently replaced math instruction classes with interactive videos offered by the online Khan Academy. The students were asked to watch the "lecture" videos at home, while in-class time was used for solving problems and for discussion. Teachers were much more effective in class because they catered to the individual needs of each student, rather than delivering a "one-size-fit-all" lecture, and they were able to follow in real time the progress of each student much more easily than by simply grading a quiz or a homework. Lectures in 5.068 were significantly changed from previous versions where more emphasis had been placed on bioinorganic techniques. In my syllabus, heavier emphasis has been placed on materials and solid state techniques. I also experimented with an alternative grading scheme where 30 minutes final presentations and 10-page final papers replaced the final examination in Spring 2012. Following students' suggestions, this format was reverted to final presentations and a final exam in Spring 2013. Excellent feedback from the Spring 2013 semester encouraged me to maintain this format for Spring 2014, when only some of the lecture content was enhanced with respect to 2013. One of the features of the class that students seem to enjoy, despite its perceived difficulty, was the final presentation, where students were required to critique a paper that made extensive use of one of the techniques discussed in lecture. The class preparation for these final presentations was excellent. Students were also graded based on their participation in class and during the final presentations. The general response for this format was positive because the students felt they could focus on topics that would help them during their research. In view of the positive response for this format, I intend to keep it for future enactments of this course.

Partially as a result of my educational initiatives, I have also been honored as a Cottrell Scholar, a National award for teacher-scholars. As part of my relationship with the Research Corporation for Science Advancement, I will be engaged in interfacing the inorganic chemistry curriculum with MITx and with the newly established Energy minor at MIT, in collaboration with Professors Cummins and Surendranath. Similarly, as part of my engagement with the Tata Center for Innovation and Design, I participate in their Sustainability initiative, my students participating in Tata-organized workshops and Sloan classes that deal with developing economies in a sustainable fashion, with an emphasis on India.

## Student and postdoctoral mentoring

Graduate students in the Dincă lab regularly participate in outside educational enrichment events. For instance, I send all my first year graduate students to a workshop covering presentation design and graphic data design and interpretation, which is typically offered once a year in Boston by Edward Tufte, one of the most recognized names in quantitative data presentation worldwide. Discretionary funds are used for this activity, which cost \$200/student. Graduate students are also encouraged to participate in outreach activities and our group has been active during the summer outreach activities organized by the CMSE and the MPC at MIT.

Undergraduate student mentoring is also an important part of our educational agenda. Our group has a steady state population of 3-5 UROPs. While each undergraduate student is assigned to a graduate student or postdoctoral scholar mentor, each undergraduate has his/her own project. As a consequence, publications featuring undergraduate students have already appeared in press (Brian McCarthy, Tachmajal Corrales-Sanchez, and Tomohiro Soejima). Our undergraduates also regularly participate with posters to the undergraduate symposium organized by Prof. Cummins, and I have served as a judge for the last four editions of this event. My group has also participated, three years running, in a summer research program for high school teachers. I offer, again from discretionary funds, research space and supplies for two months for a high school teacher. This experience has been very fulfilling for my group; significantly, one of our summer high school teacher/researchers figures as a contributing author to one of our recent publications (Talia Clark).

## Jason G. Gillmore

Chemistry  
Hope College



I have known I wanted to be a chemist since I was a sophomore at North Hunterdon High School in Annandale, NJ, inspired at least in part by the Exxon research facility across the street! By the time I finished my BS/MS at Virginia Tech, I aspired to an academic career. I liked to teach, liked research, and was beginning to savor the special sense of independence only an academic career could bring. Early in my PhD work at Rochester, I mentored a talented young REU student from Miami University. It was then I realized my calling! I still liked research, still liked teaching, and was developing an interest in constructivist pedagogy. But what I absolutely loved was the hands-on mentoring of undergraduate students embarking on their first significant independent foray into research. After ten years on the faculty at Hope College, I continue to delight in research in the laboratory and library, enjoy teaching laboratory courses, and especially love to both lecture and apply pedagogies of engagement in the classroom. Yet my deep abiding passion remains the spark of discovery and budding scientific independence I am privileged to witness as undergraduates embark on real research. While at Hope, I have shown leadership in improving student learning in organic chemistry, increasing the depth and breadth of students' undergraduate research experiences, and preparing future faculty for careers at primarily undergraduate institutions (PUIs). In each case, I have adopted and adapted best practices from the literature and my own experiences, articulated a clear and incremental plan for improvement, and demonstrated the value of the change through high quality assessment.

***In the classroom:*** My primary teaching responsibilities are in the CHEM 221,231 Organic I & II "lecture" sequence (35-75 students/semester), and the CHEM 255,256 Organic I & II laboratory sequence (16-20 students/semester). Upon my arrival at Hope, I began implementation in CHEM 221,231 of the Peer-Led Team Learning (PLTL) model I had learned at Rochester from the late James Flack Norris awardee Jack Kampmeier. I had observed firsthand the powerful sense of ownership of content and increased problem solving ability students gained from this constructivist approach, which could be added to a traditional lecture course with minimal disruption to other course components. At Hope, we retained three traditional chalkboard lectures each week but replaced a weekly faculty-led recitation session with a group problem solving session. Essentially we implemented the team learning aspect without genuine peer leaders. Instead my faculty colleagues and I served as roving "leaders" in the first year, and then added the assistance of 1-2 roving undergraduate TAs in subsequent years. Since obtaining NSF funding for PLTL as part of my CAREER award in 2010 we have fully implemented PLTL in all sections of the course, with a dozen or more trained peer facilitators each semester facilitating groups of 6-10 students tackling challenging problems that expand upon what is seen in lecture and homework. The facilitators are students previously successful in the course with good "people skills" whom I train in constructivist pedagogy and group dynamics and provide with appropriate refreshers on the course content. My organic colleagues have whole-heartedly embraced this methodology and continued implementation even in several semesters I have been absent from the course. With the assistance of the College's Carl Frost Center for Social Science Research, I have completed a major assessment of our PLTL implementation, including grade and ACS exam outcome data (spanning 30 years of pre-implementation, partial implementation, and full implementation) as well as student and leader surveys and focus groups. Preliminary analyses indicate significant objective gains in ACS exam percentile scores and course grades, while qualitative data support student and leader perceived gains in content knowledge and problem solving ability, and leaders' group facilitation skills.

In the second semester of organic chemistry lab, students can elect to take CHEM 256B, an optional second credit continuation. These students learn to use the library and SciFinder, craft their own proposals for a three-step synthesis of a target of their choosing, and order supplies and chemicals. They then have five weeks to execute the syntheses, purifications, and characterizations, and prepare a comprehensive report. When I arrived at Hope, these projects either focused on a theme ("everyone must employ a Robinson annulation") or were dependent on student fancy ("something purple" or "something that smells pretty"), and the products ended up in chemical waste. I have led my colleagues in shifting this

to an increasingly research-relevant opportunity in which students have contributed molecules to the research programs of almost all the faculty in the department (and even to a few biologists, physicists, and engineers). This gives students the opportunity to contribute to authentic research while remaining independent and largely self-directed. We also are “greener” by making compounds of use rather than just chemical waste. Many students use this as an “in” to a research group and springboard from these projects into full-time summer research. It also provides a research experience for students we are unable to accommodate in our individual research groups. Together with our organic lab coordinator, I am in the midst of a major assessment of our laboratory sequence and particularly the independent projects, based primarily on an extensive multi-part implementation of the CURE survey. We have presented these results, indicative of gains approaching those of a summer research experience, nationally and are currently preparing a manuscript on this work.

*In the research laboratory:* I find the research laboratory to be a place not only for the advancement of science through research, but also one of my most significant educational activities. An important part of my research program has been providing opportunities for students who might not typically get the chance to do research, including under-represented minority high school students and two-year college (2YC) students. Hope has developed relationships with several regional and Chicago-area 2YCs. These schools are typically more ethnically and economically diverse than Hope. I have enjoyed establishing a collaboration with Prof. Dan Stanford at Harper College, working with several of his students over the years who begin their work in his lab before coming to mine for a summer or more. It has been rewarding to see these students go on to successfully complete four-year degrees (some of them at Hope), having built confidence, competence, and a relational support network through research. We have even published together, both scientifically and on the 2YC-PUI pipeline.

My group’s ongoing physical organic research program is not only fundamentally interesting and technologically relevant, but also ideal for the development of the next generation of organic chemists. Photochemistry predominates, particularly in the area of photochromic rearrangements. These rearrangements are of interest for changes in redox properties (photochromic photooxidants – a decade-plus long project in my group) or coupling molecular to macroscopic shape change (for photomechanical materials – an exciting new collaboration of my group with a colleague in mechanical engineering and materials science). The necessary photochemical, photophysical, electrochemical, polymer, and materials science concepts that underpin these research endeavors broaden students’ organic experience. These are topics that are covered sparsely, if at all, in the traditional undergraduate curriculum. The experimental horizons of students in my laboratory are similarly broadened as they conduct photochemical experiments, UV-vis spectroscopy, steady-state fluorescence measurements, cyclic voltammetry, etc. Our work also reinforces more fundamental and deeply satisfying skills in making molecules, purifying, and characterizing them. Such a core skill set is vital if one wishes to proceed in any area of organic chemistry, be it at the bachelor’s level, or in pursuing further study in natural product synthesis, methodology development, medicinal chemistry, materials chemistry, or mechanistic study. Meanwhile the diversity of intellectual topics and the sequential and global thinking required to conceptualize and contextualize the entire project contribute to the critical thinking skills, logic, and problem solving abilities of students regardless of eventual aspirations. The modular nature of the research (syntheses and structural characterizations of varying complexity, photochemical and electrochemical or materials characterization, applying our molecules to real systems, and supporting computational studies) allows a maturing progression for long-term students (I keep many students for 2-3 years), as well as the opportunity for shorter-term students to choose a manageable piece of the overall program suited to their individual interests and abilities. Effective communication is an essential skill for all students. Thus all students in my group present at least annually at a formal College-wide Celebration of Undergraduate Research. Summer researchers all present both a short seminar and a poster in symposia here at Hope. Most present at regional or national meetings as well. All group members prepare written progress reports each semester and summer. A final report in journal article format is required prior to a student leaving my group or substantially changing projects. All students are expected to prepare at least the experimental section of any publication arising from their research. Advanced students are also encouraged to contribute to other writing associated with publishing their work. Nearly the entire first drafts of three of our four most recent journal articles were prepared by the respective undergraduate first authors on these papers. Students from my group have gone on to a range of excellent graduate (Michigan, Michigan State,

Texas, Wisconsin, Central Michigan, Northern Illinois) and medical (Michigan, Iowa State, Wayne State) programs as well as directly into chemical industry (Dow, Perrigo, Pleotint, FONA International). My first research student to complete his PhD is currently a tenure-track Assistant Professor of Chemistry at Seton Hill University, a PUI in northwestern PA.

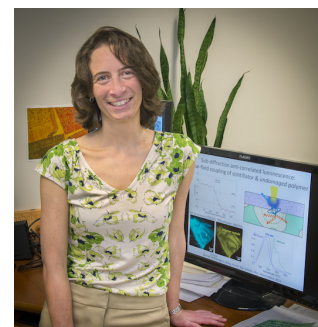
*Preparing future faculty:* A burgeoning passion of mine is to mentor future chemistry faculty. While preparing my NSF-CAREER proposal, I identified a need for more professional support for post-docs considering careers at PUIs. I proposed a biennial three-day “Postdoc to PUI Prof” (P3) workshop at Hope College focused on developing future chemistry faculty and increasing awareness among postdocs of the diverse career possibilities provided by the broad range of PUI types. We recruited panelists from a range of teaching-centered and research-rich undergraduate institutions spanning public, private, and Church-affiliated two-year, liberal arts, and comprehensive institutions. We presented sessions on the range of academic institutions, faculty life and expectations, preparing application packages, interviewing, negotiating offers, funding and grantsmanship, launching a research group, and a sampling of modern pedagogies, as well as networking opportunities. We required participants to submit mock faculty application packages that are individually reviewed and critiqued by the panelists ahead of the workshop. We received 250+ competitive applications for what was originally intended to be a total of 65 spots in our first two workshops, expanded to over 100 thanks to generous ACS co-sponsorship. To date nearly half of our participants have secured positions at PUIs! As NSF funding for the biennial workshop at Hope expired, ACS took on a slightly smaller but annual commitment to fund the workshop continually, now based on a past host, host, future host model, rotating across the country at the nation’s most research-rich PUI’s while drawing panelists from the full range of PUIs within that geographic region – the first such annual workshop was held at Furman University (SC) in 2016, with the next at Trinity University (TX) planned for 2017.

I hope these examples illustrate the co-equal educational mission of my career as a teacher-scholar at a research-intensive undergraduate liberal arts college. At Hope I have been able to conduct and publish important scientific research with undergraduate coauthors, make and assess meaningful changes in the chemistry curriculum, and become a leader in important professional development work. I continue to find this breadth of involvement deeply fulfilling and look forward to a long future of guiding the development of more undergraduate students in the research laboratory and the classroom and, with the ACS, growing professional development opportunities for new and future faculty.

## Naomi S. Ginsberg

Chemistry & Physics

University of California, Berkeley



To be able to connect with and transform the perspectives of a diverse, ‘state school’ student body has been more gratifying than I could ever have anticipated, and is a responsibility that I do not take lightly. Below, I summarize my dedication to undergraduate education through a combination of my approach in the classroom and as a mentor in the research lab and beyond.

Undergraduate teaching: I have primarily taught upper division physical and biophysical chemistry. These courses are ones for which many students show up with an unfounded negative preconception that they will be unable to master the mathematical manipulations or the physics-related material. Some of my students are interested in grad school, some aspire to be doctors, yet most do not plan to be physical or biophysical chemists. I teach the why and how behind many equations that are mainly stated, memorized, and used in general chemistry. To get the students interested in going deeper, my first task is to build trust, to erase any negative attitudes about the students’ potential, and to provide clear motivations for why they will end up more satisfied with a deeper understanding of the origin of many common chemical phenomena. This often involves physical demonstrations to help in visualization, but it also includes a little physical comedy, puns, poems, learning the majority of their names, and a lot of ‘audience’ participation and feedback. Presenting myself as a professor who is herself only human enables otherwise hesitant students to begin viewing the material at face value and themselves as physical chemists. Then, enthusiastically covering the curriculum is far more effective toward our learning goals. I emphasize that achieving the highest degree of understanding of a physical concept requires being able to explain it with a compulsory combination of physical pictures, graphs, equations, and words. The students get out what I put in so they spur me to put in even more. I attribute the recognition I’ve received for my teaching to my taking the students through the same thought process that I underwent when first struggling to learn the material. This approach has inspired many elaborate new homework and exam problems, and I emphasize it to my teaching assistants to help them best relate to the students as well.

Consider several classroom examples that embody my teaching philosophy, starting with Biophysical Chemistry, a class that treats quantum mechanics and spectroscopy applied to biomolecules. While students often think quantum mechanics is abstract, even when applied to molecules, my main objective is to show them all of the ways that quantum mechanics affects their everyday lives. Since demonstrations truly inspire the students, I begin this class with the quest to explain not only why my vial of pigment-containing proteins looks orange, but also why it turns red when I illuminate it with a green light. Gathered close around my vials, our excitement is infectious and carries them through the tenets of quantum mechanics all the way to proudly estimating the color of different carotenoid isomers several lectures later. With repeated comments like “our quest is to understand what about a molecule’s structure gives it a particular color”, I can better equip students with a context in which to accept abstract concepts, like the canonical ‘particle in a box’ calculation. In another variety of demo, I ask the students to keep track of the ‘resultant vector’ of my two arms while simultaneously swinging them in opposite directions at different rates (takes practice!) to help explain complicated spatiotemporal concepts like optical rotator dispersion. I am equally apt to dizzily portray a proton spin in a magnetic resonance experiment. In my well-attended midterm and final exam review sessions, I have the students use their arms to show possible normal modes of a methylene group as a seventh inning stretch. They remember the motions from my earlier demo. I also have the students in this class do an edifying final project in which they report on a journal article of their choice that describes a spectroscopy we’ve studied applied to a biological system. Overall, my hope is that they will be able to look at a spectrum taken with radiation from any part of the electromagnetic spectrum and work their way back through identifying transitions in an energy level diagram to visualizing the molecular processes occurring to create the spectrum. On the final exam, they practice exactly that, usually applying every single type of spectroscopy that we covered to the same, newly introduced system.

Similarly, when I teach statistical mechanics, thermodynamics, and kinetics, I emphasize what a system looks like at different stages in a process. For example, after drawing a giant phase diagram on the chalkboard, I ‘decorate’ by sketching on it how the different phases appear in order to relate our ‘shorthand’ plots of coexistence curves to what we might visualize inside the system. My exams guide students stepwise toward solving an important problem; some even say they are fun! For example, following Randy Schekman’s Nobel Prize, the students had to consider the mass equilibrium governing an idealized vesicle budding scenario. As an extra credit assignment, inspired by the challenges of composing the most pedagogical homework and exam problems, I have the students develop their own. Former students repeatedly tell me how my class prepared them for further studies or for the hard-core problem solving on their MCAT exams.

In my office hours there are no foolish questions. For instance, a student once appeared with an accumulation of questions she had been unwilling to pose. I insisted she ask some, in spite of her calling them silly. They were deep and excellent points of discussion for all of us; this one event empowered all those present to more confidently ask questions for the rest of the semester, even when in larger groups! Another one of these students gave me a thank-you card stating, “you saved me [from leaving chemistry]” after her first semester transferring to Berkeley! Office hours also include chats about how our course relates to others and about science research, graduate school, and industry jobs. Those chats often extend to more personalized advising meetings, overseas phone calls, or sorority dinners to help students chart their careers.

Undergraduate research mentorship: I recently taught a course that introduces our ~120 freshman majors to research. Teaching the course previously consisted of coordinating a set of research talks by col-leagues, some student and alumni panels, and a final poster project for which the students interview a grad student about research. In addition to continuing these traditions, I spent the start of each lecture presenting an overall context for undergraduate research. I described the 5 W’s of research, how it differed from class-work, and what unexpected activities it can entail. I also discussed how to choose an area, how to apply for positions, how to be politely persistent in pursuit of a position, and how to pitch seemingly unrelated hobbies that involve problem solving (like experimental baking or motorcycle repair) as valuable experience when the students feel they have none. I consolidated this advice into a comprehensive resource now being disseminated more widely through our department website (<http://eduinfo.cchem.berkeley.edu/research-tips.shtml>). At our poster session, I asked each of the students I encountered if they would like to do research in the lab that they had learned about. A few were very eager, but I was delighted that those who said “no” said so because they had already developed an idea of which areas of chemistry might be better suited to them! Speaking with the students one-on-one also underscored that individualized encouragement is often a required catalyst to enable them to act on their interests.

In my own lab, I have had a total of 6 undergrads, three of whom are women and one of whom is an underrepresented minority. When asked the size of my research group I reflexively include them in the count, and they rise to the occasion when I explain that they will ultimately obtain the same rights and responsibilities as the grad students. I spend countless hours ensuring that everyone understands the major goals of their projects, obtaining the resources required for success, and fostering the critical thinking that will keep their projects on track. Each student is exposed to many different experimental methods, both in our lab and around the campus, and they are fully integrated into their subgroup activities. As a result of their significant contributions, my first three undergrads have all been co-authors on our publications, and the three newest students are each now involved in preparing manuscripts. I also coach the students toward delivering stellar presentations in our group meetings and at our annual college undergraduate research fair, even if they start out very shy. I have successfully nominated all of them for summer research stipends, and over half of them have insisted on staying on in the lab to work on their projects after graduation, as a testament to their positive experiences. I explain in advance what grad school and its application process entail, and I have counseled those in my lab and a larger number of others for whom I write letters or whom I meet at student panels on deciding where to apply or accept. Many departing students take me up on the offer to keep in touch.

As a final note, my favorite day on the academic calendar is graduation. Making my way down the student queue before the procession to catch up one last time, the atmosphere is joyous. Each year I remark there is no other day that a professor's dedication to education is more celebrated.



## Joshua E. Goldberger

Chemistry & Biochemistry  
The Ohio State University



Having been raised in Northeast Ohio and receiving my undergraduate education at OSU, I am excited to be an Assistant Professor here. The Great Lakes Region is currently in the midst of trying to shed its “Rust Belt”-status, a term that exaggerates the now-defunct centers of heavy industry.<sup>1</sup> For much of the 20th century, this region was the manufacturing center of the United States. However, the combination of globalization and free trade agreements caused US manufacturing to decline from 25% of the economy in the 1960’s to 15% of the economy in 2007.<sup>2</sup> The lack of opportunities in recent years has caused a mass exodus as census data shows that from 1990-2010 over 420,000 people aged 20-34 moved out of Ohio.<sup>3</sup> These effects can be partially ameliorated by encouraging greater levels of student involvement in science, technology, engineering, and mathematics (STEM). According to the social scientist Richard Florida, the “creative class,” the core of whom consists of a STEM educated workforce, fuels the economic-development of post-industrial cities.<sup>4</sup>

I believe, as researchers and educators, it is paramount for us to develop education programs that promote STEM as the foundry of innovation, ideas and lifelong career opportunities. As I teach in my general chemistry class, I’m struck by the fact that many revolutionary materials-based discoveries were made in this region. For example, the electrolytic purification process of aluminum discovered by Charles Martin Hall at Oberlin, dramatically lowering its cost and allowing it to become an inexpensive, manufacturable material. The need for innovative materials discoveries is even more critical in the 21st century economy. Some of the biggest challenges we face today, such as the growing demand for energy and fossil fuels, can only be solved by new discoveries that will be made by physical scientists. I have a strong dedication to the education of the next generation of students in the chemical sciences, both in mentoring the next generation of students, and via less-traditional laboratory-based approaches. Below I summarize my accomplishments and describe my future plans.

**Student Mentoring:** The most significant impact that a PI can have is mentoring the next generation of students into sharp, effective, and creative scientists. My current research group consists of eight Ph.D. students, and four undergraduate students. Group alumni include three postdoctorate researchers, 1 Ph.D. student, 2 M.S. students, 6 undergraduate students, and two high-school researchers. My advisees have been successful in landing STEM-related positions. For instance, my first postdoctorate researcher Yi-Hsin Liu is now an assistant professor in the Department of Chemistry at National Taiwan Normal University.

I have actively recruited undergraduate students to participate in research. Since one of the major reasons that I decided go into the field of chemistry rather than medicine was my undergraduate research experience, I am passionate about giving undergraduates the same positive experience that I had. The undergraduate researchers in my lab have been incredibly effective researchers and have contributed as either lead-authors or co-authors on eight publications, and have won many awards. Of the six undergraduate alumni in my research group, three are now graduate students in chemistry or materials science programs. My training program is to initially give each undergraduate their own short term research project under the supervision of a graduate student who will help train them in the wide versatility of techniques that are necessary to conduct modern materials research. As they progress, I seek to foster the same amount of independence that I would give an upper-level graduate student. I expect that they come up with their own ideas, and learn how to troubleshoot independently.

**Research Experience to Enhance Learning (REEL):** Exposing large numbers of undergraduates to cutting edge research experiences will not only demystify the scientific process but encourage greater numbers of students to pursue academic research by showing them that the unknown is fun and exciting. The Research Experiences to Enhance Learning (REEL) is an originally-NSF sponsored program whose stated goals include; 1) transform the current 1st and 2nd year chemistry courses into a research-intensive program so students will pursue additional scientifically oriented training, appreciate scientific and ethical

nature of research, and adopt the scientific method as a lifelong problem-solving technique, 2) increase the retention and graduation rates in STEM fields.<sup>6</sup> As a result, OSU has now implemented research modules in the tail end of their general chemistry and analytical chemistry laboratory sections. During the 2012-2013 academic year, ~2500 general chemistry students participated in a REEL laboratory project in the second semester class. A research module is a self-contained research project that integrates numerous lecture concepts together, exposes students to current problems, and gives them the opportunity to adopt the scientific method. Students have an opportunity to design their own experiments, collect data, analyze their results and communicate their findings. Ideal research problems are those with immediate technological relevance that investigate a large parameter-space such that the combined efforts of the students generate a combinatorial set of data that leads to useful scientific knowledge.

From 2010-2012, I helped design and implement a REEL module that focused on discovering new dyes for dye-sensitized solar cells (DSSCs) in my second semester general chemistry course. This lab integrated numerous lecture concepts, including materials and solids, inorganic chemistry, electrochemistry, and thermodynamics. In its current implementation, this lab tasked students to identify a dye that could be extracted from a food or plant source that would produce the highest open-circuit voltage ( $V_{oc}$ ), and prepare a DSSC with it. The team with the highest  $V_{oc}$  was awarded bonus points. My students thrived on the competition and actively dug through the scientific literature to target dyes and separation protocols. According to course comments, this lab was far and away the student's favorite lab in the general chemistry series, REEL: I propose to redesign this REEL module to provide a more valuable educational aspect. Students would often hypothesize that the dye that absorbed more visible light would correlate with a greater  $V_{oc}$ . However, in a DSSC, the  $V_{oc}$  relies strongly on the difference in relative redox levels between the  $TiO_2$  conduction band, the chromophore, and the electrolyte, whereas the wavelength-dependent incident photon to charge carrier efficiency (IPCE) is better correlated to the absorption spectrum. Thus, it is challenging for students to make an informed hypothesis of a winning dye. Instead, we will design an initial lab period to first give students a preliminary understanding on how the efficiency of a DSSC depends on the absorption spectrum and redox potentials of the dye's HOMO and LUMO, before they make their hypothesis. They will measure the absorption spectrum of various dyes that will be provided (metal porphyrins), and give them the redox potentials. This data will be compared to IPCE and current voltage (IV) curves of DSSCs fabricated from these materials. In the remaining 2-3 lab periods, students will identify and isolate a dye from a food or plant source of their choosing, construct a DSSC with it, and measure both the IV and IPCE curve of their solar cell. The students will also measure the absorption spectrum of their dye and determine how it correlates with their I-V and IPCE measurements. We will test-run this lab in a ~60 student Honors General Chemistry lab before integrating it into the larger General Chemistry sections.

By the end of the modified labs, students should be able to (1) explain what dye-sensitized solar cells are and why they are of interest, (2) follow the path of electrons moving through a cell and understand the chemistry at a basic level, (3) be able to comment on what makes a good dye for harvesting sunlight, (4) gain experience and exposure to sophisticated, yet common, laboratory instrumentation that they may not see otherwise including white light sources and absorption spectrometers. We will test the extent that students are able to understand these goals using report questions that they turn in at the end of the lab, which will be prepared in consultation with education evaluation experts from OSU's University Center for the Advancement of Teaching. Also, we will gauge how this lab influenced their interest in chemistry and scientific research with survey questions at the start and end of the term.

**Undergraduate Mentorship:** I will continue to build upon my group's excellent track record of supporting undergraduate research by accepting 1-2 new high-school/undergraduate students every year to join my lab. During the summer I will partner with OSU's Center of Emergent Materials (CEM) REU and high-school program to support at least one undergraduate or high school student. For example, this past summer, I hosted Aisha Iftikhar, a talented 16-year old student from Columbus School of Girls, through the CEM. I will also recruit undergraduate students directly from my General Chemistry class and via various departmental opportunities.

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## André Hoelz

Chemistry & Chemical Engineering  
California Institute of Technology



Having had the great privilege of being trained by fantastic educators and outstanding mentors during all educational stages, I am deeply committed to sharing my scientific knowledge, experimental skills and passion for experimental research with my own students at Caltech, and helping them realize their full potential. In pursuing an academic career, I consider the education of graduate and undergraduate students as important as conducting original research. Since my arrival at Caltech as an assistant professor, I have been actively engaged in a variety of educational activities in both the laboratory and classroom settings. Educating the next generation of scientists that will exceed our greatest expectations and will propagate our established knowledge to future generations is perhaps the most important aspect of our profession in addition to doing exceptional research. In my opinion, one of the best ways to learn science is by doing science. To achieve my educational goals, I have generated a multi-faceted program composed not only of various classical courses I teach at Caltech, but also through providing research opportunities and internships for undergraduate students and students from local high schools in my laboratory. Moreover, I am teaching a practical course that trains students in the hands-on technical skills required to carry out biochemical experiments. Of central importance to me is my commitment to provide research opportunities for minorities, women, and undergraduates from backgrounds which may not make them obvious candidates for a scientific internship at Caltech, such as Caltech freshmen and undergraduate students from liberal arts colleges and smaller universities both nationally and internationally. One of my goals is to maintain cultural, gender, and ethnic diversity within my laboratory by sponsoring students from all backgrounds. Due to the interdisciplinary nature of my research, my group is composed of chemists, biochemists, biophysicists, molecular biologists, cell biologists, structural biologists, chemical biologists, and chemical engineers. This mixture combined with a culture of active communication and mutual learning between students, postdoctoral scholars, and research staff creates a unique, rich, and very broad educational environment in my laboratory, contributing to everyone's scientific growth. Despite having been a faculty member at Caltech for only four years, I believe that the educational programs I have initiated provide a well-rounded education for students from diverse backgrounds and at various skill levels. Prior to joining Caltech, I started my research program at the Rockefeller University, guiding a small group of students. My current educational program was developed based on my combined experiences as highlighted in the following paragraphs.

Teaching undergraduate and graduate level lecture and laboratory courses. In parallel to providing research opportunities in my group for Caltech and Non-Caltech undergraduate students, I am deeply involved in the biochemistry curriculum at Caltech through teaching five undergraduate and graduate level courses: (1) "Frontiers in Chemistry" with Peter Dervan (Ch 10abc), a year-round undergraduate seminar course aims to attract freshmen to join a chemistry laboratory within the first few months on campus, providing them with the opportunity to learn science by doing, (2) "Introduction to Biochemistry" with Jack Richards (Bi/Ch 110), which is directed towards the study of protein structure and function through various classical examples, (3) "Modern Concepts of Cell Biology" with David Chan (Bi/Ch 113), which focuses on the biochemistry of basic cellular processes and their relationship to human disease, teaching students how a mechanistic understanding can provide critical clues for the development of novel therapies, and (4) "Biochemistry and Biophysics of Macromolecules and Molecular Assemblies" with Shu-ou Shan (BMB/Bi/Ch 178), which is the last course of a series describing real case studies of various macromolecular cellular machines and teaches students how to apply the appropriate experimental techniques to decipher functional mechanisms.

In addition to these lecture courses, I am incredibly excited by a new course I have just put together and named "Macromolecular Structure Determination with Modern X-ray Crystallography Methods" (BMB/Bi/Ch 230). This new course combines traditional lectures on X-ray diffraction theory and cutting edge macromolecular X-ray crystallography methods with an extensive hands-on course, which teaches undergraduate students with prior biochemical research experience or graduate students how to determine a crystal structure from scratch. The 3-month course will teach all the necessary steps, including protein

crystallization, crystal freezing, X-ray diffraction data collection at a synchrotron beamline, structure determination by experimental phasing and modern molecular replacement methods, model building, model refinement, model validation, deposition to the protein data bank, and the preparation of publication quality illustrations. Students will determine the structures of a series of GFP variants, with each student working on one variant with a known structure and another novel variant whose structure is yet unknown. I am very pleased that Roger Tsien has provided me with a large series of unpublished GFP variants specifically for his course. Thus, the course will provide the students with the ability to not just replicate the structure determination process conducted by others in the past, but to actually solve a novel structure. At the end of the course, all participants will collaborate on a manuscript that reports the novel structures for publication, which will also teach students how to compose a scientific manuscript. I am very humbled that Caltech has agreed to provide full financial support and cover all expenses associated with this elaborate and costly course. It is intended that the departmental funding fraction of the Camille Dreyfus Teacher-Scholar Award will be used towards this course.

For the next year, I am already planning a complementary biochemistry laboratory course with the goal of teaching students basic molecular biology and biochemistry techniques. Specifically, students will learn to generate bacterial protein expression constructs, to optimize a bacterial protein expression protocol, and to purify a target protein to high purity with cutting edge methods. The protein targets in this instance will be a series of engineered enzyme variants that possess novel catalytic activities. My plan is to teach this course in the term preceding the X-ray crystallography course, providing students participating in both courses with the opportunity to solve the crystal structure of their purified proteins. This setup will not only provide an optimal learning experience for the students, but will also yield results that are of actual scientific significance in that the choice of target proteins will provide insight into the dynamics of large enzymes, data that cannot easily be obtained by any other method.

Teaching and mentoring in my experimental research group. My decision to pursue academic research was largely shaped by two outstanding research opportunities during my undergraduate studies at the University of Freiburg, Germany. My passion for structural biology started in my first research internship in Georg Schulz's group during my freshman year, where I learned all essential X-ray crystallography methods, including protein purification and crystallization, X-ray diffraction data collection, and structure determination through direct mentoring from a very talented graduate student, Clemens Wild. In the following year I joined the Decker group, where another superb graduate student, Susann Schenk, taught me all the basic molecular biology and biochemistry techniques. Together, we identified several new enzymes that act in the nicotine degradation pathway of the gram-positive bacterium *Arthrobacter nicotinovorans*, developed bacterial expression constructs and purification schemes for them and characterized their function through various biochemical assays. My internship was originally setup to last only 10 weeks, but I ended up staying for three years and publishing my first paper. Looking back, these research experiences during my undergraduate education not only sparked my passion for biochemistry and structural biology, but were also critical in shaping my abilities to formulate testable hypotheses and design biochemical experiments. Ultimately, they led me to pursue graduate school at the Rockefeller University, a research powerhouse in the United States. Therefore, I feel very strongly about the importance of creating research opportunities for motivated undergraduate students.

Based on my own experiences, the benefits of such programs are obvious and manifold: top students are identified and recruited into scientific careers, talented and energetic young researchers allow the exploration of new research directions, and graduate students and postdoctoral scholars are provided with mentorship opportunities, skills that they will later use in their independent careers. In addition, by serving on two graduate admission committees at Caltech, for the Biochemistry and Molecular Biophysics (BMB) and the Chemistry Ph.D. programs, I have learned that the most attractive applicants are not only stellar academically, but also possess a substantial amount of research experience. This creates a dilemma for applicants from liberal arts colleges and smaller universities, which are generally less focused on providing hands-on scientific training or lack sufficient capacities to provide research opportunities to all interested and deserving students. Thus, the most successful graduate school applicants tend to be selected from only a small pool of universities with strong traditions in the natural sciences, disadvantaging many able candidates. Therefore, I have decided to provide research opportunities in my group for non-Caltech undergraduate students from colleges and smaller universities to help them identify their scientific

passions and provide them with the necessary research experience to be competitive for admission to top graduate programs. Also, my laboratory regularly hosts freshmen from the Caltech undergraduate programs with the intent that the early practical training will qualify them for competitive summer research internships at different universities. In addition, my group provides research opportunities for underserved public high school students, mostly from the Pasadena area.

My commitment to providing high school students and undergraduates from very diverse educational backgrounds with research experience can best be gleaned from the numbers of student researchers I have mentored in my laboratory since I started at Caltech four years ago, both independently or through existing Caltech programs: my laboratory has hosted a total of 30 students, including 2 minority students and 17 women. To maximize the educational experience for each student while at the same time furthering the scientific goals of my laboratory, I assign undergraduate projects that are independent but related to the work of the graduate mentors. This setup not only fosters the students' original and independent scientific thinking and research. I have also found that, the undergraduates are keen to take ownership of their projects and are very excited to learn more and move the project forward. Illustrating the strong scientific background of the projects, several of my students have managed to receive prestigious fellowships supporting their summer research internship, for example Camille Bayas (Amgen Scholar), Antoine Koehl (Amgen Scholar), Samantha Parsons (Amgen Scholar), Steven Klupt (Amgen Scholar), Jonathan Herrmann (Amgen Scholar), Ellen Yu (freshman, Caltech SURF), Slava Butkovich (freshman, Caltech SURF), and Lennart Schada (Studienstiftung, Germany), and many more. Eight of our publications have undergraduate authors and several more are in preparation. I am particularly proud to note that all my students who decided to pursue a career in experimental research upon graduation, have been admitted to top Ph.D. programs, and joined the laboratories of scientific leaders, for example Jonathan Herrmann (Axel Brunger, Stanford), Camille Bayas (Nobel laureate William Moerner, Stanford), Antoine Koehl (Nobel laureate Brian Kobilka, Stanford), Sandra Schilbach (Patrick Cramer, MPI Goettingen), Lennart Schada (Julia Vorholdt, ETH Zürich), and many more.

Having hosted so many students, I am certain that the best way to teach chemistry to undergraduate students is to get them involved with original research. While classes can be stimulating by presenting some of the exciting established knowledge, exposure to cutting edge research provides the attraction sometimes necessary to get young students enthusiastic and passionate about a field of science. Caltech recognizes this and is able to provide a vibrant undergraduate research environment. However, even at Caltech it can be difficult for an inexperienced freshman to find a research position. Since my own research experience as a freshman sparked my passion for biochemistry and experimental research, it has always been clear to me that as a faculty member I would constantly provide at least one freshman each year with a research position in my laboratory. In addition, I encourage my faculty colleagues to do the same through the "Frontiers in Chemistry" (Ch 10abc) course I co-teach with Peter Dervan, which is designed to attract incoming students to join a chemistry research laboratory within the first few months on campus through enticing faculty seminars.

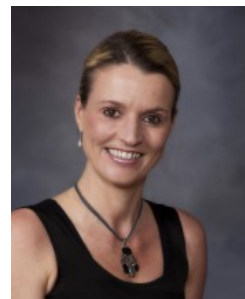
Identifying international talent. Maintaining research excellence in the United States is highly dependent on the identification of exceptionally talented and highly motivated students and their recruitment to follow a scientific career. The established educational programs I described above have helped in the identification of such students from diverse backgrounds in the United States at the high school, undergraduate, and graduate level. On a worldwide scale, I have established an internship program in my laboratory for truly exceptional international undergraduate students. To this end, I have partnered with international funding agencies, faculty members at various research institutes and universities outside the United States, and have served as a judge at the Intel ISEF. Qualified students are invited to conduct research in my laboratory at Caltech for one year, funded either from a fellowship or from my laboratory's research funds. To help international students integrate into the vibrant and diverse community at Caltech, I am serving on Caltech's Foreign Students and Scholars Committee, which organizes a variety of social events. So far, my group has hosted six international students who were all subsequently admitted to top Ph.D. programs and have already substantially enriched the research community, for example Susanne Kassube (UC Berkeley), Daniel Wacker (Scripps Research Institute), Lennart Schada (ETH Zurich, Switzerland), Sandra Schilbach (MPI Gottingen, Germany), Yanbin Fan (Fudan University, China), and Ferdinand Huber (Caltech). All of them obtained research results that earned them co-authorships on

publications from my group and several others are in preparation. I am especially pleased to report that several of my former international undergraduate students have gone on to achieve stunning research breakthroughs that reached international recognition and were published in high impact journals during their graduate studies. One such example is Daniel Wacker, who carried out a structural and functional characterization of several G-protein coupled receptors and reported his results in an impressive series of four papers, published in Nature and Science.

Providing role models for minorities and female students. Finally, I am a co-organizer of Caltech's Biochemistry Seminar Series that invites about 12 speakers per year. In this seminar series, speakers present important advances in the general area of biochemistry, biophysics, and cell biology. Biochemistry and Molecular Biophysics students at Caltech have the opportunity to closely interact with the invited speaker. A particular highlight is the lunch shared by students and the guests, where the research and career path of the invited speaker is discussed in great detail. I am especially focused on inviting leading female scientists as speakers in this seminar series in an effort to provide role models to female undergraduate and graduate students. This is of particular importance as women and minorities remain severely underrepresented in academic positions. Whereas the graduate student entry classes have an equal fraction of male and female students, only a much smaller percentage of female postdoctoral scholars ultimately apply for independent faculty positions. I am especially proud to note that I have received wonderful feedback, especially from female undergraduate and graduate students, demonstrating the effectiveness of this educational program.

## Andrea E. Holmes

Chemistry  
Doane College



My highest expectation of myself is excellence in teaching, service, and research. More importantly, it is my goal to combine these three expectations in order to create a unique learning experience for undergraduate students at our small liberal arts college.

What makes Dr. Holmes' teaching so unique is her inclusion of hands-on experience; using research as a teaching tool; implementation of hierarchies of students mentoring students; outreach to secondary students; and her industrial/governmental connections that she shares with students.

### Teaching organic chemistry

Dr. Holmes is an organic chemist by training who has made several advancements in her discipline. In lecture, she ensures that students are actively engaged. In lab, she ensures that students gain experience with sophisticated technical instruments. One example of Dr. Holmes' creativity in her teaching is the topic of three-dimensional thinking, stereochemistry, and chirality. These areas continue to prove a large challenge for students. To engage students more actively in learning about this complex material, she involved her students in new lab experiments that were based on recent literature in chirality. She and her students used circular dichroism to conduct several chirality experiments, including the conformational analysis of DNA, proteins, and enatio-discrimination of enantiomers. The project led to students' better understanding of chirality as a feature of molecular structure. The circular dichroism instrument used for these activities was funded by a Course and Curriculum and Laboratory Improvement grant awarded by the National Science Foundation (NSF).

To further allow students hands-on access and experience with modern state of the art technology, Dr. Holmes designed Nuclear Magnetic Resonance (NMR) experiments that would allow her students to learn about cyclo-hexanes chair conformations and enzymatic resolutions of diastereomers. Several publications co-authored by her undergraduate students also resulted from these pedagogical innovations, including in The Journal of Chemical Education. The NMR instrument was obtained by a Major Research Instrumentation grant awarded by the NSF.

### Fostering interest to produce scientifically literate students

To help freshmen chemistry students become familiar with the chemical field, Dr. Holmes has designed a new professional development course (CHEM 110) that introduces the chemistry major to potential careers in chemistry, as well as preparation for life after Doane. This course exposes students to a wide variety of careers for chemistry and biochemistry graduates and taught students key skills in seeking those careers. Other topics that are addressed are professionalism, opportunities for undergraduates, prerequisites for professional/graduate school, and more. Through collaboration with Doane's College to Career Center, Dr. Holmes developed several major industry partnerships, providing places for students to pursue internships and begin their careers in the field.

She also co-designed the subsequent course for freshmen. "Chemical Research Course," that introduces the students to research being done at Doane and other institutions by their senior peers. This shows the chemistry freshmen what options they will have in the future and what type of research projects are available to them in the junior and senior years. To close the loop once the chemistry students are seniors, they enroll in a research communication course that provides them an opportunity to present their research to the freshmen in the same course that they had taken when they were first-year students. Dr. Holmes pushed for these changes to improve program outcomes; retention of students; preparation of students for their future (career and/or graduate school); and to create a community on campus for chemistry and biochemistry majors.



## **Role in Experiential Learning**

Dr. Holmes has provided extensive opportunities for experiential learning through research experiences and internships. In the past ten years, she has mentored a minimum of 11 students from various class-levels in research projects during each academic year and summer. Besides undergraduates, she has worked with numerous high-school students and high school teachers, many of them coming from disadvantaged socioeconomic backgrounds. In addition to chemistry students, she has involved biology, environmental science, math, and biochemistry students. These research experiences have been possible in large part due to the efforts of Dr. Holmes in seeking extramural funding. In the past ten years, Dr. Holmes has been awarded several major awards totaling over 3.5 million dollars. She has secured many of these as the sole PI, and others as a Co-PI. This funding has procured major instrumentation; contributed to the general fund and the science discretionary fund; and provided students and faculty with the resources necessary to carry out high-level research with undergraduate students at Doane College by providing salary and stipends for the students, and funds for research supplies.

In addition to student research experiences, Dr. Holmes has a close connection to Novel Chemical Solutions in Crete, where seven recent students have completed internships under her supervision as a faculty advisor. These internship experiences allow students to work on real-world chemical processes while gaining experience in the commercial sector, preparing them for graduate school and/or their future careers, and getting a network established for letters of recommendations for the students.

## **Writing in organic chemistry-Vertical integration of knowledge**

Dr. Holmes has implemented rigorous training in lab report writing for her students. They learn how to write formal abstracts, introductions, methods, results, analysis, and references sections. Furthermore, they learn how to keep a formal lab notebook. The writing experience is integrated vertically into advanced level courses because Dr. Holmes provides her lab grading rubrics to her colleagues who teach the upper level chemistry courses and then use them as similar lab grading rubrics for their courses. This allows tracking and assessment of student progress across grade levels. For Dr. Holmes' research students, this writing culminates into writing research proposals, standard operating procedures, and co-writing journal articles all involving a high level of technical writing skills.

## **Post-doctoral training**

Since 2007, Dr. Holmes has employed five post-doctoral fellows funded by NSF and one funded by NIH. Dr. Holmes has mentored these post-doctoral fellows to become mentors and teachers to undergraduates. Consequently, undergraduates at Doane receive a very multi-faceted training, working with professors and post-docs, and therefore learn the collaborative process. Four post-docs are now faculty members themselves and mentor undergraduate students. One of the post docs is employed in a major pharmaceutical company as a senior scientist. The sixth post-doc is still working in Dr. Holmes' lab and also mentors undergraduate researchers, thus the impact from mentoring post-docs to mentoring undergraduates continues.

## Ramesh Jasti

Chemistry

University of Oregon (*award made to Boston University*)



Many of the important scientific problems facing our society today do not solely rest in an individual discipline, but often involve concepts that cut across disciplines. For instance, approaching the problem of sustainable energy through development of new solar panel materials requires knowledge of chemistry, engineering, as well as physics. As stated by the philosopher and professor Karl Popper, “We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline.”

In order for chemistry—the “central science”—to reach its full potential, its practitioners must understand its impact across other fields. More and more, we see that engineering and biology (as two examples) have become molecular sciences and are greatly impacted by chemists. Much of my educational beliefs with regard to interdisciplinary science stem from my own personal experience at the Molecular Foundry—a nanoscience institute that houses chemists, biologists, physicists, engineers, and theoreticians. The close proximity of the wide array of scientists fosters highly collaborative work that would be impossible via a sole, traditional discipline. Although this concept is extremely powerful, it is often very difficult for scientists trained in a specific discipline to understand and appreciate the perspectives and approaches of scientists from a differing discipline. This ability to understand and communicate across disciplines is a skill that requires time to develop. Providing this early exposure of interdisciplinary thought to chemists is an educational goal that is an essential component to my teaching philosophy.

### Connecting Sophomore Organic Chemistry to Interdisciplinary Science

At Boston University, I teach approximately 200 students in sophomore organic chemistry in the Spring semester of every year. The organic chemistry course contains a diverse group of students. A relatively small fraction of the population (~20%) is chemistry majors with the remaining students being biochemistry, psychology, nutrition, and even engineering majors. Because the course is taken by such a wide variety of students, it provides a great platform for illustrating chemistry’s central role in these varying fields. Organic chemistry intersects with a variety of other disciplines and by highlighting these connections students find the course more interesting and rewarding. For example, one of the classical topics in organic chemistry is aromaticity. In the second year of teaching this course, I used this topic as an opportunity to also teach students the concept of conducting organic materials and its relationship to modern engineering such as organic light-emitting diode (OLED) screens. I also described the structures and properties of carbon nanotubes and graphene. Building this interdisciplinary connection from organic chemistry to nanotechnology definitely heightened the students’ interest in the subject and also gave them an even greater appreciation for chemistry’s role in society. I had several students ask more about this topic in office hours and many were fascinated by the use of organic molecules in electronics—a subject that most students had never considered.

With the success of this idea, I have since incorporated even more interdisciplinary topics related to organic chemistry. During the last part of the course, the concept of cycloaddition reactions is introduced. In the past year, I introduced the concept of a “click” bioorthogonal reaction ([3+2] Huisgen cycloaddition) and how it’s being used for bioimaging in live animals (e.g. the work of Prof. Carolyn Bertozzi). With the high number of health field majors, this type of connection between organic chemistry and biology greatly increased student interest in organic chemistry. In the future, I would like to provide a drug development story and show how organic chemists, biologists, and materials scientists work together to facilitate the drug discovery process from a lead compound all the way to formulation. In addition, I am developing a laboratory module to be included in the sophomore organic chemistry course focusing on light emitting polymers, where students will synthesize the conjugated materials and then characterize their emissive properties. My colleagues are in support of this idea and the Departmental Chair has agreed to allocate the departmental allowance of \$7500 from this award to this activity. Currently the organic chemistry students have no practical exposure to organic materials or polymer synthesis. Providing real-

world interdisciplinary concepts will provide significant added value to my sophomore organic chemistry course.

### **Broad Impact on Chemical Education through Outreach**

In order to teach the power of interdisciplinary science and chemistry's central role to high school students, I have designed and implemented Chemistry & Nanotechnology outreach programs in partnership with two local organizations—The Steppingstone Foundation and the Upward Bound Math and Science (UBMS) Program. The Steppingstone Foundation is a nonprofit organization that develops programs for urban schoolchildren in order to increase their chance at acceptance and success at four-year colleges. On average, the students are roughly 46% African-American, 21% Hispanic, 19% Asian-American, 9% multiracial, and 6% white. After reaching out to the leaders of the Foundation, I recognized that the students do not have any opportunities to observe a real chemistry research laboratory. I think these experiences could positively impact their interest in chemistry and science in general. In the past two years, my research group has hosted a program with 18 students attending ranging from grades 9-12. In the morning, typically a short presentation about chemistry and its role in nanoscience is delivered including some of the research in my own laboratory. I structure the talk in such a way as to illustrate how chemistry is one of the central drivers of nanoscience. In the afternoon, my graduate students and I lead the Foundation scholars through several hands-on experiments that demonstrate the power of chemistry in interdisciplinary science/nanoscience. As an example, we discuss nanoscale polymeric materials and how they are potential candidates for site-specific delivery of medicine in the future. Then we have the students synthesize Nylon for themselves. This exercise allows the students to get a feel for an interdisciplinary problem that involves biology, nanoscale materials, as well as polymer synthesis/chemistry. Other types of experiments involve making ferromagnetic fluid and their own "Magic Sand." In all of these experiments, we try and stress how numerous science disciplines intersect, but often chemistry is central to the effort. Similarly, we have also designed a program in conjunction with the Upward Bound Math and Science Program at BU. UBMS is a federally funded program, whose purpose is to prepare low-income and first-generation college bound students in higher education. During the summer, approximately 60 students have the opportunity to live on BU's campus for a six-week intensive program. This past year, we hosted our second group of approximately 10 students from a nanotechnology program for a full day. We plan on continuing and expanding these outreach programs in the future, with the goal of stressing interdisciplinary science and chemistry's central role.

### **Education of Graduate Students in Physical Organic Chemistry**

During my first four and a half years at Boston University, I have had the opportunity to teach the graduate level physical organic chemistry course (CH 642, 12-20 students per semester, including approximately 5 undergraduates)—this course is typically the first course for graduate students in organic chemistry at most institutions. I was extremely excited to teach this course in that it was my favorite course in graduate school in that the subject is the underpinning of a broad range of modern fields from chemical synthesis to chemical biology to materials science. My goal in teaching the class is to provide students the basic intuition to predict how molecules interact with each other using frontier molecular orbital (FMO) analysis. The basic principles of reactivity are useful whether the student chooses to focus on synthetic chemistry, materials science, or even biochemistry. I lecture each day on the chalkboard, with a few added handouts. Drawing all the 3-dimensional structures on the chalkboard paces the lecture at a reasonable speed, as well as forces the students to also draw the molecular structures in their own notes (something I do in my sophomore class as well). Organic chemistry is in many ways a geometric science and I think the best way for students to learn to think 3-dimensionally is for them to interact with the molecules on paper and with molecular models when necessary. I was once told "your ability to draw a 3-dimensional structure of a molecule on paper illustrates how well you see it in your mind." I wholeheartedly believe this concept and therefore include this into my teaching philosophy. In addition to the standard lectures, I conduct additional one-hour discussion sessions every week where students provide answers to homework problems on the chalkboard. This allows the students the opportunity to communicate to their classmates how they arrived at a particular solution and to describe their reasoning. Communicating your ideas is a major part of being a successful scientist and so these discussion sessions provide the students some early exposure in this respect.

## Mentoring of Undergraduate, Graduate and Postdoctoral Students

The benefits of undergraduate research experiences are widely appreciated by the education community. In my laboratory, I typically have four to five undergraduates working as part of my team. The undergraduate students have a graduate student mentor that guides them through their first semester or two then typically the undergraduate students transition to an independent project that we design together. The students participate in group meetings and also present once each semester. Last year, an undergraduate student in my lab, Douglas Allison, was given Boston University's award for best undergraduate research project. He is currently a student at Albert Einstein Medical School. This year I have several more equally talented seniors. One of my students, Dharati Joshi, is working on a manuscript as lead author and has already gained admission to numerous chemistry graduate schools such as Harvard, MIT, and UC Berkeley.

The synthesis and study of carbon nanostructures has been a fantastic platform for interdisciplinary education in my laboratory. The challenging, highly strained CPP structures have provided graduate and undergraduate students with the fundamental principles of mechanistic analysis, structural determination, as well as basic synthetic planning. These molecules have also served as inspiration to explore theoretical chemistry. Many of my students have conducted basic DFT calculations. In addition, with each new CPP prepared, my students have also explored the new molecules using optical spectroscopy and cyclic voltammetry, further expanding their chemical knowledge base. Also, my laboratory has many on-going collaborations, which provide an even broader educational experience. We have a project with Prof. Alejandro Briseno at UMass Amherst where we are fabricating devices from these short fragments of nanotubes. In that the CPP structures have size-dependent optical properties, we are also exploring their potential as interesting materials for solar cell applications with Prof. Kamat at Notre Dame. All my students (including undergraduates) have a chance to observe and participate in these meetings and collaborative activities. Students trained in my laboratory are well versed in materials science/nanoscience, but retain the skill set of a synthetic organic chemist.

## Michael C. Jewett

Chemical & Biological Engineering  
Northwestern University



In the early stages of my independent career I have dedicated myself to high quality education in the chemical sciences. I bring passion and enthusiasm to my role as a teacher, especially in teaching undergraduate students where I choose to devote energy to educating future chemists and engineers in ways that go beyond the basic expectations accompanying my professional appointment. Below I describe activities in advancing innovation in chemical education representative of my commitment to excellence in teaching.

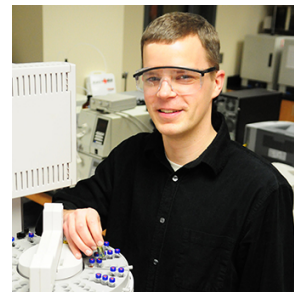
To advance chemical education at Northwestern University, I sought pedagogical development. In 2010-2011, I was selected as a Teaching Fellow of Northwestern University's Searle Center for Advanced Learning and Teaching, where I learned to implement and critically assess student learning and develop my own teaching style. In my project, I developed methods for using cooperative learning to integrate knowledge in Chemical Engineering (ChE) 375: Biochemical Engineering. Teaching students to integrate multiple bioprocess engineering principles for the design and analysis of chemical processes is a fundamental challenge. By implementing regular small group problem solving methods (e.g., think-pair-share), large group problem solving (e.g., jigsaw), and several in-class demonstrations (e.g., a 10L high density fermentation in my lab), I was able to make more time for students to engage and explore core concepts in the same method as we approach research. This enabled students to gain a deeper understanding of fundamental concepts, as assessed through several student performance metrics. I presented an interactive session on this topic and my experiences in the Teaching Fellows Program at the first-ever Northwestern University learning, teaching and assessment forum, which was organized by the Provost to promote teaching to undergraduates.

In addition to introducing pedagogical innovations, I have also enhanced experiential learning opportunities in the classroom by developing original hands-on curricula that permit students to learn by doing. At Northwestern, I co-founded and have jointly led the international Genetically Engineered Machine (iGEM) competition team for the last six summers, mentoring more than 40 undergraduate researchers. The iGEM competition is an interdisciplinary undergraduate synthetic biology experience in which teams of students design and build engineered biological systems that address pressing scientific or societal needs, tackle open-ended problems, and interact with peers across the world. The most striking thing about the iGEM experience is the infectious enthusiasm the students share. One reason for this enthusiasm is that students can address key societal needs while "building stuff"—perennial favorite activities. Closer examination has revealed that the format provides an excellent learning forum, supported by the active learning literature. I have thus leveraged boot camps developed for iGEM to further innovate in the undergraduate classroom. Specifically, I implemented a fermentation module to grow bacteria in my ChE 375 course. I developed pre- and post-assessment metrics including surveys and rubric-based evaluation of written responses to evaluate learning outcomes. Assessments showed that this classroom innovation helped students build stronger intuition as to how process parameter changes impact the fermentation.

Looking forward, I seek continued innovation in chemical education by introducing experimental modules to enhance a synthetic biology course that I developed from scratch. Modules will be designed to be inquiry-based and will bring synthetic biology to undergraduate classrooms, connecting students to novel science carried out in my research laboratory.

## Jeffrey B. Johnson

Chemistry  
Hope College



As an educator, my goal is to use my knowledge and enthusiasm to encourage students to contemplate the world around them and to stimulate their interest in science. This takes on many forms: nuanced debates about reaction pathways with upper level chemistry majors, broad generalities about basic scientific concepts with humanities majors, or shared enthusiasm and wonder of a new observation with elementary school students. Regardless of one's academic major, education level, or future career path, I believe that it is my responsibility to convey the excitement and challenge of the scientific process and the wonders of the natural world.

*Research Mentorship:* Research within the Johnson lab is modular in nature, allowing the inclusion of undergraduate of all experience levels and abilities, facilitating my "open door" policy—any student with a desire to pursue a research experience will be accommodated in some way. The array of projects, including basic organic synthesis, methodology optimization, organometallic synthesis, and kinetic measurements, requires students to contextualize their project within a breadth of course backgrounds and contribute to each student's ability to think critically and to solve complex problems. Regardless of their background knowledge or their ultimate career path, students in my lab develop general scientific literacy and a general understanding of the scientific process.

At the onset of undergraduate research, I work with students to convey the fundamentals of the project and how it fits into the larger group program. As they grow in knowledge and ability, I encourage them to become independent. It is my goal that students truly engage in their research and take intellectual ownership of their project, when they have a natural desire and pride in their work that leads them on a natural progress to the presentation and publication of their results. It is tremendously rewarding to contribute to the growth of students and to watch them develop independent scientists as they become comfortable in asking questions and designing experiments. Ultimately, it is the accomplishments of these students that drive the success of the Johnson group.

Effective communication is imperative, regardless of one's area of specialization. A key facet of the research process is the dissemination and communication of results and conclusions. Student presentation of their work at summer research symposia, at Hope College's annual Celebration of Undergraduate Research and Creative Performance, and at regional and national meetings is highly encouraged, and written reports are required of all research students, prepared in journal article format. The preparation of these presentations is highly collaborative within our group—students actively assist and learn from one another, striving to hone organizational and presentation skills to offer the best possible product.

But communication to one familiar with the field is a luxury. In recent years, I have placed much greater emphasis on communication with a general audience, using resources such as those from a recent NAS Colloquium on Scientific Communication as conversation pieces at group meetings.<sup>1</sup> Periodically, I challenge members of the Johnson Lab to convey the goals and basic structure of their research to a general audience, such as their parents or to their neighbors—in forty-five seconds or less (with the rationale that an interested audience will ask for more!) This method clearly bares a student's basic understanding of their project, simultaneously leading them to a greater knowledge of their work in a larger context. Finally, I ask students to share their description with one another at a group meeting while sharing candid conversations of the effectiveness of each description before sharing their work with friends and family. This has been a tremendously enlightening process, and it seems to work—I've received numerous comments from parents about the descriptions they hear of the research process!

*Scientific Communication:* The advanced organic chemistry course at Hope College emphasizes the basic principles of physical organic chemistry and predicting reaction mechanisms for known reactions. In recent offerings of this course, I have also placed a significant emphasis on general scientific communication, particularly on writing. While reading and discussing articles like that published by

Gopen and Swan,<sup>2</sup> my goal is to prompt students to consider the audience for whom they are writing, and then to think critically about their writing from the perspective of the reader rather than simply listing their results. Students are tasked with incorporating these aspects into a final assignment for the course—taking a research article of their choice and reverse engineering a complete proposal that may have been written to fund the research. Following a series of interactive steps to strengthen their work, the submitted proposals are anonymized and subjected to blind peer review by other class members. Students are encouraged to provide constructive criticism, largely focused on writing style and the clarity of the work, while also critically evaluating the work and noting effective strategies or approaches. Students often comment on the difficulty of the writing assignments, but also rave about the preparation they provide in writing research reports and applications.

*Outreach and Science Literacy:* Whenever possible, I take advantage of opportunities to engage with school groups to share the wonders and excitement of science. Over the past several years, this has included work with Upward Bound, the Girl Scouts, and local school and daycare groups. Although the children (and adults) present at each event have a different level of understanding and experience with science, my goals are the same—to encourage each person to be curious and ask questions about the world around them. Through various demonstrations and hands on activities, I emphasize the importance of observation, the cycle of hypothesis and experimentation, and the value of the unexpected result, with the hope of encouraging participants to appreciate and engage in the scientific process.

Specifically, my lab has interacted extensively with the Hope College TRiO Upward Bound program, which supports local at risk high school students and prepares them for continuing on to higher education following their graduation. During the academic year, my students and I have served as tutors for science courses, delivered sessions for study skills and test taking strategies, and served on panels for to assist students with college applications. During the summer session, when Upward Bound students take courses on the Hope College campus, my group works to develop activities that augment the concepts learned in their chemistry and physics classrooms. These interactions are mutually beneficial—my research students share their passion and enthusiasm for science while learning of the challenges of effectively teaching and communicating scientific concepts, while the Upward Bound students realize the accessibility of college and overcome their apprehension of science through relationships with current college students. While not all of these students are destined for careers within the science field, these positive experiences and interactions promote an appreciation for science for all involved.

1) Arthur A. Sackler Colloquia, The Science of Scientific Communication. National Academy of Sciences, 2012.

[http://www.nasonline.org/programs/sackler-colloquia/completed\\_colloquia/science-communication.html](http://www.nasonline.org/programs/sackler-colloquia/completed_colloquia/science-communication.html), accessed April 2015

2) Gopen, G.; Swan, J. American Scientist, 1990. <http://www.americanscientist.org/issues/num2/the-science-of-scientific-writing/1>, accessed April 2015.



## Dipannita Kalyani

Chemistry  
St. Olaf College



While at St. Olaf, I have grown as an educator and scholar through various teaching, scholarship and service activities. The following sections highlight my commitment to education in the chemical sciences and detail my endeavors and future outlook toward advancing as an educator.

**Teaching In the Classroom:** My teaching methods target the strengthening of problem solving, critical thinking and pattern recognition skills, which hone student aptitudes toward effectively communicating with the outside world and addressing real life challenges. Each class brings with it unique personalities with a range of work ethics and aptitudes, demanding my continuous reflection and adaptation to engage and support the diverse groups of students. My courses begin with an overview of the real life applications of the subject to increase awareness about the impact of chemistry in our everyday lives. I stay abreast of organic/organometallic chemistry literature and share current advances with students. Furthermore, I make an intentional effort to educate students about the various careers available to a chemist, beyond the traditional health profession disciplines. Most importantly, I convey my energy and passion for chemistry, which serves as the catalyst for kindling enthusiasm in my students.

The organic/organometallic courses I have taught demand very different teaching practices. The sophomore organic chemistry course (Chem 247/248) presents an opportunity to teach a broad spectrum of students, while the advanced courses are geared primarily toward chemistry majors. I implement a course structure that provides support for students at varied levels to be engaged and successful. For example, in Chem 247/248 I assign pre-lecture and weekly quizzes as well as midterms and finals. These frequent assessments instill regular study habits in students, while also providing immediate feedback on learning. Furthermore, I implement in-class activities (e.g., Organic Chemistry Pictionary, an activity designed as an end of the semester review of course concepts) to make this challenging course welcoming and engaging to students in a fun and meaningful way. Unlike Chem 247/248, students in advanced courses like Organometallics and Advanced Organic Chemistry assume an increased level of ownership and responsibility toward their learning. These courses reflect contemporary and historically relevant concepts and landmark transformations in organic/organometallic chemistry. I provide a capstone experience in Advanced Organic Chemistry by selecting topics and problems that require students to integrate concepts from various core chemistry courses including General, Organic, Inorganic, and Physical chemistry.

Beyond lecture courses, I have participated in revising the Organic Chemistry Laboratory curriculum. I have introduced lab practicals/quizzes as a means to increase and assess student learning. Students find these challenging yet integral to their mastery of concepts, and instructors have noticed an increased level of student conscientiousness in the lab. Furthermore, I have placed a greater emphasis on oral presentations while simultaneously providing clearer expectations for these assignments, which has significantly enhanced the quality of these talks.

Over the next five years I am excited to continue teaching and advancing the introductory and advanced organic/organometallic chemistry courses. I plan on introducing green chemistry principles more extensively in my courses. Specifically, I will compare and contrast the 'greenness' of the reactions presented in textbooks with more contemporary methods of conducting similar transformations. I will continue to collaborate with the other organic chemistry instructors in furthering the lab curriculum. Specifically, we envision a curriculum for Organic Chemistry I lab that focuses on mastering techniques, and a second semester lab experience that involves two-three week hypothesis-driven assignments. I am also enthusiastic about teaching general chemistry courses and participating in the Science Conversation program at St. Olaf, a one year series of courses geared toward both science and non-science majors.

**Research:** Research is an invitation to be a critical thinker, an attribute that is invaluable for any career a student might pursue. Inspiring undergraduates to pursue research begins with my pedagogy in the



classroom. My research interests are integrated into all my courses. In Chem 247/248, the electrophilic aromatic halogenation lecture provides an opportunity to present a glimpse of my graduate research on Pd-catalyzed C–H halogenation. The stereochemistry lecture is an opportune moment to present my postdoctoral research on asymmetric catalysis. The cross-coupling chapter enables me to discuss my current research on Ni-catalyzed transformations. My passion and enthusiasm in these lectures ignites student interest in conducting research in my lab.

My research group comprises a mix of sophomores, juniors and seniors with varied levels of research competencies. The beginning research students are paired with more experienced undergraduate researchers in my group. This peer learning structure provides a unique opportunity for student mentors to experience the reciprocity in teaching that fosters a mutual learning relationship between students and teachers. Another consequence of this peer learning structure has been its impact on the sophomore organic chemistry lab curriculum. The past two years, my research students have served as teaching assistants for these labs. Their experience in my research group has translated into greater effectiveness, confidence and leadership in assisting the students, thereby enhancing the learning of organic lab students both in and outside the classroom. Peer learning and teaching are avenues by which I inspire a sense of giving back to the community, thereby fostering a self-perpetuating family comprising current and future generations of scientists.

My research interests are cognizant of the environmental and the economical sustainability challenges facing the world, thereby inculcating in students a sense of service to the global community while conducting fundamental scientific research. The undergraduates in my lab are exposed to cutting edge areas of research. Students discover new chemistry and strive for publishable results. At this time my lab has published seven research articles on the basis of my students' accomplishments. Students are introduced to high ethical standards for interpretation and dissemination of their research results. It is truly rewarding to witness students gain autonomy in their projects. The sense of accomplishment and responsibility students express upon publication of their scientific discovery is a joy to be a part of.

I emphasize effective communication of the research problems to a broad audience. My students have presented posters at St. Olaf College sponsored symposia as well as national and regional conferences. I have also guided several students for their senior thesis research presentations. A few students have also given a 'chalk talk' on their research projects in joint group meetings with organic/organometallic research groups at Carleton College. These internal and external presentations provide an opportunity to mentor students toward communicating their research projects to both a scientific and a broad audience (inherent to a liberal arts setting).

Moving forward, my vision is to maintain a self-sustained and well-funded research program at St. Olaf. I will assess and enhance the impact of my research program by participating in the survey of undergraduate research experience (SURE III) developed by Professor David Lopatto at Grinnell College. Finally, collaborations with the U.S. Department of Education grant-funded St. Olaf McNair, Upward Bound, and Student Support Services programs will enable greater participation of underrepresented groups and low income/first generation high school and St. Olaf students in my research program.

**Outreach:** I recently participated in an outreach event for the Educational Talent Search program at St. Olaf College. Alongside my research students, I taught a mini-class to ~thirty low income/first generation 9th grade students. I have also established collaborations with chemistry teachers at St. Paul Central High school and delivered similar presentations to two different chemistry classes at this school. The presentation entitled "Organic Chemistry: The Playground of a Molecular Architect" included highlights of college and research experiences of my research students. We introduced the students to the impact of organic chemistry in our daily lives. Students were taught the concept of enantiomers using active learning with model kits. Thereafter, examples of enantiomerically-enriched pharmaceuticals were presented to impress upon students the importance of synthesizing molecular architectures using organic chemistry principles such as stereochemistry. The overarching motivations of my research program were presented through an activity in which students were asked to map the biaryl motifs synthesized in my research group onto structures of pharmaceuticals and agrochemicals. The mini-class concluded with demonstrating the idea of catalysis using the "elephant's toothpaste" experiment. Beyond participating in

these outreach events myself, I have initiated a program for my research students to present similar talks/activities to the chemistry classes at their home high schools. A junior chemistry major, Jennifer Crawford, has spearheaded this effort and I funded her trip to present at her alma mater in Chicago. These efforts are an excellent opportunity to mentor my research students toward communicating the impacts of organic chemistry and basic research to a broad audience. Furthermore, these activities will likely inspire high school students toward pursuing a college degree and perhaps basic research in the STEM fields.

**Summary:** Witnessing the students grow as individuals and scientists is the most rewarding aspect of my career. Students challenge me in unique and exciting ways to grow as an educator; whether it is teaching problem solving in a classroom, engaging students in scientific discoveries in lab or mentoring them toward giving back to the community through outreach. I have enjoyed the balance of teaching, scholarship and service and will continue to seek opportunities to advance in all three areas with the key motivator being enhancement of opportunities for current and future generations of students at St. Olaf and the community at large.

**Aditya S. Khair**  
Chemical Engineering  
Carnegie Mellon University



The education of undergraduate and graduate students in chemical engineering is a central mission of my career. For instance, I am a passionate supporter of undergraduate research, which is a known vehicle for increasing enrollment into graduate programs: I have supervised 15 undergraduate researchers since arriving at Carnegie Mellon University (CMU) in 2010, three of whom are currently pursuing a PhD degree in Chemical Engineering. Four students have won competitive Summer Undergraduate Research Grants at CMU to work with me. Alexandra Frankel received the 2015 Geoffrey Parfitt award for excellence in undergraduate research from the Chemical Engineering department for research conducted under my supervision. Three papers published from my group have undergraduate co-authors, including one paper where the undergraduate (A. Frankel) is the first author. Needless to say, undergraduate research will play a key role in my future education activities at CMU.

In 2012, I was awarded a Wimmer Faculty Fellowship from the Wimmer Foundation and Eberly Center for Teaching Excellence at CMU. This fellowship afforded me the opportunity to work with a dedicated education specialist, Dr. R. Poproski, at the Eberly Center to develop educational modules that introduce undergraduate students to perturbation methods, which are powerful mathematical tools that I utilize in research. My goal was to present techniques that I employ in research to undergraduate students in an accessible manner. In particular, perturbation methods serve to: (i) obtain approximate solutions to mathematical problems that cannot be solved exactly; (ii) provide physical intuition for complex problems in limiting situations; and (iii) complement numerical computations. The successful application of perturbation methods is as much art as science, requiring students to develop a rather different skill-set compared to standard undergraduate mathematics courses. In particular, perturbation methods enable students to attack problems that cannot be solved exactly; of course, most problems in research cannot be solved exactly. I developed a set of six self-contained educational modules, each corresponding to fifty minutes of lecture time, which have been used in the sophomore Mathematical Methods of Chemical Engineering course that I taught in spring 2013-2016. My goal is to develop these modules into a junior and senior elective class for chemical engineering students. The opportunity to work with colleagues from the Eberly Center improved my effectiveness as an educator, in terms of structuring lectures to emphasize learning objectives and student outcomes.

The most intimate educational interaction that I have is with PhD students that I supervise. Beyond technical training, I believe that a key responsibility is to train students to clearly communicate their research ideas to non-experts, be it fellow graduate student, undergraduates, or the general public. My research is primarily theoretical and computational. It is challenging to develop clear and accessible talks on such work; specifically, to put the complex mathematics aside and instead focus on explaining concepts in a physically intuitive manner, which is what I think a good “theory talk” should emphasize. I make a great effort to train my students in this regard. In fact, I was recently approached by a graduate student from our Physics department to develop a seminar tutorial on delivering clear theory-based talks. (That student had heard a number of my PhD students speak at our annual Chemical Engineering graduate student research symposium in September 2015.) I plan to utilize this opportunity as a first step toward creating more detailed educational materials aimed at training graduate students in clear communication of their mathematically oriented research.

**Jared C. Lewis**  
Chemistry  
The University of Chicago



Over the past four years at the University of Chicago, I have worked to improve my abilities as an educator in both my research group and the classes I teach. This has involved developing more effective communication skills and building teaching/research environments that encourage open exchanges with and between students.

## Courses

I have taught four different courses at Chicago to date: introductory organic chemistry (Chem 222, undergrad., 2 quarters), honors organic chemistry (Chem 232, undergrad., 2 quarters), physical organic chemistry (Chem 321, grad., 3 quarters), and organometallic chemistry (Chem 304, grad., 2 quarters). These courses require addressing many similar pedagogical issues, such as dynamically adjusting the difficulty and quantity of material presented, but each poses unique challenges based on class size and student background.

Chem 222 completes the introductory organic chemistry sequence at Chicago and is intended for non-chemistry majors. The course is quite enjoyable to teach because it introduces the rich chemistry of carbonyl compounds (e.g. ketones, acids, amides, peptides, proteins, etc.). I present this material with a strong emphasis on arrow pushing mechanisms, equilibrium processes, and applications in modern chemical synthesis that integrate many of the reactions introduced in the previous two quarters. All of these subjects are more complex than material presented earlier in the sequence. I have learned to simplify the material presented in class to focus on core reactivity principles and to illustrate these phenomena using examples in natural and synthetic molecules familiar to the students (e.g. pharmaceuticals). I have found that these simplifications clarify presentation of the material in a lecture hall format (>150 students), and allow more time for questions during lectures and for brief discussions with small groups of students after lectures. Feedback from students has been essential to my initiating these improvements, and I have used mid-quarter evaluations to increase the frequency with which I can make modifications. Chem 232 covers essentially the same material as 222 but with significantly more depth. The smaller class size (~40 students) allows me to more deeply engage students and to explore new methods for doing so. In the future, I plan to incorporate Wiki assignments into this course aimed at improving coverage of course material on Wikipedia (<http://wikiedu.org/teach-with-wikipedia/>).

While students enter Chem 222 or 232 with relatively similar backgrounds, students who enroll in Chem 321 range from advanced undergraduates to graduates of liberal arts colleges or large universities. A unifying theme among these students is that essentially none of them have taken a course quite like physical organic chemistry. This subject requires a rigorous understanding of electronic structure theory, chemical kinetics, and thermodynamics to predict and rationalize organic reaction mechanisms. Needless to say, this is a large volume of difficult material, and once again, student feedback has led me to refine both the scope and depth of my lectures. Specifically, I have worked to deemphasize somewhat esoteric material often covered in physical organic chemistry courses and redundancies with other courses offered at Chicago to allow more time for in-class discussions of the core physical phenomena noted above. More recently, I have integrated examples of these phenomena from the current chemical research into both my lectures and my problem sets to better highlight the relevance of this material to students' own graduate research and proposals.

Most recently, I have taught Chem 304 (organometallic chemistry), which is atypical for "organic chemists" at Chicago. Due to the tragic passing of my colleague and mentor Prof. Gregory Hillhouse and my background in this field, I was asked to take on Chem 304. The class would not have been offered if I did not do so. Despite the significant load of taking on a new class, this has proven to be an absolute joy and an important learning experience. My research deals extensively with organometallic chemistry and catalysis, so I quickly noticed that I drew on my extensive personal experience in these areas to provide far

more effective explanations for the organometallic canon than I would have provided based on lecturing from texts alone. I will certainly apply this lesson to classes that I teach in the future.

I am also planning a new course, "Catalysis and Society," for graduate and advanced undergraduate students focused on modern catalysis. It will survey heterogeneous, homogeneous, and biological systems to illustrate unifying themes and unique challenges in catalysis and highlight the impact of these systems on human health and the global economy.

Outside of the classroom, I have built an interdisciplinary research group focused on developing novel catalyst systems for challenging chemical reactions. The breadth of knowledge and techniques that we employ, spanning organic and organometallic synthesis, protein engineering, and biocatalysis, has made the group an enriching environment for training high school students, undergraduates, graduate students, and postdocs. I have actively recruited students with diverse scientific backgrounds, including undergraduate and graduate students specializing in organic and inorganic chemistry and chemical biology and postdocs with experience in microbiology, structural biology, and biophysics. I have also served as a mentor to URM students in the Leadership Alliance Program and the UChicago Post-Baccalaureate Research Education Program. Projects are carefully structured such that each individual plays an intellectually important role in driving research regardless of their background. Fifteen undergraduates in my group (seven current) have specifically contributed to projects that are currently in progress or are being followed up by graduate students that should result in strong publications. Two high school students have also carried out meaningful research in the group. Gratifyingly, this group and project structure has led to extensive communication, collaboration, and cross-training between group members. New techniques and ideas rapidly propagate from experts to novices who are able to use these tools to advance their own projects. It was not clear that launching three separate projects at the start of my career was prudent, and while our initial progress may have been slowed a bit by this approach, I believe the intellectual foundation that it provided and the collaborative culture that it fostered will more than offset any induction period that may have existed.

Students in my group have extensive opportunities for presenting their research to expert scientists, non-expert scientists, and non-scientists. My students are involved in an NIH-funded Chemistry and Biology Interface Program, organometallics super group meetings, and various regional and national meetings. My group is a member of the NSF-funded Center for Selective C-H Functionalization, which, in addition to providing extensive intellectual support, affords students with additional presentation opportunities at weekly teleconferences and yearly center-wide meetings. Finally, I was recently awarded an NSF-CAREER Award for a proposal that involves developing supplemental teaching modules on chemistry, catalysis, and materials in collaboration with local middle school (Grade 8) students at the Hernandez Middle School for the Advancement of the Sciences. My group's involvement provides Hernandez students with curriculum-relevant discussion of catalysis and UChicago students with real world training at explaining science and receiving feedback on their teaching. This has involved visits to my lab, science fair adjudication, and science club demos. Funding from the Dreyfus Foundation would ensure the longevity of my group's interactions with Hernandez. Excitingly, this program is now being used as a model for a department-wide outreach initiative at Chicago. I will lead a module for first year chemistry graduate students on outreach, my students will provide instruction to these students on several demos developed in my group, and they entire first year class will be matched with schools to conduct demos. Ideally, this will happen on a yearly basis to establish long-lasting relationships with area schools. Given my group's leadership position in this planned effort and our continued efforts to test new demos and outreach approaches, Dreyfus funding would have an impact far beyond my group.

## Hai Lin

Chemistry

University of Colorado Denver



Growing from a student with a D in high-school chemistry into a chemistry professor now for 8 years, my experience tells me that the most important thing for an educator is not to teach, but rather to inspire. By the end of each semester, it really does not matter how much specific knowledge in chemistry that the instructor has conveyed to the students. Many of them will forget most of the compounds, reactions, mechanisms, etc. in the years following the courses they take. What really matters is the passion for chemistry that a teacher ignites in those young minds, as it is this enthusiasm for the subject that will accompany them all the way into the future.

My position at CU-Denver since 2005 has provided me an excellent opportunity to inspire. As a typical urban university, CU-Denver serves a large and very diverse student population. Many of our students are non-traditional students who work part time and have families to support. For example in my research group, one student is a single mom with a 4-year old child, and both of another student's parents have disabilities. I have always been impressed by the eagerness to learn that my students show in classroom and research lab, despite facing so many difficulties, and I am devoted to helping them grow and excel.

### 1. Classroom Teaching: Curiosity is the best teacher

Let us face it: Chemistry is not an easy subject. The remedy: Curiosity is the best teacher. I always try to make my class fun to the students by combining various instructional formats, including lecture, in-class hands-on training, homework assignments, group-study, coursework projects, guest seminars, and student-led chalk-talks, to create active learning environments that stimulate students' interests in studying chemistry. I bring the state-of-art chemistry research to the classroom in ways that could be easily understood by undergraduates. For example, I once showed my class a movie of computer simulations of a DNA double helix. The students were astonished to see that the helix disbanded into two single chains during the search of the most stable geometry of the complex. After I explained the "unexpected" outcome in terms of electrostatic interactions, hydrogen-bonding interactions, and activation barriers, all of which had been taught in the course (General Chemistry II), excitement was ignited in the whole class and led to extensive discussions.

### 2. Teaching Enhancement: Revise existing courses, develop new courses, and apply for teaching grants

Since I joined CU-Denver in 2005, I have taught 9 courses, including 2 lower-division undergraduate courses, 4 upper-division undergraduate courses, and 3 graduate courses for M.S. students. A list of those courses is given on page 4 of my CV. The typical enrollments are 80-200 in the lower-division, 20-40 in the upper-division, and 10 in the graduate classes.

I have significantly revised the curriculums of 4 courses. For example, in Physical Chemistry Laboratory II (CHEM 4538), I incorporated computational projects to let the students get a "taste" of the interplay between theory and experiments. For instance, in the lab of HCl/DCI FT-IR spectra, I let the students carry out quantum calculations to optimize the molecular geometry and predict the spectra, compare their theoretical predictions with measurements, and discuss the agreements and discrepancies they find. Many students said that they loved those projects, because they nicely connected the materials they learned in the lecture and the observations they made in the laboratory, helping them gain deeper insight into the related concepts.

I have developed 3 new courses. For example, I have designed and taught Computational Chemistry (CHEM 5510), which is open to both undergraduate and M.S. students. This course provides students basic theoretical background and practical skills to solve chemical problems by computations. Students

who took this class had applied the computational techniques to help their own research projects back to their laboratory. (I even received "thank-you" notes from their research supervisors.)

I also served in the departmental curriculum committee, which oversees the departmental curriculum development.

I have applied for 3 internal grants for promoting teaching, which had been funded by ~\$40,000 in total. Those grants helped in updating the teaching facilities and improving the effectiveness of teaching.

### **3. Undergraduate Research: Grow interests, build self-confidence, and prepare for future careers**

Mentoring undergraduate students in research is a great way to inspire, because students not only learn new knowledge and gain experience, but also grow interests and build self-confidence. Undergraduates have become a crucial part of my group's research program. These students have carried out a number of application-oriented projects, where we applied computational methods to study the structures, mechanisms, kinetics, and dynamics of chemical reactions in biochemistry, organic chemistry, and atmospheric chemistry. What makes me proud of the students is that, instead of passively waiting for me to tell them what and how to do, they actively bring up ideas to the projects, communicate with collaborators, present results in symposiums, and draft manuscripts. One undergraduate, Nara Chon, recently travelled to University of Bergen, Norway for a two-week scientific visit to our collaborator Reuter's group. Reuter told me later that Nara had accomplished in just two weeks what her Ph.D. students will typically take 4-6 weeks to finish!

I have supervised 17 undergraduate students doing research in my group. The majority of them have been supported by the external grants to my group. Moreover, 8 undergraduates have applied as student PIs and received 7 internal grants for a total of ~\$10,000 from the Undergraduate Research Opportunities Program (UROP). For their contributions, 7 undergraduates have become coauthors in 5 journal papers, and 12 students have presented in the American Chemical Society National Meetings and other conferences. Several undergraduates have received recognitions: Mia Smith (2011 Undergraduate Outstanding Research and Creative Activities Award), Christal Davis (2012 ACS Student Travel Award), Nara Chon and Eun Kim (2013 Chancellor's Award of Excellence in Undergraduate Research), and Nara Chon and Christal Davis (2013 Damrauer Scholarship).

The undergraduate research prepares the students for graduate program in chemistry and jobs in chemical industry. Among those 13 students graduated from my group, 4 continued Ph.D. (2 at Penn State, 1 at CU-Boulder, 1 at UC-San Diego), 4 went to medical/veterinary schools, and 2 worked in chemical industry.

### **4. Outreach: Get K-12 teachers and students involved**

The inspiration goes beyond the university campus. I have participated in several outreach programs, having hosted middle-school teachers and high-school students doing summer research in my lab. Since 2010, I have worked with a high-school teacher in developing course materials of computer visualization and modeling for the high-school Advanced Placement Chemistry course, which were subsequently used by the high-school teacher in his teaching. Feedback showed that the materials have significantly enhanced students' understanding of atomic and molecular structures. I have given many seminars to elementary school classes talking about scientific research methods, and I served as a judge several times in Science Fairs interviewing students. I enjoy sharing the passion for chemistry with the future generation, and to me, it is one of the rewards of being a chemical educator.



## Casey H. Londergan

Chemistry  
Haverford College



**Research mentoring.** A central part of my undergraduate teaching has been the mentoring of students in research. As of mid-May 2015, I have mentored 30 graduated students, 27 of whom were my senior thesis students. 16 unique undergraduate researchers have been co-authors with me on 12 published papers.

Of my graduated students, 6 have matriculated to medical school, 8 are in or have completed Ph.D. programs, and 3 are currently in M.D.-Ph.D. programs. My research students are sought-after graduate students who are generally admitted to most or all of the programs to which they apply. In my lab, my students expect that they will take early intellectual ownership of their projects. Each of my students has his/her own project and collaborates with others inside and outside the lab to advance a project-specific set of goals. My students do not become single-technique specialists, but rather acquire new techniques and expertise as they design and execute their own projects. When we develop new collaborations outside the laboratory, one of my undergraduates usually drives the relationship. The majority of my research students have been so for more than one academic year; their required senior thesis work is often the most productive time in the laboratory, but it is usually the capstone on a lot of prior lab work rather than an introductory research experience. I helped to propose and develop a novel curricular way to encourage early engagement in research: since my third year as a faculty member, our department offers full-year, half-credit research courses that provide a flexible and continuous mechanism to document, encourage, and credit early student involvement in research.

**Inquiry-based introductory laboratory courses.** One hallmark contribution of mine at Haverford that provides a nationally accessible model is inquiry-driven first-year laboratory modules. During my second year, I developed a full-semester lab course where students work in groups to propose, design, and carry out experiments to identify and characterize a set of difficult unknown (usually organometallic) compounds. This full-semester experience provides a speedy transition from high school qualitative analysis-based bench chemistry to modern spectroscopic characterization techniques, and it culminates in an ACS-format full-semester lab report drafted in pieces throughout the semester. This module, which has now been taught by several faculty in my department, will be offered in fall 2016 for the 8th time with some new wrinkles developed in concert with local high school teachers through funding from my current NSF-CAREER grant.

**Primary literature in courses across the chemistry curriculum.** One aim of each of my courses (at all levels) has been to directly imbed current, primary scientific literature. A personal goal is for all of my students to be conversant enough in primary literature that they can critically extract important information about the significance of current work, regardless of their training level. My nonmajors-level course in nanotechnology is introduced through a series of papers, from the original molecular rectifier proposal to present-day nanomaterials for drug delivery, and that course also includes several evolving government policy documents including materials associated with the National Nanotechnology Initiative and EPA directives on nanoscale materials. Each of my introductory level courses has included current problems to help frame the course: most recently in my freshman-level Chemical Dynamics (thermodynamics and kinetics) course, much of the course was posed in terms of recent advances in surface science and heterogeneous catalysts for either nitrogen fixation or hydrogen fuel cells. A higher-level recent example of a course driven by primary literature was a senior seminar course taught in spring 2015 on multidimensional spectroscopy, which included many very recent examples of innovative new ultrafast spectroscopy experiments in several different frequency ranges that provide frequency correlations and dynamics in systems associated with important chemical problems. That particular course was reformulated from a literature-driven class that I taught to first-year physical chemistry graduate students at the University of Pennsylvania in fall 2013.

**Physical chemistry curriculum.** Starting from my first junior-level physical chemistry classes at Haverford in 2006-2007, I have worked continuously (joined more recently by my colleague Joshua Schrier) to teach two physical chemistry classes that reflect the current practice of physical chemistry. My thermodynamics



class begins with statistical mechanics (enabled by earlier introductions to quantum states and Boltzmann distributions during the freshman year) and is situated in a context of protein folding, single molecule experiments, and thermodynamics of complex and coupled systems rather than just relying on gases and gas-phase molecular partition functions. My quantum mechanics class includes extensive coding and visualization of functions associated with molecular orbitals and provides a hands-on introduction to several electronic structure methods and theory associated with basic absorption spectroscopy.

**Disadvantaged students.** I have made major efforts to provide opportunities in chemistry for students from a variety of backgrounds. I have taught three introductory-level courses intended for freshmen with documented challenges to success in chemistry. In spring 2013 I taught the inaugural section five-day-a-week section of our Chemical Dynamics class that provides extra contact time for its student population: the 2013 class of 19 students yielded five chemistry majors, which matched the relative yield of the general population nonintensive first-year course. I just retaught that intensive class in spring 2015. I have also been a long-term research mentor for some of Haverford's Chesick Scholars, who are highly capable, underprivileged students who join research groups following their freshman years. I led a departmental assessment of the impact on our most challenged students of our recent introductory curricular changes, and that review led to some structural changes intended to better fit those students' needs.

**Active classroom and dynamic teaching techniques.** I have evolved into a teacher who works strongly to use the classroom as actively as possible for student learning. My classroom teaching style has evolved to essentially lecture-free, enabled by "flipped classroom" video technology: I am most interested in creating an environment where students can accomplish the hardest parts of their own learning in the classroom. Through pre-class assessments, in-class group work, and assigned problems at many difficulty levels, I try to keep my class as active as possible so students are directly struggling with, and communicating about, class material with the possibility of my assistance or guidance. A current goal for me is to combine literature and problem-driven curricula in the most active classroom I can provide to my students, to engage them at the level of important large problems while working through the fundamental details.

**Moving forward: communicating science.** During this past academic year, I was a participant in the Faculty Seminar program of Haverford's Hurford Humanities Center, where I pursued a year-long process of scholarly inquiry with six other non-science faculty on the topic of "Time/Revision" associated with time, memory, and the consequences of traumatic personal and cultural events. This provided me with many opportunities to interact and communicate with colleagues outside the sciences about my own work and theirs, and it has provided a fertile platform for me to refine my approach to communicating my work outside of the chemistry community and the sciences. The strong pull of central problems associated with overpopulation and energy management, and the cultural and personal effects of these issues, provided a strongly unifying narrative thread to our discussions and could fuel much future on-campus interdisciplinary dialogue. My long-term commitment to chemical demonstrations both on and off-campus also continues to be strong, and my hope is to expand both my chemistry outreach and my formal connections to non-science disciplines over the next few years.



It is a basic responsibility for researchers at universities to be a devoted educator. I have great admiration and respect for those professors who dedicate their time and efforts to share with students their vision of science and guide the students' development. In my own career, I have committed to scientific education and will continue to do so, and hope to establish effective teaching programs that could inspire a diverse body of students.

#### **Course development (undergraduate level)**

At the lower-undergraduate level, I had the opportunity to independently teach Physical Chemistry Lecture 1 both in the fall of 2011 and in the fall of 2013. Physical Chemistry is an indispensable element in the curriculum of undergraduate chemistry education, as it lays down the framework of thermodynamics, chemical kinetics and quantum mechanics. The materials are relatively abstract and quantitative involving heavy mathematics. I found many students often get trapped by the technical details of the equations. Hence, in my practice, I tried very hard to help the students develop concise intuitions by emphasizing more on the physical models and the scientific motivations behind concept development. From the results of the exams, I was glad to see that many students can indeed grasp the key concepts. I plan to continue to encourage students to appreciate the conceptual beauty and rigorousness in physical chemistry.

During my teaching practice, I found that many popular textbooks of this subject lack concrete contemporary examples in modern chemistry research. The absence of real-world footprints has detrimental consequences. It makes it rather difficult for the instructor to motivate the young students at the onset to appreciate the fundamental importance and broad impact of physical chemistry concepts. To solve the above problem, in addition to the regular textbook materials, I have assembled a set of contemporary topics, and introduced these examples to undergraduates. These concrete cases are closely tied to the fundamental principles (thermodynamics, chemical kinetics and quantum mechanics), providing students a clear overview of the prominent and overwhelming applications of physical chemistry in modern research and society.

(A) Single-molecule spectroscopy. The advance of single-molecules spectroscopy has made substantial impact to the current molecular sciences. While conventional spectroscopy techniques are performed on ensemble of molecules, single-molecules spectroscopy can unveil not only the stochastic nature of the molecular dynamics but also the temporally transient intermediate. After teaching the basic chemical kinetics and molecular spectroscopy, I have showed students how the unique advantages of single-molecule spectroscopy are particularly powerful in the studies of complex protein and enzyme reaction dynamics.

(B) Thermodynamics at the microscopic scale. The laws of thermodynamics describe the general nature of energy exchange processes of macroscopic systems. In macroscopic systems, behavior is reproducible and fluctuations are small, which are what one normally teaches to undergraduates. However, I believe that it is important for the students to be aware of that even the well-established thermodynamics is not a sealed subject. Particularly, as a system's dimensions decrease, thermal fluctuations can lead to observable and significant deviations from the system's average behavior. As a result, such microscopic systems cannot be described by classical thermodynamics. Thus, after finishing the regular lectures, I had given a dedicated lecture along this line, particularly, on the Jarzynski equality and the related Fluctuation Theorem, which forms the exciting field of thermodynamics at the microscopic scale.

(C) Dye-sensitized solar cell (DSSC). How to solve the energy problem presents a grand challenge to the physical scientists of our generation. DSSC is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a so-called artificial photosynthesis system, offering a promising inexpensive alternative to the traditional silicon-based solar cells. The DSSC has a number of attractive

features; it is simple to make using conventional roll-printing techniques, is semi-flexible and semi-transparent which offers a variety of uses not applicable to glass-based systems, and most of the materials used are low-cost. In this case, I introduced the students the basic photoelectrochemical diagram of DSSC. I aim to convince students by this concrete example that the understanding of quantum mechanics could help contribute to solving one of the biggest problems in our society.

Through teaching these three prominent examples, students could appreciate the major footprints of physical chemistry principles (thermodynamics, chemical kinetics and quantum mechanics) in the cutting-edge research and in the modern world. I plan to continue to do so to keep on encouraging students to become interested in this core element of chemical science.

### **Course development (graduate level)**

Based on the research results of many scientists (including my own) in the field of optical biophysical chemistry, I have developed a new course of Optical Bioimaging offered through Chemistry Department to both graduate students and upper-level undergraduates. I have offered Optical Bioimaging twice (in 2010 and in 2013) since I joined Columbia University.

This interdisciplinary course teaches fundamental knowledge of optics, laser, linear molecular spectroscopy and nonlinear molecular spectroscopy to chemistry students who generally lack of training in this area. On the technical side, students also get to learn various emerging optical techniques including single-molecule microscopy, multi-photon microscopy, label-free chemical imaging, super-resolution imaging and novel molecular probes. Several guest lectures from experts in other departments (such as Biology and Engineering) have been also offered, giving students the fresh perspective of the cutting-edge researches.

The students are requested to identify a problem in their related fields during the semester. The final term project is about writing a technical proposal to solve this problem. They can thus obtain an opportunity to explore the application of tools and methodologies taught in the course material. To my delight, several students (including undergraduates) in the past years have come up with rather creative proposals to address important biophysical problems. This course has been quite popular, as students from other departments or institutions such as biomedical engineering and chemical biology program of tri-institute have actively enrolled in this class.

In the future I plan to add a significant component of subjects related to my own research into this course. Currently I am in the process of designing and including a lab demonstration lecture by taking the students to my laser laboratory and showing them several home-built multiphoton optical microscopes (both fluorescence based and Raman based) working in action. I aim to inspire students to recognize the importance of physical instrumentation and the nature of interdisciplinary research involving physics, chemistry, biology and engineering.

Through interactive questions in the class, course assignments and the University's course evaluation system (one written evaluation/student/semester), I have received constructive feedback on these newly developed courses/lectures. I will constantly modify them as necessary to achieve student learning goals. Finally, not only will my research inform my courses, but the courses will, in turn, inform my research.

### **Research training to summer undergraduate students**

I have integrated my research program to increase diversity in science and engineering by providing summer research opportunities to undergraduates. In particular, my lab has offered and will keep offering undergraduate research opportunities via the University's Summer Undergraduate Research Fellowship (SURF) and Amgen Scholars Summer Research Program. Over the past four years, I have guided Stephan Zhou (freshman), Tim Poterba (freshman) and Matthew Horwitz (sophomore) through three different projects along biophysical chemistry.

Both SURF and Amgen programs provide a \$4000 stipend for students to spend ten weeks on an independent research project. My lab has committed half of the stipend (\$2000 per student). In the future, besides promoting interdependence, special attention will be paid to (1) designing the research more relevant to students' undergraduate course objectives, and (2) creating assignments that fit best each student's personal skills and interests.

### **Expansion of research infrastructure**

My goals in this area are two-fold: (1) expand instrumentation, techniques, and the general knowledge base in the area of multiphoton microscopy across the Columbia campus and (2) introduce and develop nonlinear Raman microscopy as a platform for teaching and for stimulate collaborations within a wider research community.

Center of Advanced Biological Imaging (CABI) of Columbia University is a new research facility that provides across the Columbia community instrumentation for those engaged in research with a bio-imaging component. I am currently one of the faculty members overseeing and designing the CABI construction. Besides the instrumentation, the shared nature of CABI provides a networking opportunity for students and postdoctoral fellows as they share techniques, experience, and information. My experience of multiphoton microscopy, especially in nonlinear Raman microscopy, will add considerably to the knowledge base available to students and postdoctoral fellows working in CABI. Over the next several years, I plan to found and sponsor a student organized and run Novel Microscopy discussion series which will formalize the currently informal network of students and postdoctoral fellows and provide a forum for sharing and obtaining information and experience in this quickly evolving field.

I have been an active member of Kavli Institute of Brain Science at Columbia University since 2011. The Kavli Institute of Brain Science particularly encourages collaborations among members to address important problems in neuroscience by harnessing emerging technique such as advanced optical microscopy. To this end, I am in the process of setting up a state-of-the-art stimulated Raman scattering microscope in the shared facility of Kavli Institute of Brain Science. This open access system, which will be operated with the help of my group, will serve as a perfect platform for neuroscience students and the wider biomedical research community in general to learn and gain access to the advanced nonlinear Raman microscopy. Several exciting collaboration projects are currently underway.

According an ancient Chinese scholar, education can be defined as to teach the student "quest, knowledge, and vision." My teaching philosophy centers on laying down a solid foundation of basic knowledge system, as well as evoking active and innovative thinking. On one hand, a broad and solid background is the starting point for original research. On the other hand, I believe that, the quest to answer a question is where the learning takes place, not the answer itself. Lastly, my own teaching style will be continually developing based on mutual interaction with the students and feedback from more experienced colleagues.

## Amanda J. Morris

Chemistry

Virginia Polytechnic Institute and State University



Over the years many theories have been developed to describe how students choose both an educational and professional path. Expectancy–value theory consistently has been the best predictor of educational choice among both general and minority (both gender and ethnic/racial) populations. The theory, briefly described, states that a student’s motivation in a certain act, subject, or career is determined by the product of his or her expectancy to succeed in such act and their value of the process and end result. Therefore, to affect a student’s educational choices, an environment that provides skills, promotes confidence in, and identifies the value of a subject is needed. In accordance with this pedagogical theory, I constantly strive to encourage my students and provide them with opportunities to explore what they could do beyond their formal educational years with the skills they learn in the classroom.

Since my arrival at Virginia Tech, I have taught nine courses, including six at the undergraduate level. These courses range from small graduate level classes with twelve students to large lecture courses with more than seventy students. While the class structure in each of these environments is unique, the incorporation of current scientific topics is at the heart of each lecture. My student evaluations in these courses are well above the departmental norms with an average score of 5.7/6.0. My students often comment on the discussions of real world applications. Here is one such comment from a fall 2013 analytical chemistry student: “I don't have enough nice things to say about Dr. Morris. Her class consistently was my favorite and most interesting class. She made me more interested in Chemistry overall and always was tying the class into current events. The lectures were great, I didn't miss a single class because I wanted to know about what we were learning about.” This comment speaks to the success of an expectancy–value theory guided approach. Not only did the student enjoy coming to class, but his/her interest in chemistry overall was enhanced.

With this said, I constantly strive to become a better lecturer, teacher, and mentor. I have attended professional development courses on such topics as incorporating media into the classroom, the use of tablets in the classroom, communicating to diverse student populations, inclusive pedagogy for all students in all classrooms, and workshops on effective mentoring. While my teaching philosophy has remained constant, these educational experiences have tuned my delivery and approach to different topics in the classroom. Recently, I have taken on teaching the non-majors analytical lecture and laboratory during the summer. The small class size allowed me to explore different teaching strategies and due to the problem-solving nature of analytical chemistry, I immediately jumped on the chance to flip-the-classroom. In a flipped classroom, the normal lecture and homework components of a course are swapped, i.e. lecture material is covered at home and the class period is spent working practice examples alone or in small groups. At Virginia Tech, we are lucky enough to have SCALE-UP classrooms specifically designed for such discussion and group work. The course was an overwhelming success and students remarked that the vast number and types of problems they were exposed to really help them understand the core principles of analytical chemistry. This summer, I plan to transition to an online/on-campus option where the problem sessions could be both attended in person or students can sign on remotely via WebEx or similar program. I think this will allow a greater number of current chemistry students to take advantage of the summer semester and attract students from other institutions and abroad.

Another initiative that I have spearheaded is the creation of three new B.S./M.A. 5-year dual-degree programs in the department of chemistry. As the face of education changes, there is a push to provide stronger integration of research thrusts and undergraduate education. The degree programs under development are in the areas of polymer chemistry, drug discovery chemistry, and chemistry at the food/energy/water nexus. I specifically chose to highlight these areas because of the current strengths and research directions of the chemistry department at Virginia Tech. For example, several chemistry faculty, including myself, were recently awarded an NSF-REU program for chemistry at the food/energy/water nexus. The REU program and current chemistry course offerings tie in perfectly to the development of a degree program in that area. Each of the programs was designed to produce students with a holistic view of

each field by including coursework in professional development, diversity, and/or business. Additionally, the programs are designed for the master's degree component (within a period of 4 years) to transition to a completely online degree option. These degree programs have enabled me to gain experience in curriculum development outside of the classroom and I have found it to be a rewarding challenge. Integration of research and teaching, producing well-rounded students, undergraduate recruitment, and international appeal are goals that I have set for these programs and I am confident that I have created a framework for success.

One of the most influential ways for students to gain appreciation of and value chemistry is through research opportunities. I actively encourage and recruit students to conduct undergraduate research throughout the College of Science and the University. Indeed, this year I developed and help coordinate the First Annual Undergraduate Research Mixer for the College of Science. At the mixer, faculty presented posters on their research projects to over 150 undergraduates looking to get involved in their field beyond the walls of the classroom. In my short time at Virginia Tech, I have advised 25 undergraduate researchers. One of the points that I take great pride in is that these students come from diverse educational and experiential backgrounds. I have mentored students from biology, chemical engineering, mechanical engineering, nanoscience, and chemistry. Additionally, I have mentored ten female undergraduate students and one African American student. Two of my students, Michelle Pomatto and Bethany Stratakes, are featured on publications that have come out of their contributions to the laboratory. Within the year, two more students will also have authoring credit on journal publications, Madeline Love and Taylor Gaillot, both of whom graduated in May of 2015. All of the students that have graduated from Virginia Tech and conducted research in my laboratory are employed or in a professional degree program. For example, I have three students this year who have been accepted to top graduate programs including Northwestern, UPenn, and UNC.

In addition to the continuation of the aforementioned efforts, my future plans include reaching beyond the University to local Virginia communities and applying the same expectancy-value theory principles at the high school level. I am currently collaborating with Tom Fitzpatrick, the science curriculum coordinator for Roanoke City Public Schools, to establish a project-based laboratory curriculum supplement at their high schools. Over the course of each the school year, students in each grade will work toward a major goal – a working solar cell, a real wind turbine, or deriving electrical energy from local pond scum. The participating students will fill in surveys at the beginning of each year to provide statistical data regarding the impact of laboratory curricula on the student's perceptions of science and resulting career choices. To bridge the gap between high school and college, participating students will also be able to participate in a course I am currently developing in the broad area of the renewable energy science. All students will receive a course completion certificate from the chemistry department. However, more importantly, if they complete the course with a grade of an A and enroll at Virginia Tech, they will earn course credit toward their degree program. It should be noted that Roanoke City is a diverse area and the schools population is greater than 50% underrepresented minorities. It is my hope that the program provides a pipeline to the diversification of the undergraduate science student population at Virginia Tech.

## David A. Nicewicz

Chemistry

The University of North Carolina at Chapel Hill



An effective educator is both an exceptional communicator and mentor. Both require an intimate relationship with students for effective communication of the curriculum and also to instill a genuine sense of intellectual curiosity. The intangible skills required to be a successful teacher and mentor cannot be learned in a classroom but rather, are borne out of experience. I have been fortunate to have such experiences throughout my graduate and postgraduate career that have had a profound effect on my career as an educator.

When I first arrived in Chapel Hill in the fall of 2001, I joined the laboratory of a first year assistant professor, Jeff Johnson. As such, I was the senior graduate student from day one until the completion of my studies. My maturation as a leader and mentor rapidly progressed as I undertook the responsibilities of training younger graduate and undergraduate students in the laboratory. I observed firsthand, the rigors of running a competitive, externally-funded research program. These experiences afford me an added level of knowledge that few people encounter in their educational training and have proven invaluable as I began my independent career as a teacher and a researcher.

Opportunities of a different sort, in the form of teaching undergraduate and graduate lectures, presented themselves during my time in graduate school. I prepared and presented a sophomore-level organic lecture on the fundamentals of the venerable DielsAlder reaction. Additionally, I taught first-year graduate students the basic concepts of the Heck reaction and its application to natural product synthesis. Though the settings were quite different (the undergraduate class had approximately 250 students, the graduate course only had 15), I felt the curriculum was more effectively conveyed when I paused during the lecture to field questions and lead the students in discussion of the topics despite the class size.

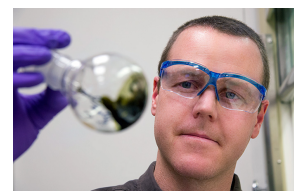
As an assistant professor, I continue to promote discussion-based learning and encourage students to be inquisitive about the broader context and applications of organic chemistry in every day life. In addition, there is no substitute for a general level of fascination and enthusiasm in the subject matter that a teacher can bring to the classroom. I often convey my interest, when appropriate, by presenting a brief history of the scientist(s) associated with a reaction or theory on a given day's lecture. By placing the concept in a historical context, it helps to make an abstract theory or reaction more accessible by giving it a human dimension. As well, I am actively involved in incorporating relevant examples in my introductory organic courses as they apply to medicine and materials.

In upper-level undergraduate courses, I challenge students to apply their chemical knowledge to solve more difficult problems. Problem set-based learning in the form of reaction mechanisms and complex molecule synthesis assignments would be the methods of choice. An introduction to the primary literature is also critical at this stage in the students' education. Since the majority of the students enrolled in the upper-level courses are science majors, the rationale behind these approaches is to prepare students to think critically as scientists for the next stage in their science education or to more easily transition into the science workplace.

At the graduate level, I have taught courses that focus on contemporary approaches to complex molecule synthesis and catalysis. The broad range of organic transformations and strategies that encompass the topics in natural product synthesis provide the fundamental basis for a concrete synthetic chemistry education. The "Classics in Total Synthesis" series provides an excellent reference to offer a historical perspective on the major contributors to the field of natural product synthesis as well as the important targets that have shaped the discipline. I have worked to incorporate recent examples from the literature that I feel are new directions in target-oriented synthesis for additional points of dialogue. Furthermore, I have begun to highlight current advances in organic methods ranging from C-H functionalizations to asymmetric bond-forming strategies. In the future, I envision creating and co-teaching a course on modern methods in radical chemistry and electron transfer that are relevant to my own research.

Lastly, as a principal investigator, I believe that the highest and most challenging form of education, mentorship, is most critical for training students to conduct meaningful and insightful research and to prepare them for their independent scientific careers. Essential to the goal of effective mentoring is the creation of an environment of open discussion in a manner similar to the mentors that have shaped my research career. To this end, I challenge my students in weekly group meetings to present topics for discussion that are outside their area of research in order to provide them with a more broad chemical education. Beyond increasing their exposure to varied research areas, it is of utmost importance to hold their research to the highest ethical standards. Leading by example, I hope to impress upon my students the value of maintaining a high standard of ethics in their research and will, through mentorship, provide guidance as they shape their identities as scientists.





My teaching thus far has been focused primarily on the Organic Chemistry Lecture and Laboratory sequence (Chemistry 351-355). This has included the development of course syllabi, Powerpoint slides for lecture, problem sets with answer keys, sample exams with answer keys, additional problems with answer keys, supplementary material on key topics, chapter outlines, and reaction summaries with mechanisms. These efforts have been overall very effective as evidenced by student evaluations and student performance on standardized national exams (most recent class average = 79th percentile on the American Chemical Society Organic Chemistry National Exam).

In addition to this work highlights of my other education accomplishments include:

- Development of new experiments for Organic Chemistry Lab II (Chemistry 355): To date I have created three (3) new experiments that have been successfully implemented in the Organic Chemistry Laboratory II curriculum. These include (1) an amino acid catalyzed reaction that introduces students to a new area of research called organocatalysis; (2) synthesis of liquid crystals which is a cooperative experiment wherein student prepared liquid crystal samples are then given to students in Materials Science 410 for analysis; and (3) biodiesel synthesis and analysis that introduces students to important concepts in renewable energy. I have also piloted a new cooperative experiment this Spring quarter in collaboration with Robin Matthews (WWU, E.Sci.) and students in her Algae Bioindicators (ESCI 428) course where algae grown by her students is then turned over to chemistry students for conversion to fuel.
- Development of a new curriculum for an advanced elective, Natural Products Chemistry (Chemistry 425a): I reworked this class to focus primarily on the biosynthesis of biologically relevant natural products. For this course I screened many and finally selected a textbook, selected topics to be discussed that included the preparation of various supplemental materials, and perhaps most time consuming prepared detailed PowerPoint lecture slides (100 slides).
- Development of a Biofuels (CHEM/ENRG 396) course to be part of the new cross-discipline Energy major/minor at WWU: I created and taught a Biofuels course Spring quarters 2012-2014. This course was designed to serve the range of backgrounds and interests for students enrolled (28/quarter) and prepare them to contribute to the various emerging Biofuel technologies. Student feedback has been overall very positive. One theme from student comments was a request for a laboratory component to the course, which I plan to pursue in the future.
- Development of a new curriculum for an advanced elective, Organic Reactions (Chemistry 425b): One of the major efforts associated with this course was the preparation of a workbook/textbook. This is a roughly 80 page book including all original text and artwork that represents nearly a 1-year effort on my part. It draws from various sources including my own expertise and primary literature.

Research is also a critical teaching tool. Students in my lab learn a variety of modern synthetic organic techniques including handling air- and moisture-sensitive reagents, inert atmosphere reactions, reaction work-up and purification, and compound characterization including both 1D- and 2D-NMR.

**Bradley D. Olsen**  
Chemical Engineering  
Massachusetts Institute of Technology



On the last day of my first summer internship at General Mills, I sat down with my supervisor Dr. Jon DeVries. Dr. DeVries was a research fellow in analytical chemistry at General Mills, and had hired me during the summer after my senior year of high school for a reason still unbeknownst to me. I vividly remember that he said to me, “Brad, in 20 years, the research you have done here will be obsolete, superseded by newer developments in the field. But, the relationships that you build will last a lifetime.” Dr. DeVries was right. Skills, knowledge, and the state of the art continuously evolve. But the impact we have through education and mentorship permanently alters the generations to come in a way that only a few research discoveries can equal.

As a student I learn the most from and am inspired the most by great mentors, and this is where I feel we make the greatest contribution as educators. While our classroom teaching is critical to imparting knowledge and some basic skills are learned through pedagogical laboratory experiences, it is through the scientific apprenticeship or traineeship that we all learned how to truly do science. Therefore, I am most excited about mentorship. I was attracted to education rather than other professions because we have the opportunity as researchers to do cutting edge science while working with amazingly talented students and postdocs, learning from their discoveries and helping them to reach their career goals. It is exhilarating to see students start out as eager and excited, mature into independent scientists, and then go on to make discoveries and build their careers. This last year, with my first group of undergraduate advisees and first Ph.D. students receiving their degrees, I attended commencement for the first time. As I sat on stage watching our graduates receive their diplomas, I wondered why only about 10% of our faculty attend. This was the best thing I did since I started as a faculty member at MIT.

Although the dominant research contributions made by institutions such as MIT are performed by graduate students and postdocs, I passionately believe that the most important part of our commitment to education in the chemical sciences is serving as a mentor to undergraduate students in research, providing them with the apprenticeship opportunities that are most critical to the application of their textbook knowledge and to their further development as young scientists and engineers. When I came to MIT as an undergraduate, my goal was to get a job as a practicing engineer and to make a comfortable life for myself, free from the financial worries that we had growing up. However, my perspective was utterly transformed by the research experience. Working with first with Ron Prinn but especially with Karen Gleason for three years showed me a new world of science and engineering, how I could apply my intellect to better the world through design and discovery and how I could make abstract textbook concepts real. The most memorable part of my undergraduate degree (besides meeting my wife in freshman chemistry) was figuring out in lab one day that the condensation of a gas stream inside a low pressure reactor was due to Joule-Thompson cooling of the gas as it flowed through a throttle valve. I suddenly saw physical chemistry at work in a real system, and could apply my knowledge to improve the reactor design. As equations, intuition, and observation combined in the lab, I felt a powerful medicine brewing that has been in me since those early days. It is from this personal commitment and this profound debt to the community for where I am today that I draw my commitment to mentor undergraduates, to start them on their way to what I hope is a life-changing journey.

In only five years at MIT, I have mentored 27 undergraduates from 6 major research institutions and 2 additional undergraduates from community colleges in the Boston area. The demands on time and resources from my lab are huge to make this commitment. Many of the students decide that research is not for them. But those who proverbially “catch fire” are truly exceptional. I have one undergraduate at MIT, one at the University of Delaware, three at UC Berkeley, and one at Stanford as graduate students in the last five years. We have published seven peer-reviewed articles with undergraduates (one more is in preparation), and I have supervised one completed undergraduate thesis and one that is in progress. Both will have led to publications. Undergraduates are listed as inventors on our first patent and on several patent applications. More than these quantifiable metrics, I am proud of who my students become. I have

the chance to form a close relationship with the approximately half of the students who stay for more than a year. Those who do not go to graduate school are leaders in industry at companies such as Genzyme and Boston Consulting Group, putting their research experience to the work of making products and processes that benefit society. The universally demonstrate the professionalism, integrity, and pride in their work that make our society great.

Classroom education represents a second important contribution that we make as teachers on campus, and I have been fortunate to contribute in both graduate and undergraduate education. I teach the first class in Chemical Engineering at MIT during the freshman spring, titled "Introduction to Chemical Engineering." This is a really fantastic opportunity to influence young students as they come through the door of the classroom asking questions as basic as, "What is a Chemical Engineer?" I show them all kinds of interesting things that chemistry can do: a huge piece of single crystal sapphire grown as a substrate for energy-efficient LED lighting, an umbrella that uses nanotextured polymer fibers to improve water-repellancy by mimicking the lotus leaf, and mass-produced cleaning pads that allow you to wash the bathroom from a distance. At the end of the semester, even though class is a lecture, we did a capstone lab where we made liquid nitrogen ice cream. But, rather than just make it, the students had to develop a complete process model and specify the exact quantity of liquid nitrogen required to freeze the ice cream. It is a great experience to see the students go from brand new to being able to provide quantitative solutions to open-ended questions.

At the graduate level, I have for several years been an instructor for one of our core first term classes, "Chemical Engineering Thermodynamics." With Arup Chakraborty, we have worked to make this class into a modern hybrid of statistical mechanics and engineering thermodynamics, deriving from molecular principles the basic mathematical structures and design equations used in chemical engineering thermodynamics, including equations of state and equilibrium relations. We show the students clearly how the laws that were first determined empirically arise directly out of simple models of molecular interactions, clearly connecting chemistry with engineering design. In addition to the honor of being lampooned for your efforts at the annual Christmas party (<https://www.youtube.com/watch?v=LvPZowxWOQA>), I was honored to receive the graduate teaching award last year for the best graduate instructor in chemical engineering.

Outside of teaching in the core chemical engineering curriculum, I teach two elective classes for senior undergraduates and junior graduate students that are core classes in our interdisciplinary Program in Polymers and Soft Materials (PPSM). The first course, "Polymer Synthesis," focuses on the chemistry and molecular design of polymers: defining chemical structures, reviewing the synthesis and properties of major industrial polymers, and covering the advanced methods used in modern academic research. I made a significant contribution to the direction of the course by introducing a large unit on biopolymers (DNA, polysaccharides, and proteins) and bioconjugation chemistries, providing a forward-looking perspective on materials chemistry that will be important in this century. I also created my own elective, "The Structure of Soft Matter," that teaches students the language of structure characterization as it applies to polymers and soft materials. After an introduction to concepts of order parameters, crystallographic order, and liquid state order, students delve into the theory of scattering and microscopy through case studies on liquid crystals, block copolymers, polymer crystals, proteins, gels, and colloids. In both classes, the focus is on projects where students integrate what they have learned and demonstrate high level synthesis and analysis skills through the application of knowledge.

In addition to these roles in mentorship and classroom education, I have volunteered for several different educational experiments and extra duties. In addition to mandatory advising duties within my department, I have volunteered each year to advise freshmen (freshmen at MIT are not assigned to a department). This time commitment bears great rewards in helping the freshmen with the difficult task of acclimating to campus and the seemingly even harder challenge of selecting their major. I have also participated as a lecturer for a multi-university course in neutron scattering in soft matter run by Oak Ridge National Lab, where I delivered lectures on scattering techniques applied to gels. This course was an exciting experiment in online and distance education, where the students and the teaching staff were drawn from many different universities to provide a specialized elective that would be difficult to execute

at any single university. The response to the course was very positive, and the impact on the ability of the U.S. to train scientists to use its world-leading neutron science centers was profound.

Recently, I have also become involved in international education through collaborators in Brazil. Brazil is currently undergoing an exciting transition, with the country seeking internationalization of its universities and academic communities. My involvement with Brazil started randomly due to the actions of a brilliant woman Dr. Vilásia Martins, who emailed me requesting a postdoc in my group. I had great trepidation about taking someone who wasn't from the group of one of my colleagues, but her expertise and interests were a very good fit for our work. She applied for and won a fellowship to come study at MIT, and in this way an exciting adventure in educational exchange started. I have since taught myself Portuguese and almost attained a conversational level of fluency in less than a year of study. I find that this effort to meet half way has opened many doors, and I am now coordinating several undergraduate student exchanges as part of the MIT-Brazil program. In addition, I have hosted two postdoctoral scholars, have two more students from Dr. Martins' group on their way to MIT, and have a proposal for a third postdoc pending. This fall I taught a short course in Brazil on bioconjugate chemistry at the Institute of Chemistry at the State University of São Paulo, providing students with English-language instruction that furthers their international exposure. It was an intriguing experience to learn the differences between the Brazilian and American educational systems and a great chance to reach out to many students. Additional courses are already being planned for future years, and my hope is that through these offerings I can support my Brazilian colleagues to advance their goals of greater internationalization of their scientific community.

## Gary J. Patti

Chemistry

Washington University in St. Louis



For the past several years I have participated in teaching Chemistry 181 (Chem 181), which is a survey course designed primarily for freshmen intending to major in science. When lecturing, I start by asking the two-week old freshmen how they should think about designing the most basic of science experiments. Every year they have answered almost unanimously by describing the traditional scientific method as was originally stated by Francis Bacon in the early seventeenth century. “Professor Patti”, they say, “you start with a hypothesis and then you design experiments to test it.” Most of them have never thought about science in the big-data era and simply regurgitate definitions that they memorized in high school. In a lecture entitled “the rise of the ‘omic sciences”, I challenge the fundamental scientific fabric that many of the students began weaving as early as elementary school. I explain that, contrary to what they may have learned in textbooks, contemporary scientists often do experiments without hypotheses. I argue that the philosophy of science is changing in light of the rapid speed in which data can be acquired and the rate that high-performance computers can analyze it. I highlight some of the seminal discoveries that have been made by performing profiling experiments without hypotheses. The majority of students are convinced. Within the hour, my objective is not only to teach them about different philosophies of doing science but also to get them to think critically about the strengths and weaknesses of each. I urge them to be willing to re-evaluate even the most established of dogma.

The approach I take in Chemistry 181 is representative of my general teaching philosophy for didactic education, which has two essential components: First, I believe that students need to know the standard body of knowledge that is printed in textbooks. In the Chemistry 181 example above, I stress the importance of Bacon’s classic scientific method, and how it is the foundation of scientific thought. Secondly, and perhaps more importantly, I think that students need to know where the standard knowledge falls short and develop the intellectual tools to expand the state of knowledge. For Chemistry 181, this means that the students appreciate the enormous power of rapidly collecting massive amounts of data and then mining it for unexpected discoveries or to formulate new hypotheses.

I am especially passionate about applying these two principles to teaching biochemistry at both the undergraduate and graduate levels. I believe that this approach is particularly important in teaching biochemistry because the field is on the precipice of undergoing a major change. The ways in which we think about metabolism, specifically, are rapidly evolving. For the last 50-plus years, the consensus in the scientific community has largely been that everything in metabolism is known. The chemical reactions and principles in canonical textbooks were thought to represent the whole story. Thus, there has been a lack of enthusiasm to pursue research and even study metabolism in the classroom. Indeed, some of our premier peer institutions have eliminated metabolism from their academic curriculum. The emergence of a large body of new scientific data over the last few years, however, has revealed that the complexity of cellular metabolism far exceeds that shown in textbooks.

When teaching biochemistry to the undergraduates, I draw an analogy to the field of physics, which was once believed to be a “finished” discipline. I argue that our understanding of metabolism is evolving much like our notion of physics evolved in the early twentieth century. With the emergence of experimental data that could not be explained by Newtonian laws, such as Einstein’s photoelectric effect, the field of quantum mechanics was born. I contend that the field of biochemistry is in a similar place. Modern metabolomic technologies have revealed that there are many important metabolites and pathways remaining to be discovered. Meanwhile, cancer studies have taught us that the “ATP-centric” perspective of metabolism shown in textbooks for the past 50 years is not always relevant. I am most excited to be educating our students during this paradigm shift. My teaching philosophy is to combine the standard textbook biochemistry that students need to know with an appreciation of what we actually do not know and how these gaps are currently being explored with cutting-edge research.

To accomplish my teaching mission detailed above, I designed an entirely new curriculum for undergraduate General Biochemistry II (Chem 482, Bio 4820), which focuses on metabolism and bioenergetics. First, with respect to my objective of teaching the standard body of knowledge in textbooks, I present the material in a unique perspective that I find resonates strongly with student interests. The overwhelming majority of students enrolled in General Biochemistry II (currently ~150 students this Spring 2015) have aspirations of going to medical school. I exploit my experiences from having attended some medical school myself to organize the course content in a framework that will be both relevant and interesting to the students. In brief, the course is structured around human disease. Instead of describing each concept as a list of seemingly boring facts, I introduce each pathway in the context of a medical pathology. I supplement each topic in the textbook with additional literature, and sometimes case studies, for this purpose.

To accomplish the second objective of my teaching mission in getting students to think about areas of deficient knowledge in the field, I have developed a map that represents all of the course's content over the entire semester. I show a simple presentation of the map on the first day of class, and then I add new details each week. This can be thought of like a traditional street map. On the first day of class, I show the street map of St. Louis but only include the major highways (40, 270, 44). As the semester goes on, I add in smaller streets like Forsyth, Big Bend, and Skinker. Given that the holes in our biochemical knowledge are largely at street intersections by this analogy, I find that this approach helps students resist the temptation to compartmentalize what seem like different topics in the textbook and rather appreciate where further research is needed.

To drive this vision of teaching metabolism, I have worked with two of my undergraduate Biochemistry students (Fuad Naser and Nicolas Spittler) to develop a digital version of the map above in which each layer of complexity can be added and removed with simple mouse clicks. The pathways are organized by different tissues, so that students can simultaneously see what is specifically happening in tissues like the brain and contrast that to other tissues like the liver. When teaching Biochemistry, students in my course are able to access the map via their laptop computers during lectures or while they are studying. Each time we learn a new pathway throughout the semester, we always start with the zoomed-out perspective so that students can appreciate how it integrates with the big picture of metabolism before zooming in to cover details of chemical structure and enzyme kinetics. In addition to the pathway visualizations, we have also organized the content of my course by topic in side pop-up windows we call learning trees. This enables students to read about ideas such as free energy, kinetics, regulation, etc. while they are looking at the related reactions. With the addition of this associated reading content, we believe that our digital mapping of metabolism will ultimately be able to replace the conventional textbook used in my course.

Thus far, the digital pathway map has been an enormous success. Fuad and Nick, the undergraduates who helped pioneer this resource, have presented the work at conferences: the American Society for Mass Spectrometry and the Educational Track of the Mass Spectrometry Applications to the Clinical Lab. Already, interest in the digital map is growing beyond Washington University.



**Michael D. Pluth**  
Chemistry & Biochemistry  
University of Oregon



Teaching is an essential component of transmitting scientific knowledge, and I have demonstrated my passion for teaching and education at the middle school, high school, undergraduate, and graduate levels. My general philosophy is that textbooks only provide the basic rules and scaffolds for thinking about science, but that real mastery (and often inspiration) occurs through the connections between different, often seemingly dissimilar, topics. I strive to present students with a professional and open classroom atmosphere and encourage in-class and out-of-class discussions.

Using a hands-on learning environment can be an effective way to increase exposure to and appreciation of science. In 2012, I co-developed (with Dr. Boettcher and Nazin) the “Furlough Friday” / “Mad Duck” outreach program at the UO (<http://sciencefriday.uoregon.edu>) in response to the decreased funding for primary and secondary education in Oregon that resulted in state-mandated furlough days. This program, which received initial funding from the Dreyfus Foundation, provides significant hands-on science education opportunities for local, underserved, middle school (MS) and high school (HS) students, with goals of (1) augmenting science education for young students, (2) increasing general appreciation for science, and (3) developing the students’ self-image as a scientist. The design of the program is simple, modular, and scalable: MS students come to the UO campus on early-release and no-school days to perform hands-on science activities run by UO faculty and graduate students, along with HS near-peer mentors/volunteers. The same HS students also perform advanced chemistry experiments either in UO teaching or faculty labs using state-of-the-art equipment. As a whole, the design strategy enables students to engage in informal science education outside of a classroom setting while also providing students with mentors/role-models that demonstrate the accessibility of careers in STEM fields. Mentors also gain valuable experience in effectively communicating scientific principles and enthusiasm to a diverse audience.

In addition to outreach environments, I also strive to engage with undergraduate and graduate students in lecture courses. A common theme in the Majors Organic Chemistry II and Physical Organic Chemistry II courses that I teach is that both courses focus on problem solving rather than memorization. Students spend one day of each week working on challenging, often open-ended questions that push them to think outside of the box and apply the chemistry that they have learned to complex problems. As a whole, I have found that most students rise to the challenge put before them, and after a bit of prodding will seek out new problem solving tools and look for different ways of thinking about questions presented in class. At the beginning of the term, many of the questions are simple to help students build confidence in their abilities to apply concepts learned in class to challenging problems. As the term progresses, the workshops get significantly more challenging. As an example of one of the questions from my Majors Organic course: Students are tasked with unravelling the mechanism of the Bergman enediyne cyclization. Students are given a list of ‘experiments’ that were performed, but are only given the structure of the reactants and NMR spectra of the products. They must first use the spectra to identify each product, and then try to devise a cohesive mechanism that accounts for each product being formed. The key point is to recognize that all of the products are derived from one common para-benzyne diradical intermediate. After the workshop, I connect these seemingly-academic reactions to a broader context by explaining how enediynes are common motifs in many anti-cancer drugs and show students how the mechanisms they determined help to explain the DNA-cleavage and anti-cancer properties of these compounds. These types of questions and exercises challenge students, but also show students that basic concepts learned in class are often all that are needed to tackle complex questions.

**Jennifer A. Prescher**  
Chemistry  
University of California, Irvine



*Providing cross-disciplinary research experiences in undergraduate laboratories*

One of my major educational goals involves exposing students to interdisciplinary science via “real world” experiences.<sup>1</sup> Rather than develop a suite of new courses, I am leveraging our existing curriculum and crafting novel methods to showcase modern science. My efforts toward integrating authentic research projects into UC Irvine lab courses are discussed below.

Upper-division laboratory research experience: Luminescence screening for bioactive compounds. Chem 128L is an undergraduate laboratory course designed to teach basic principles and techniques in chemical biology. Approximately 80-100 upperclassmen enroll each year. This course is often a student’s first exposure to biology-related lab skills, as most chemistry graduates do not enroll in an advanced biochemistry course (offered by a different department). Thus, a large part of Chem 128L is devoted to mastering laboratory fundamentals: pipetting, gel electrophoresis, etc. To provide these students with more than just a set of techniques, I developed experiments that not only teach basic skills, but also incorporate an element of research. The most popular of these experiments involves a high-throughput screen of small molecules for anti-cancer properties. UCI is home to a collection of 3000+ molecules synthesized by various research labs on campus. The molecules are arrayed over 96-well plates and provided to researchers courtesy of the UCI High-Throughput Synthesis and Screening Facility (HTSS). For the lab exercise, the students screen the compound library using luciferase-labeled cancer cells. Cellular readouts are obtained using luminescence screening equipment, with a loss of signal correlating with cell death. Students work in teams to collect data and present their findings (via classroom PowerPoint presentations). Additionally, undergraduates interested in follow up analyses of compound “hits” are eligible for summer research opportunities. The experiment has thus far been a success: over 250 students have screened a total of >1200 compounds (in triplicate), and compounds with anti-cancer properties have been identified. Students have consistently praised the “real world” nature of the screening exercise in written evaluations. Importantly, the experiment also provides training in key areas relevant to chemical biology: compound screening, pharmacokinetics, assay development, and data analysis.

Lower-division laboratory research experience: Engineering new luciferase-luciferin pairs. Motivated by the success of research experiments in Chem 128L, I am developing lab modules for lower-division undergraduate molecular biology and organic chemistry that bridge the two courses. One experiment builds on research efforts in my own group: identifying mutant luciferases that accept distinct, chemically modified versions of luciferin. The organic lab students utilize luciferin precursors (supplied by my lab) and “click” chemistries to synthesize unique analogs. The scaffolds are screened against mutant luciferase libraries generated by the molecular biology students. This project is truly cross-disciplinary: lab students are paired together and work as teams to generate data, analyze results, and present their findings. Funds from a Cottrell Scholar Award (Research Corporation) are supporting the development and implementation of these laboratory exercises.

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## Jonathan R. Scheerer

Chemistry

The College of William & Mary



My experience as an educator has led me to a core teaching philosophy: whether in lecture or lab, teachers can capture student enthusiasm and attract intellectually curious pupils by reinforcing the subject through illustrations of recent advances in the broader scientific community. Framing subjects against real global challenges (disease, antibiotic resistance, environmental and energy sustainability, etc.) also appeals to student interest and the role of their societal obligations in their future endeavors.

Combined with general chemistry, organic chemistry is the only interaction many students have with our discipline, and in this sense, these introductory classes have the greatest possible influence. When a student begins organic chemistry, most have succeeded in prior science courses due to their aptitude in mathematics. Organic chemistry is the first place where the majority of concepts are entirely new and demand a paradigm shift in learning. Moreover, the sophomore-level organic chemistry sequence casts a wide net, drawing students with diverse majors and interests. This is a challenging, but exciting and rewarding place, to be situated as an educator. A central goal of organic lecture should be to appeal to these wide interests, affirm the central role of organic chemistry in the life sciences, and provide attractive glimpses of current pressing problems for students to take with them, wherever their studies lead.

At the introductory level, I have been primarily responsible for the second semester of organic chemistry. I regularly apply my general teaching philosophy to this course. As an example, one lecture regarding the relative electrophilicity of carbonyl functional groups has elicited an overwhelmingly positive student response. In addition to coverage of the core concept, I detour to discuss  $\beta$ -lactam antibiotics (e.g., penicillins). In order to explain the relevance of these therapeutic molecules, I first provide some background into the history of penicillin and offer a primer on the structure and biosynthesis of the bacterial cell wall, highlighting the similarities and differences in enzyme-catalyzed (vs. organic laboratory-based) amide formation. I impress that the  $\beta$ -lactams are exquisitely designed amides that are effective because the strained amide retains the electrophilicity of an activated ester. I can then describe bacterial resistance due to widespread incorporation of the genes encoding for production of  $\beta$ -lactamases. Ultimately, I leave the students to think about Augmentin, a widely used  $\beta$ -lactam antibiotic (amoxicillin) that is co-administered with a  $\beta$ -lactamase inhibitor (clavulanic acid). I ask students to draw a reasonable mechanism that explains how clavulanic acid covalently deactivates the  $\beta$ -lactamase. This mechanism is above the level of the course, but for many students this teaching exercise has resulted in dedicated effort and an extended dialogue with me. With a little coaching, students often realize that they have most of the tools to solve this problem. One student initiated a conversation with me on the topic that spanned nearly three weeks. I sent her several papers and even showed her crystal structures of  $\beta$ -lactamase proteins; she would return with more curiosity and additional questions. This student, while not initially inclined to research or even chemistry as a major, joined my research lab and ultimately began graduate education at University of North Carolina (Chapel Hill).

*Background on the College of William & Mary and the teaching and research environment: working to incorporate research into the undergraduate introductory teaching laboratory.*

The College of William & Mary is a primarily undergraduate institution with an undergraduate student population of approximately 6,000. With roughly 50–60 chemistry majors annually (most of which pursue the ACS certified degree track), the department is a top producer of chemistry majors nationwide, both in per capita production and in total numbers.<sup>1</sup> The introductory organic chemistry sequence typically enrolls more than 300 students in organic II (and roughly 350 in organic I). Because the chemistry and biology departments at William & Mary are research active, but still involved in the instructional laboratory and attuned to undergraduate research capabilities (no PhD programs), we are positioned to integrate research into the instructional laboratory curriculum.

I have always had a great appreciation for practical aspects of chemistry. A student who learns a concept in

lecture *and* employs the theory in a productive experimental setting has a different understanding; there is no substitute for learning “with your own hands.” This is one reason that a close symbiosis of lecture and laboratory experiments is ideal, even though this is often difficult to achieve in practice. Even when lecture concepts align with the instructional laboratory, most experiments at the introductory undergraduate level are expository in nature, where students often know the expected outcome. While such traditional labs can enhance knowledge and generally serve to demonstrate common techniques and instrumentation, they do not promote scientific thought or problem solving abilities; they have little in common with the practices and intellectual effort required of the research endeavor. As a consequence, many teaching lab exercises fail to inspire. In my experience based on our current organic laboratory, students are the most engaged in the two labs that require identification and determination of unknown substances. In these labs, students are required to understand spectral data, perform and interpret chemical tests, and synthesize disparate concepts to solve for unknown substances. Of course, the substances are only unknown to the student. The exercise is pedagogically useful, but bereft of meaning outside the instructional laboratory setting.

In response to the concepts that work best and with an eye towards incorporating real research and discovery, I have developed and am working to implement a teaching laboratory research experience. This idea was inspired in part by an article by Scott and O'Donnell that provides a framework for the integration of research into academic training.<sup>2</sup> The concept of bringing research into the teaching labs was also the focus of a recent article that appeared in the March 2016 *C&E News*.<sup>3</sup>

While there are several reactions and bioactive scaffolds that inspire such approaches, I have focused these efforts on diketopiperazines (DKPs), the cyclic dimers of amino acids, which are a large and diverse family of natural products that exhibit an equally wide range of biological activities.<sup>4</sup> In particular, I have dedicated the departmental advancement funds provided by the Dreyfus Foundation for the implementation of this capstone organic lab research experience based on the aldol condensation of bisacetoxymglycine anhydride and an aldehyde component. The reaction leads to novel alkylidene DKPs similar in structure to the promising anti-tumor natural product phenylahistin<sup>5</sup> and its simplified synthetic derivatives, including pinabulin which is currently in phase II clinical trials.<sup>6</sup>

In the development of an undergraduate teaching laboratory sequence that attempts synthesis of novel chemical entities (for 300 students), one encounters many obstacles and practical considerations. In the case at hand, several favorable reaction attributes have made the lab sequence a realistic possibility as we move toward full implementation next year. When implemented, I anticipate that the entire organic laboratory can generate 100–200 compounds annually that will be tested for biological activity. Currently, a brine shrimp lethality test is being explored, though we are also considering a Kirby-Bauer<sup>7</sup> diffusion assay, which involves growing bacteria (*e.g.*, possibly *S. epidermidis*, or *S. Aureus* ATCC 25923) in the presence of disks impregnated with DKP compounds. These are simple, safe, qualitative assays that can be easily incorporated into the final lab period.<sup>8</sup>

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## Jordan Schmidt

Chemistry

University of Wisconsin-Madison



The introductory first-semester general chemistry course frequently provides undergraduates' first (and often last) exposure to the physical sciences. This course thus plays a crucial role not only in teaching chemistry, but also in preparing students to address crucial societal issues requiring scientific literacy.

Unfortunately, many students struggle with introductory chemistry. This observation has been attributed (in part) to the fact that chemistry spans a variety of conceptual levels: the macroscopic, corresponding to observed chemical reactivity; the microscopic, where reactivity is rationalized based on the properties of individual atoms and molecules; and the symbolic, where chemical reactions are written in terms of abstract symbols and equations. Beyond these conceptual challenges, students of color face additional hurdles: statistics at UW-Madison highlight a significant "achievement gap" in introductory chemistry (and other large, lecture courses) between minority and majority students, a gap which persists even after controlling for prior academic background.

Seeking to better reach and teach our undergraduate population, I am a leader in a number of initiatives targeting the undergraduate chemistry curriculum (both here at UW-Madison, and beyond), with the ultimate goal of raising student performance overall and narrowing the associated achievement gap. I will focus on three specific efforts:

1. Integration of chemical visualization into the general chemistry program
2. Course-reform efforts targeting general chemistry aimed at closing the achievement gap
3. Integration of computational chemistry across the undergraduate curriculum

### Visualization in General Chemistry

Visualization is a powerful approach to communicating complex chemical phenomena, helping bridge the span between the macroscopic, the microscopic, and the symbolic. Since arriving at UW, I thus have made visualization a major point of emphasis in my teaching, incorporating chemical visualization and simulation throughout my general chemistry course. This effort is motivated by extensive prior literature highlighting the efficacy of visualization in the chemical sciences. I draw upon a wide variety of sources for visualizations, including PhET (out of UC-Boulder), resources compiled by the Journal of Chemical Education, and those of my own creation (often using WebMO, see below). I find that simulations which emphasize a "molecular" perspective are particularly valuable in bridging the divide between everyday macroscopic properties and the underlying molecular structure and dynamics. For example, I use a molecular simulation of liquid water to illustrate: the basic properties of solids, liquids, and gases in terms of the underlying molecular arrangements; the connection between temperature and molecular motions; and the associated connection to phase transitions. I return to this, and other, simulations numerous times throughout the semester to elaborate on and reinforce these basic concepts.

Visualizations are particularly powerful when paired with complementary demonstrates or figures, and the use of multiple representations has been shown to be a powerful mechanism to improve learning outcomes. For example, when discussing Rutherford scattering (demonstrating the existence of the positively charged dense nucleus), I use a combination of a static diagram of the experimental setup, lecture and chalk discussion of the underlying physics, and a simulation of the scattering events. The simulation displays the paths of alpha particles as they scatter off of a gold nucleus, showing the trajectory of each particle. Most particles have high impact parameters, and thus trajectories that deviate only modestly, while a small number with very small impact parameters scatter nearly backwards. In order to increase the impact of these simulations, I often place links to the simulation on our online course management system so that students can explore these simulations on their own after class.

## Closing the Achievement Gap

I have been a leader in an ongoing course-reform effort with the Vice Provost to close the “achievement gap” between our majority and minority students, targeting general chemistry. Our strategy involves the introduction of a variety of new “best practice” strategies into the curriculum. These new elements include: (1) mandatory weekly online homework assignments, increasing students’ time-on-task; (2) weekly group-based problem solving sessions, where students come together to solve homework or supplemental problems; (3) in-class interactive “clicker” questions, increasing engagement; and (4) group-based “guided inquiry” exercises, introducing students to new concepts via an inquiry-based process.

Of these changes, the emphasis on group-based learning has been the most impactful. I believe that the most effective way for students to progress from novice to expert is to first struggle through the material individually, and then to teach the material to their peers. Group-based problem solving sessions provide an opportunity for students to practice both roles. Students work in groups of 4-5, and work semi-independently on a set of similar (but not identical) problems. In practice, students engage each other and/or collaborate on the most challenging problems, struggling together while teaching and learning from each other. Faculty and/or teaching assistants serve primarily to prevent groups from going too far astray and to shepherd groups back in the right direction.

“Clickers” have been another important addition. While use of clicker technology is now fairly common, I have taken a somewhat novel approach by focusing almost exclusively on conceptual questions, probing student understanding at a more fundamental level (as opposed to rote process memorization). Since common “databases” of clicker questions contain few, if any, conceptual questions, most of these questions were designed or adapted by me. More recently, I have taken this focus on conceptual chemistry even further by including a selection of conceptual questions on my midterm exams. The results are extremely illuminating, and occasionally highlight student misconceptions far more vividly than “standard” questions!

We hypothesized that these approaches would lead to higher student engagement, inclusion, and integration, and thus perhaps narrow the achievement gap, while simultaneously benefiting the broader student population. While the data is still preliminary (and well-controlled studies are difficult), our results thus far suggest that these efforts are paying off, as the rate of adverse outcomes among the targeted groups have reduced substantially over the past several semesters.

## Computation in the Undergraduate Curriculum

One of my major and long-term educational goals is to encourage the integration of modern computational chemistry approaches across the undergraduate curriculum. Computational chemistry is now well-established as the “third pillar” of chemical inquiry, complementing both experiment and theory. It has become nearly ubiquitous, and substantial a fraction of all published papers (from synthetic organic, to inorganic, to physical chemistry) now include some computational data. As such, it is thus crucial to expose undergraduate students to these modern computational techniques.

Responding to the growing importance of computational chemistry, I am continuing my 15-year role as the principle developer of the “WebMO” software package. WebMO is a web-based interface to state-of-the-art computational chemistry software that allows students to focus on the practice of computational chemistry without the associated technical burden of learning archaic command-line operations, constructing complex input files, or parsing multi-page text output files. WebMO thus eases the steep learning curve often associated with computational chemistry and allows students to access state-of-the-art calculations from their web browser. WebMO provides visualization capabilities for a wide variety of properties, including orbitals, molecular vibrations, and spectra. WebMO has been downloaded over 20,000 times from dozens of countries, primarily by colleges and universities for use in their undergraduate and graduate curriculum. Many of these installations serve hundreds or thousands of students each. Thus WebMO is impacting the education of hundreds of thousands of students across the world, including a recent effort of the National Center for Supercomputing Applications to deploy WebMO to high school classrooms across the state of Illinois.

Since arriving at UW, I have also been working locally in collaboration with other faculty to more broadly integrate computation across our own undergraduate curriculum. For example, I designed a new computational laboratory for our first-semester general chemistry program, asking students to evaluate simple VSEPR-based models against calculated geometries and to rationalize the deviations; I have also assisted with far more extensive integration in the organic and physical chemistry lab programs, where a substantial fraction of wet labs now have a computational component.

### **General Teaching Philosophy**

My teaching style is guided by two overarching principles: clarity and enthusiasm. I re-emphasize key concepts in lecture using several approaches to reach students with a variety of learning styles, focusing both on the macroscopic, qualitative chemical description and connecting to the underlying microscopic description. I find that continually making and returning to this macro-micro connection throughout the semester helps alleviate many misconceptions and meshes both with my interest in visualization (described above) and my philosophy as a physical chemist. Yet even the most cogent lecture will be poorly received without an enthusiastic presentation. Although undergraduate courses should not be reduced to mere “entertainment”, I have come to appreciate that lecturing to a class of 350+ does involve many elements often associated with theater. In particular, students respond to the energy of a lecturer, drawing them into the material. I thus engage my students using a combination of energetic presentation, lecture demonstrations and simulations, interactive clicker questions, and a smattering of my dry sense of humor.

While these principles are admittedly not unique, I believe that they yield a result that is extremely effective at reaching both prospective science majors and non-majors. Thankfully, my students seem to agree and they have selected me as a university “Honored Instructor” for three consecutive years.

## Joshua A. Schrier

Chemistry  
Haverford College



Coursework should prepare students for research in the chemical sciences, and students should see “research” as natural continuation of the material they are studying. To achieve this, my main project has been to incorporate computation into all levels of the chemistry curriculum. New forms of pedagogy (e.g., “flipped classrooms”) help enable this goal by providing more class time for challenging, open-ended problems. More broadly, to help give students the mathematical and computational tools they need for success, I’ve cooperated with the local mathematics and computer science departments and the broader mathematics/computational education to help define and revise new curricula. Below, I discuss my efforts towards these goals.

**Computation in the Physical Chemistry Curriculum.** Modern physical chemistry research relies heavily on computational methods, but introductory physical chemistry textbooks are nearly silent on this topic. Most undergraduate textbooks take the “solve a bunch of equations by hand for a very simplified model system” approach (typically limited to gas phase problems), and more recent textbooks include at-best exercises using packaged “black-box” Hartree-Fock/DFT calculations. To empower students to read computational chemistry papers and participate meaningfully in computational chemistry research, they need to understand what is going on inside the “black-box”. The best way to understand something is to build it yourself—as Richard Feynman said, “What I cannot create, I do not understand.” To achieve this, I have written a textbook (to appear early 2017 from University Science Books) that guides students through building their own Metropolis Monte Carlo, molecular dynamics, stochastic kinetics, atomic and molecular Hartree-Fock, tight-binding, quantum Monte Carlo, DFT, etc. models and using them to solve chemical problems. It is designed to be used either to supplement a traditional introductory physical chemistry textbook (I use it along with the McQuarrie and Simon series), or as a standalone textbook for an advanced course dedicated to computational chemistry. Students come away from this with basic programming skills, an understanding of fundamental numerical techniques and algorithms that are applicable to a wide range of research problems, and a greater ability to critically evaluate computational results in the literature. Moreover, this allows us to bring modern areas of physical chemistry—interacting systems, condensed phases, etc.—into the introductory physical chemistry curriculum, rather than deferring them to special, dedicated courses.

**Computation in the Freshman Chemistry Curriculum.** Since Fall 2010, our department has been revamping the introductory chemistry curriculum towards a new model that integrates treatments of concepts common to organic and inorganic chemistry. The first semester emphasizes atomic and molecular quantum mechanics, bonding (organic, inorganic, and organometallic) and spectroscopy. This is a natural place to incorporate computational chemistry exercises for first-semester freshmen. Using the WebMO package, I’ve developed classes and exercises for students to calculate, quantify, and visualize atomic and molecular energy levels, atomic and molecular orbitals, and to visualize vibrational modes for the interpretation of IR spectroscopy. This complements the readings (and static pictures) in their textbook, giving them a greater sense of “ownership” of the material. Moreover, it provides students with a tool for going beyond the simple diatomic molecules that are in the introductory textbooks, which they can utilize in many areas of chemical research, and later chemistry classes.

**New pedagogy: Gamification of the Chemistry classroom.** Using insights from the psychology-of-learning literature—and in particular its applications to language learning—I’ve been working over the past two years to develop a web-based “game” for learning organic spectroscopic interpretation. This project has been supported by institutional funding for student entrepreneurship and Teaching with Technology, and by the teaching support offered by the Dreyfus Teacher-Scholar award. We are doing a controlled study on student performance during Fall 2016, and after that will expand the project to other schools in the Liberal Art Consortium for Online Learning (LACOL), before releasing this publicly.

**New pedagogy: Flipped/Blended Classrooms.** An emerging pedagogical strategy is the “flipped classroom”, where students watch pre-recorded lectures at home before class, and then class time is spent working on projects. Realizing that this was ideal for creating more dedicated classroom time for problem solving—both “by hand” derivations and computational problems, I “flipped” my Quantum Chemistry (second semester physical chemistry) course in Spring 2013. A semester course consists of a over 100 “mini-lectures” (typically 5-15 minutes long, averaging about 10 minutes). This was a great success—not only did students spend more time with material suited to their level of preparation, e.g., to review math topics, or to get “bonus” advanced material, but it also allowed us to tackle even more challenging computational work in class. After spending 10 minutes answering general questions, the remainder of the class is spent on problem solving, tutorial-like instruction on specific problems and student presentation of solutions. Based on the success of this course, I flipped the Statistical Thermodynamics and Kinetics (first-semester Physical Chemistry) course and in collaboration with my colleague Prof. Robert Scarrow, flipped the first semester of freshman chemistry in Fall 2013. In all cases, we have found that the flipped experience improves student learning and performance on summative assessments, especially for motivated but under-prepared students. I have presented these efforts at two of Haverford’s “Teaching with Technology Forums”, as well as participated in Bryn Mawr College’s “Blended Learning Forum”.

**Promoting Mathematical and Computational Education for Chemists.** Mathematics is essential for the success of current physical chemistry students. Besides working with the Haverford mathematics department to revise the introductory math curriculum to better meet the needs of chemistry and physics students (coming online in Fall 2014), I served on the Mathematical Association of America’s Committee on the Undergraduate Program in Mathematics study group (2013-2014) on Chemistry, chaired by Prof. Martha Siegel (Towson Univ.) to develop a document of recommendations. Moreover, computational expertise is going to be essential for all scientists—experimentalists and theorists—in the future. To prepare students for this, I was a member of the Education working group for the NSF-sponsored workshop of “The Rise of Data in Materials Research” (2015). In addition to my role as coordinator of Haverford’s Scientific Computing Concentration, I am currently developing an introductory course in computer science for students in the physical sciences, with a strong emphasis on simulation and data-mining as it applies to chemistry/physics/materials research.

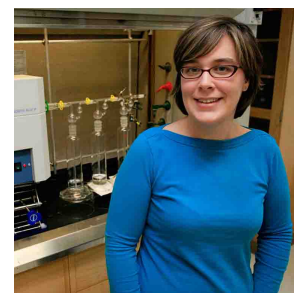
**Blurring the distinction between “teaching” and “research”.** The ultimate goal is to prepare students to engage in independent chemistry research. The courses described above provide students with a computational “toolbox”, enabling them to more effectively read the research literature and perform their own calculations to address their own research problems. Additionally, many “end of semester” projects in physical chemistry for the past years have been aimed at giving students a head-start on their senior thesis research, in consultation with their advisors. Another form of “teaching” is in the form of research tutorial courses during the year. Besides advising senior theses, I also have a course for sophomores and juniors to conduct research during the year. This provides students with the continuity needed to complete research projects that they started in the previous summer or start new exploratory work. Third, I create a bidirectional relationship between teaching and research. Several of my papers originated from student questions or topics in the physical chemistry curriculum. Besides including “hints” about the project in lectures, problem sets, and exams, I also invite students in relevant classes to review my manuscripts. This illustrates that the material they are learning in class is “exciting” and allows them to understand some new, previously unconsidered area of science. I have also taught several half-semester advanced “Topics in Materials Science” courses on my research interests in (i) semiconductor nanowires; (ii) graphene, and; (iii) data-mining for materials discovery. The student “output” from these courses is a mini-literature review of a particular material, which gives me an opportunity to do my own background literature reading and keep abreast of these fields.



## Sara Skrabalak

Chemistry

Indiana University Bloomington



**Educational Mission:** *My ultimate goal with regards to science education is to contribute to the development of an engaged and scientifically literate public while equipping students with the skills and enthusiasm to be effective interdisciplinary scientists and ambassadors of science.*

**Overview:** I believe that an essential feature of any effective science education program is the capacity to equip students with the skills for engaging citizens in scientific exploration and inquiry. I agree with the AAAS resource *Science for All Americans* that students' knowledge of and ability to use science depends on the "character, distribution, and effectiveness of the education people receive."<sup>1</sup> Yet the National Science Board reports that US students are near the bottom compared to other OECD countries with regards to science understanding.<sup>2</sup> To address challenges in STEM education, the board recommended providing "education that increases the public's knowledge of, and appreciation for, the importance of science and technology in the context of quality of life, economic prosperity, and national security."<sup>2</sup> In doing so, public literacy of science will be enhanced to facilitate greater "discourse on issues pertaining to science and technology."<sup>2</sup> *Outlined are activities that highlight my dedication to promoting scientific literacy through educational efforts that engage students at all levels as educators themselves.*

**Undergraduate Instruction.** I redesigned *Chemistry 100: World of Chemistry* to place chemistry topics in social context. *Chem 100* is a large (60-80 students/year) introductory course for non-science majors that I taught for five semesters between 2008 and 2012. The redesign involved:

- (1) selecting *Chemistry in Context*<sup>3</sup> as a textbook and adding science policy movies such as *An Inconvenient Truth*<sup>4</sup> into class and discussing the accuracy of the science presented in the films and counter-point articles.<sup>5</sup>
- (2) developing a *Science Media Project* in which students critique news articles about a science topic of their choice and create a news article for their family.
- (3) developing a *Children's Book Project* where students explain a chemistry topic (e.g., ozone depletion or global warming) for kids age 7-8 (see Figure 1).

Students become better equipped to evaluate science media outside of class and more effective communicators of science by analyzing sources of science and putting complex ideas into their own words. I spoke on these classroom innovations at the Spring 2010 American Chemical Society (ACS) Conference<sup>6</sup> and published a manuscript in an ACS Symposium Book.<sup>7</sup>

Also *Chem 100* was part of the course bundles for the 2010 and 2012 Themesters on *Sustainability and Good Behavior, Bad Behavior: Molecules to Morality*. Themester is an Indiana University (IU) initiative to engage undergraduates in interdisciplinary learning via campus-wide programming and thematic coursework across departments. New activities were integrated into *Chem 100* as part of each Themester. For example, students presented posters on topics such as natural gas as an energy source and the Great Pacific Garbage Patch during the *Sustainability* Themester. Students also toured IU's Central Heating Plant and their Children's Books were displayed in the Themester closing ceremony, which was attended by Bloomington 2<sup>nd</sup> graders. I discussed this project in IU's workshop, *Tales from the Trenches: Strategies for Teaching Effectively*. More recently, I co-developed the first upper level undergraduate course in materials chemistry. A model of co-teaching was adopted so students could be exposed to the diverse topics in an integrated manner and foster understanding of structure-property relationships regardless of materials class (e.g., hard *versus* soft). In-class activities emphasized group work to facilitate discussion among students with different scientific interests and often required "flash" presentations. These types of active learning activities and student engagement have been shown to enhance student comprehension and performance in science. I will continue teaching chemical concepts through the lens of social context and integrate in activities that require students to serve as teachers. As the old motto goes, the best way to learn something is to teach it yourself.

**Science Ambassadors.** How do I reach people in rural Indiana and enhance public literacy about chemical

topics? As it turns out, I interact with effective messengers everyday: the IU undergraduates. At IU, many students are in-state and from places I hope to reach. Currently, I am piloting a *Science Ambassadors* program. Undergraduates are recruited to conduct research in the Skrabalak Laboratory and be *Science Ambassadors*. During May when high schools are in session but summer break has begun at IU, these students return to their hometowns to teach a chemistry class with their former teacher in which they discuss their research and experiences as STEM majors and perform demonstrations. *Science Ambassadors* get a stipend and help with drafting letters of contact, packaging demonstrations, and critique of their presentation. Benefits include that (i) students know the school they are visiting, (ii) the cost is low compared to other high school outreach programs, as students have their parents' homes to return to, (iii) the students' parents are indirectly targeted (e.g., one can envision discussions at dinner tables about chemistry that would never occur otherwise), and (iv) compared to normal summer jobs, this program is attractive. The program should also be a valuable recruiting tool as (v) college students can serve as role models who inspire high school students to pursue STEM degrees while also (vi) feeding the "pipeline" of scientists at the high school level. (vii) The program also enhances undergraduate training by valuing effective communication and reinforcing scientific concepts. As of summer 2016, 320 high school students were contacted through these trips and surveys indicate that ~40% of the students are now more inclined to seek out research opportunities (55% for self-declared STEM majors) and ~40% stated they were unaware of undergraduate research opportunities until the visit. These results are encouraging as studies show students, especially from underrepresented groups, are more likely to pursue careers in science if engaged in research early on.<sup>8</sup> An article describing this program is in preparation.

**Graduate Student Training.** I am actively involved in teaching students in my research group advanced experimental design and providing guidance in writing and presentation. Weekly group meetings are held and students have access to my calendar for scheduling individual meetings. As of fall 2016, my research group consists of 10 graduate students, 3 postdoctoral scholar, and 3 undergraduate students. I have graduated 6 PhD students and 2 MS students to date. I actively promote my students' professional development, with them giving over 60 presentations (either poster or oral format) at regional or national meetings between Aug. 2008 and Dec. 2016. Many have also received awards sponsored by the Chemistry Department or University as well as professional societies (e.g., travel awards). Training in the Skrabalak Laboratory is also enhanced by the interdisciplinary nature of the research and *Science Ambassadors*, which requires assistance of graduate students in training undergraduates in research and as ambassadors.

Beyond the Skrabalak laboratory, equipping graduate students with the required skills to be effective ambassadors of science requires emphasis on communication. Graduate instruction in *Fundamentals of Materials*, which I have taught for 6 semesters and am currently teaching, uses examples of materials in everyday life to teach concepts. The course also includes a materials project on a "hot topic". Peer review activities are incorporated to train students in this important service. Finally, as a Senior Personnel on a Cottrell Scholar Collaborative Project sponsored by RCSA (\$25k), I am working with a national group of scholars to develop resources to train teaching assistants in effective inquiry-based means of instruction, which are shown to develop problem-solving skills and promote students' science literacy and confidence.<sup>9</sup>

**Chemistry of Everyday Life Seminar Series.** With an ACS *Innovative Project Grant* (\$2500), I co-founded a *Chemistry of Everyday Life Seminar Series* to bring chemistry to the Indiana University campus and Bloomington public at large. For example, in spring 2011 Prof. Bamforth (UC – Davis) spoke on the chemistry of beer. His talk was co-sponsored by Upland brewery and attended by ~200 people (including Bloomington's home brewing community). At least one seminar in the series is held per academic year and is organized now by a graduate student committee with assistance of the current chair of the local ACS section.

**Concluding Thoughts.** Chemistry is the central science because it intersects with physical, biological, and applied sciences. As such, knowledge of chemistry is vital to being an engaged citizen; however, too often the experiences people have with chemistry result in withdraw from science altogether. Greater scientific literacy can be achieved by discussing chemistry through a social lens and enhancing the communication skills of chemists themselves.

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## Paul Clinton Spiegel

Chemistry

Western Washington University



The majority of my teaching efforts at WWU focus on Biochemistry. Courses that I routinely teach are Biochemistry I and II, Biophysical Chemistry I and II, Biochemistry Lab, and an elective Enzyme Chemistry course. Based on student and peer evaluations, my teaching efforts have been exceptional during the past eight years. As should be the case with everyone who educates, I view my journey as a teacher as an evolutionary process. Adapting to the needs of my classroom and to the subject at hand is tantamount to success.

### Accomplishments

When I first came to WWU, I was given the opportunity to update the curriculum that we provide for our biochemistry majors. To this end, I have successfully implemented writing proficiency components into two upper division courses, introduced the theory and practice of structural biology methods in the biophysical chemistry curriculum, implemented a working knowledge of molecular graphics into multiple courses, and have been innovative with new approaches to teaching our upper division biochemistry lab course. In this particular course, students are tasked with six-week lab module where they identify and characterize an unknown protein. This approach not only exposes undergraduates to the idea of the unknown in scientific research, but it also provides them with the opportunity to formulate a hypothesis that is verifiable via biochemical experimentation. This six-week long experimental approach was recently published as a unique way to teach biochemistry and protein folding thermodynamics (BAMBED 38(1): 17-22.). Additionally, I have written another laboratory module that exposes students to macromolecular mass spectrometry. In this experiment, students are given two different unknown proteins that are analyzed with an ESI-MS system. Following data collection of the  $m/z$  ESI spectra, students are tasked with calculating the molecular weight of their unknowns and then comparing their results to a list of possible proteins. I was also recently awarded a \$45K grant for the purchase of two biolayer interferometry (BLI) instruments. I am developing new laboratory modules that employ BLI, an optical biosensor technique that can directly measure the kinetics and thermodynamics of macromolecular binding. The two labs being developed measure the binding and release of antigens bound to antibodies and homing endonucleases bound to target DNA sequences. Lastly, I am continually evolving and improving my elective lecture course, Enzyme Chemistry. Each time I've taught this course, I've significantly changed the curriculum to match the current state of the rapidly progressing enzyme field. This year, the class focused on selective inhibition of kinases by chemical genetics, high affinity transition state analog inhibitors based on kinetic isotope effects, engineering of enzymes with novel activities, chemical rescue of structure for the allosteric activation of enzyme reactions, and the structure, function and engineering of gene specific nuclease reagents for gene alteration.

### Approach

To be successful in teaching within the field of Chemistry, I have a list of four principal goals that I try to achieve with every course I teach:

Provide students with a broad, comprehensive understanding of both the background and theory of the subject. In my experience, there must be some basal level of classroom lecture that presents students with the core concepts in a creative, captivating manner. This might include applicable examples of each concept in a broader context or a humorous way of explaining something otherwise viewed as esoteric. The lecture material can be further coalesced in the students' minds by supplemental discussion and reasoning in small groups. As is often the case, small group discussions may help students overcome misconceptions.

Allow students to develop working knowledge of relevant instrumentation and experimental findings in Chemistry. One of the most effective ways in which one can truly instill the complex workings of

Chemistry to undergraduates is to expose them to cutting edge instrumentation that would be utilized in the research environment. Additionally, by outlining “classic” experiments in Chemistry that have allowed our chemist predecessors to develop working models of the biological and chemical worlds, a teacher can enlighten their students to the wonderment of the scientific process.

Teach students how to critically assess primary scientific literature. The vast world of peer-reviewed scientific literature is often intimidating to undergraduates. There is but one way to overcome this hurdle, and it is by “immersion” of undergraduates into the complex sea of jargon that is primary literature. With every upper division course I teach, students read at least one article from the primary literature that is further discussed in class. These articles are strategically chosen such that students will not get overwhelmed upon first exposure. With later courses, I have charged students with the task of finding articles themselves, distilling them independently, and the presenting them in a coherent manner to the class.

Develop independent, critical reasoning skills. At the end of the day, my ultimate goal is to develop scientists and informed, critical thinking citizens. By strategically implementing the first three goals, I have found that developing students into active, skilled minds is attainable. In order to spark the development of these skills, I routinely assign students to: (1) give oral presentations of various sorts (for example, presentation of their written research proposals or a literature review), (2) write research papers based on their ideas and/or experimental results, and (3) give out take-home exams that take the better part of a week to complete.

### **Research with students**

Research experience is a critical teaching tool for many students interested in a scientific career. Students in my research group gain significant experience in ubiquitous molecular biology and protein chemistry methods. Further, many students gain the experience of growing protein crystals, collecting diffraction data and determining crystal structures of protein complexes. Other students likely gain experience collecting GTPase kinetic or equilibrium binding data. Several research students have presented their findings at regional and national scientific conferences, and many of them have been co-authors on peer-reviewed primary research articles from my lab. Lastly, my efforts as a mentor in using research as a teaching tool goes beyond students that have contributed to my research projects. For example, I received a Murdock Charitable Trust Partners-In-Science grant, which brings a high school teacher into my research lab for two summers to perform experiments full-time and bring their experiences back to the classroom. Julie Pohlman, a science teacher from Sehome High School in Bellingham, WA, worked on structural characterization of antibodies that inhibit hemophilia A treatment in my lab for two summers. Her efforts led to her being a co-author on a recent manuscript published in the Journal of Biological Chemistry. I have also been directly involved in the WWU Chemistry REU Program funded by NSF. For this program, I co-wrote each grant proposal and have served as the co-Director for the first three-year granting period, and I now serve as Director for the renewed second three-year granting period. In this program, we focus on bringing students to WWU for an authentic research experience from schools or backgrounds that do not have access to research opportunities, namely students from community colleges (~40% of REU students) and underrepresented minority groups (~40%).

**Dwight R. Stoll**  
Chemistry  
Gustavus Adolphus College



### Undergraduate Courses, Pedagogy, and the Separation Science Community

At Gustavus Adolphus College I am the only faculty member in the chemistry department who is an analytical chemist by training. This means that my main teaching responsibilities in the department have been focused on our traditional wet chemical Quantitative Analysis course (Che270, spring semester, with two lab sections), and our Instrumental Methods of Analysis course (Che380, fall semester, with one lab section). I have also contributed to our Introductory Chemistry course, our Special Topics course, a January-Term Research Methods course, and our Chemistry Seminar series.

In the case of my Quantitative Analysis course, I have made, and continue to make, significant changes in the way that I implement the course. First, I have begun to convert some of the material I normally discuss with students in a traditional lecture format into videos that are viewable via YouTube, any time, any place. This allows me to move the delivery of some key content outside of the classroom, and spend more time in class working with students more interactively on concepts they have difficulty with, and working through problems as a means of practicing critical chemical thinking with them. Second, for the past three years, I have implemented a laboratory practical skills exam in which I ask students to demonstrate proficiency for a randomly selected skill used in quantitative chemical analysis. I find that this is a very effective means of holding students accountable for actually learning the details associated with proper quantitative lab skills, as opposed to simply 'going through the motions'. I continue to use a traditional approach to the laboratory that involves a number of titrations and a gravimetric analysis experiment, because I believe these are effective vehicles through which students can develop the physical skill and mental discipline required for accurate and precise chemical measurements and manipulations.

In my Instrumental Analysis, I have made a number of course changes that have proven helpful. As with Quantitative Analysis I have begun developing video-based lecture material, with the goal of transforming what I do with students in the classroom from traditional lecture format, to a more interactive problem-solving format. The bulk of my effort in making changes to this course over the past four years has been focused on modernizing the laboratory curriculum I inherited upon arriving at Gustavus in 2008. Currently, students in this course gain hands-on experience with chromatography (liquid and gas) coupled with both mass spectrometric (MS, and MS/MS) and non-mass spectrometric (FID, UV/Vis, Fluorescence) detectors, sample preparation (Solid-Phase Extraction), and spectroscopic methods (UV/Vis and Fluorescence). They also gain hands-on experience with simple electronics as it relates to instrument control and data acquisition, and simple programming in LabView to learn basic concepts in digital instrument control and data acquisition. I have also condensed the laboratory curriculum somewhat to create time and space for students to carry out an independent research-like project using chemical instrumentation in the last third of the fall semester.

Historically the laboratory component of our Introductory Chemistry course has been quite traditional, involving time-tested experiments such as qualitative analysis of inorganic compounds. During the 2011-2012 and 2012-2013 academic years, I led an effort to change this laboratory curriculum from one focused largely on inorganic chemistry to one that is focused on a deliberate exposure of first-year students to a more diverse set of chemical topics from inorganic, analytical, environmental, and physical chemistry, in addition to biochemistry. We are currently assessing the impact of this change, which we expect to discover by following students as they matriculate through our chemistry and biochemistry programs, and learn about any impact of this change on their decisions to pursue specific career paths.

Finally, I am collaborating with analytical chemists globally in academia and industry to develop web-based tools for learning analytical chemistry. My primary activity to date has been focused on the development of a web-based simulator for High Performance Liquid Chromatography (HPLC). This started out as a local collaboration with Professor Peter Carr, and the simulator was developed in a

Microsoft Excel spreadsheet. About four years ago Dr. Paul Boswell agreed to help transform the simulator into a web-based tool, which has been live online, and freely available for about three years. Feedback from numerous chemistry educators across the globe has been very positive, and a manuscript written by us and submitted to the Journal of Chemical Education was recently accepted for publication<sup>1</sup>. More recently I have become involved (as a Department Head) in the development of CHROMAcademy ([www.chromacademy.com](http://www.chromacademy.com)) as a web-based training tool for separation science and mass spectrometry in academia and industry. I believe this is an exciting time in analytical chemistry education because we now have the software tools available for developing tools that simulate complex analytical chemistry concepts.

### **Research Experiences as Part of Undergraduate Chemical Education**

Upon arriving at Gustavus in 2008 I knew based on previous experiences mentoring undergraduate researchers at St. Olaf College and the University of Minnesota that I was very interested in developing my career at a liberal arts college where faculty/student research is especially encouraged. While I thought then that independent research (i.e., different from a regular semester course) was an important part of an undergraduate education in chemistry, I have been genuinely impressed at the intellectual maturation and growth that I have observed in students as a result of these experiences. I realize now, after working with 25 different students in my research laboratory over six years, that when a student is confronted with a bona fide research question for which the ‘answer’ is truly unknown, they learn a lot about themselves and their level of internal motivation for becoming a student of science in addition to being a student of the college. I tell students and their parents that one of the special values of the undergraduate research laboratory is that it is a safe place to fail, sometimes repeatedly, while ultimately succeeding in learning essential skills including how to design an effective experiment, and make judgments about what constitutes high quality experimental data. For these, I strongly encourage all of my advisees to commit themselves to a project, rather than simply putting in the time to satisfy a graduate requirement or add a line to their resume.

#### **References**

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**Joseph E. Subotnik**  
Chemistry  
University of Pennsylvania



Every January, for the past five years, I have sat on the admissions committee for the department of chemistry at the University of Pennsylvania. For roughly 12 spots in physical chemistry, we receive ~25 domestic applications, compared with ~75 international students. When they interview with me, domestic students show a strong interest in the problem of radiationless, electronic relaxation. However, typically, these applicants have taken only two semesters of mathematics, which does not include linear algebra or any computer programming. By contrast, the international applicants have far stronger backgrounds, with coursework that often includes high level quantum mechanics and object-oriented code writing.

Inevitably, our admissions committee find itself conflicted about whom to admit: On the one hand, do we want to admit seemingly weaker domestic students so that we can invest in and educate America's youth for the future? One immediate problem is that these students often have trouble finding an advisor. On the other hand, if we want to recruit students who are ready to jump into research immediately, we might want to admit stronger international students with more mathematical skills and research experience. In fact, two years ago, we chose the latter option and our incoming class included only three domestic students, each with undergraduate majors in chemistry. Unfortunately, the domestic students felt very alienated and isolated in a class where they had little communication with their peers; one has already dropped out. Our experiment failed badly.

From these experiences, I now understand that exposure to computation and critical thinking with computers must be addressed at the undergraduate level to facilitate the transition out of college for our chemistry majors. Compared with their international peers, many American graduates in chemistry simply do not have enough exposure to computers to enter graduate school as productive physical chemists. In particular, even at my own university, some of our chemistry majors graduate with minimal experience in scientific computing. Even though scientific computing can be difficult to learn without linear algebra, computers are a modern advantage that simply cannot be ignored by physical chemists. To address this concern, here are the steps I am currently pursuing.

### 1. Using MATLAB and advanced software in undergraduate courses

In the spring of 2012, in my second year at the UPenn chemistry department, I taught my first undergraduate course and my course evaluations were simply atrocious. On a scale of 0 to 4, I received a 1.8--and my department warned me that I needed to improve my approach. In 2013, I doubled my rating to a 3.6 (and my department smiled). From my perspective, the essential difference between the two years was my inclusion of MATLAB software as a tool for the students to model high-level scientific concepts. One of the essential differences between chemistry and physics is that the former is much messier than the latter. Whereas one can solve many problems in physics with pencil and paper (e.g., balls and springs, gravitational motion around the sun, etc.), there are very, very few such problems in chemistry. As a result, for chemistry undergraduates to master their course material, I have long felt that students must use the power of modern computers to simulate the concepts in their textbooks.

This necessity is certainly true for graduate students in my subfield of electronic relaxation.

To test my hypothesis, in 2013 I gave my students in honors freshmen chemistry a MATLAB tutorial on the first day of class. Thereafter, for every (weekly) homework assignment, the students were assigned at least one MATLAB problem. Through MATLAB, the students could easily answer all of the frustrating questions in thermodynamics that are difficult to address only because of the messy mathematics -- not because of conceptual difficulties. For instance: How does one compute and plot the exact free energy curve as a function of reaction coordinate (and disentangle  $\Delta G$  from  $\Delta G_0$ )? Why (numerically) is free-energy linearization a good approximation for electrochemistry? While these concepts are often discussed in upper-level physical chemistry courses, my students were able to digest this material fully as freshmen,



while also mastering software that they can use in all future coursework. It is worth emphasizing that MATLAB is ubiquitous in the field of engineering.

## **2. Open workshop with MERCURY: Molecular Education and Research Consortium in Undergraduate Computational Chemistry (<http://mercury.chem.hamilton.edu>)**

Each year for the last ten years, MERCURY has held an annual meeting, bringing together undergraduates, faculty at primarily undergraduate institutions (PUT's), and faculty from major research universities– with the goal of improving research opportunities for undergraduates and encouraging a diverse pool of students to continue onwards with careers in chemistry.

In July 2013, I led a day-long workshop for introducing advanced undergraduates and faculty at primarily undergraduate institutions to algorithm development and implementation within electronic structure theory; there were approximately 30 students and faculty attending. The goal of the workshop was to go beyond “canned” quantum chemistry codes and to let participants see for themselves the insides of electronic structure packages. Rather than emphasizing job submission, scripting and data processing, this workshop instead allowed participants to jump into the guts of a modern fully operational quantum chemistry software package. Electronic structure packages are very large pieces of software, composed of hundreds of thousands of lines of code, and the learning curve for undergraduates or non-specialized faculty can be daunting. I introduced the students to the Q-Chem software package (for which I am a developer), and students and faculty implemented their own code within Q-Chem. In the end, everyone not only gained familiarity with modern codes, they also learned the necessary tools for making progress in real code development—including exposure to LAPACK algorithms and modern compilers. This workshop was a unique learning opportunity for undergraduates to learn where molecular orbitals actually come from and how the Schrodinger equation is solved in practice (rather than in abstract form).

In July 2016, I am running another afternoon long workshop on 1-dimensional methods for wave packet dynamics using MATLAB. This workshop will be targeted to typical undergraduate students who have had physical chemistry and have solved the stationary states of the particle in a box--but who have never simulated the time-dependent quantum mechanics of the particle in a box. In this workshop, I will also engage faculty at primarily undergraduate institutions who similarly often lack experience with wave packets. The goal of this workshop will be to demystify quantum dynamics, so that students and faculty attain as much intuition for quantum dynamics as they have for classical dynamics. From my experiences at Penn, I am convinced that our students are in dire need of such intuition if they want to understand spectroscopic data, cross-sections and energy conversion in modern experiments. Luckily, in one dimension, a movie of wave packet propagation can be finalized in under 20 lines of MATLAB code, and one of the outcomes of this workshop will be a set of simple codes for undergraduate students to use at home and in their future coursework.

## Nathaniel K. Szymczak

Chemistry

University of Michigan



Scientific inquiry and creative approaches for problem solving are key drivers of productive chemistry research and to train the next generation of scientists, these skills need to be efficiently passed on to undergraduate students. Unfortunately, some aspects of the undergraduate experience have traditionally de-emphasized the scientific method in order to instruct on a particular technique/concept. Without continuous reinforcement of approaches to attack scientific questions, students can miss a key area in which scientific research really shines: how to ask meaningful questions and develop strategies to answer them. I have found that it is in the pursuit of answering these questions that students build strong connections between otherwise seemingly disparate topics. By engaging students to help them make connections, I try to instill an enthusiasm for the scientific process that I hope will follow them through their career paths in industry, academia, medicine, or policy.

### Commitment to Undergraduate Research

As an undergraduate student, I enjoyed taking classes and labs; however, once I was exposed to a laboratory research environment, I was hooked. Being on the front lines and asked to use any means necessary to address a research problem was incredibly exciting and brought clarity and enhanced meaning to the topics of my class work. As a result of my own experience, I am highly invested in bringing this excitement to undergraduate education and have worked extensively to educate students in my own research lab, as well as in the courses that I teach. In my research lab with undergraduate students, I actively recruit students from areas of traditionally underrepresented groups and encourage students to continually question the “why” and “how” in their experimental design and analysis. It is extremely satisfying to watch students evolve in their abilities from, at first, fairly timid practitioners in the research lab environment, to highly skilled scientists capable of pursuing their own independent ideas.

In my research group, I have worked to actively engage and promote scientific discovery and have mentored 18 undergraduate students. All undergraduates and summer exchange students work closely with me and a graduate student or postdoctoral fellow, and are mentored in all aspects of scientific laboratory work, from project design/relevance to detailed laboratory procedures and time management. In addition to modeling a rigorous, innovative, functional lab, I also intentionally address the essential elements that lead to that success. A portion of weekly group meetings are devoted to discussions of topics highly important to academic and industrial research, including safety and scientific ethics that are best learned by continued reinforcement. Subsequent placement of undergraduate students from my lab is excellent. Of the eight undergraduate students that graduated from my lab, six are pursuing graduate education in top programs (Caltech, Berkeley, Johns Hopkins, U. Washington, etc.) and two are in medical school. As a result of the research by these impressive students, five manuscripts have been published that list these undergraduates as co-authors. I am excited to continue this trajectory and recruit and mentor 2-3 new undergraduates each year, which will augment student’s education by exposing them to real-world hypothesis-driven research.

### Undergraduate Teaching

Hypothesis-driven experimentation drives scientific research and promotes creative cognitive skills, yet is underutilized in most undergraduate lab courses. I have redesigned an upper-level synthetic chemistry laboratory as part of a larger effort to broadly apply an authentic research design (ARD) approach for synthetic chemistry lab courses at Michigan. The central hypothesis of the approach is that participation in ARD will enhance student critical thinking and problem-solving skills, which will stimulate creative thinking by encouraging student engagement to solve/explore research problems. This approach serves to augment the academic experience afforded to students at the UM, and future laboratory courses nationwide, by promoting an action-based-learning experience within a laboratory setting. I have targeted the: (1) development of a reusable infrastructure for undergraduate synthetic labs that can be readily

incorporated by instructors with minimal redesign, (2) assessment of gains in critical thinking applied to scientific methodology and writing, and (3) dissemination of course outcomes through online chemistry resources, publication and conference proceedings.

College-level STEM laboratory courses traditionally employ expository instruction using recipe-based lab experiments, which limit critical thinking. This model does not reward ingenuity and restricts student engagement in the scientific method toward testing a hypothesis; it instead promotes the practice of lower order cognitive skills, such as application, comprehension, and knowledge. Problem- or inquiry-based labs, where students generate and pursue their own questions, represent the epitome of how we should educate students to develop critical thinking skills. However, these strategies have rarely been reported for use in synthetic chemistry labs. ARD is a variation of Problem-based innovations that engage students in an authentic research experience and also promote constructive cognitive behaviors in graduate student instructors as they take on the role of the PI in laboratory settings.

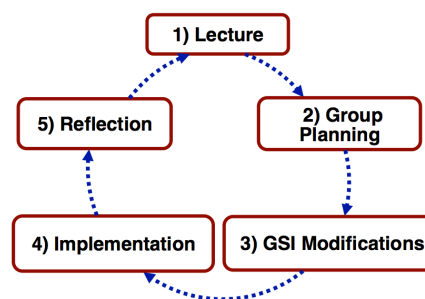
The authentic research design curriculum was implemented three times thus far in the advanced synthesis lab at UM (Chemistry 482) using three new problem-based experiments, which allowed students to design experiments to test their unique scientific questions. We incorporated online resources (Google documents), and in-class discussions with the graduate student and instructor to allow students to design and redesign experimental protocols to test their own hypotheses. The implementation of this model required restructuring the experimental design and execution (Figure 1) and consists of five phases:

(1) During lecture, I discuss options for experimental design as well as some associated problems and potential workarounds.  
(2) After the introduction, students work together in groups of four to brainstorm experiments then plan a proposed laboratory experiment, which is submitted to the Graduate Student Instructor (GSI) 48 h in advance of the lab session.

(3) The GSI identifies any operational or scientific logic issues, and provides timely feedback to the students.

(4) Students perform experiments that they have planned. During the lab session, the GSI helps students to troubleshoot any operational challenges that invariably can arise during new experiments.

(5) After the experiment, students reflect on the experimental outcome in individual writing assignments that can include data collected from the entire course.



Algorithm for Student-Centered Research Design

The Student-Centered Research Design model has been successfully implemented in three upper level experiments that are intensive and encompass 17 laboratory sessions. We have provided students with an opportunity to participate in real scientific discovery. For one laboratory focused on catalyst design, student groups combined discovery-based research methods to identify a suitable metal, ligand, and catalytic reaction and then subsequently used hypothesis-driven experimentation for optimization. Both of these approaches simulate a real-world scientific reaction development algorithm. In the most recent year, students prepared several dehydrogenation catalysts that among the most active known, and were developed in my research lab. Because these catalysts are still new, novel catalytic reactions are routinely being discovered by our group. Students were tasked to aid in this venture and for their final 6 week lab experiment; they designed both known and unknown catalytic reactions. After honing their skills with a known class of reactions to ensure competency, reactions for which we do not know the outcome were evaluated after consultation with the GSIs and/or instructor. Because the reactions were open-ended, students were required to troubleshoot and adjust their protocols in order to obtain useful results: a strategy routinely used by independent researchers. Thus, this approach was not a “model” of authentic research, students actually performed research in a manner that is actively pursued in my laboratory. The outcome was promising, and two groups of students uncovered an interesting lead that was not known prior to the course. These and other leads can be pursued in more depth by future students in the academic and/or my research lab.

All students completed a pre/post Science Learning Environment Inventory, which was designed to compare their perception of experiences in the course relative to other UM laboratory courses.

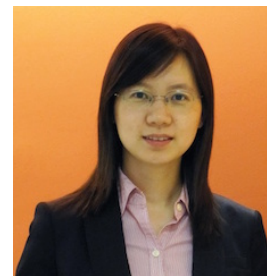
Participating students' responses changed substantially over the course of the term and were significantly different from non-participating students. Students indicated that they: (1) had more freedom to explore, (2) were required to design experiments in response to a given problem, (3) were more self-directed, and (4) worked more cooperatively with other students. Initially, students were not completely comfortable with the freedom that was provided, as it was different from their prior experiences, but they later embraced it and took real ownership of the experiments. Since validating the approach, I am committed to further improving the engaged learning process with re-engineered experiments to further build the field by developing curriculum models that support student inquiry within an authentic research experience.

## Douglas A. Vander Griend

Chemistry & Biochemistry  
Calvin College



Consistent attendance is key for success in chemistry, especially if the professor is at skilled at making class time worthwhile. At Calvin College, daily attendance in general chemistry hovers around 90% with class sizes of about 50. Not bad, but 5 students a day is far from optimal. It means more emails, office visits, and then lower grades because every day missed makes it substantially harder for a student to succeed. I believe getting students to attend is key part of my job if I care about their learning. Early on I tried a policy wherein a random student every day had to summarize the previous day. If you weren't there you got a zero. Colossal fail – for numerous reasons. Later I went to requiring attendance, but ended up wasting precious time monitoring it with little improvement. Then I started using communal attendance – just count empty chairs and by the end of the semester the more absences, the less the final exam replaces the lowest test score for the whole class. This got attendance up over 95%. Recently I modified the strategy yet again: I simply projected a transparency sheet with every student's name on it on the side board, and required students to check themselves in with chalk. The communal attendance policy was still in effect but now students knew that everyone else would notice their absence. Success: >99% attendance. The class even began competing to see who could get everyone in their column on the board there first. They were almost obsessed. From focus groups that I run at the end of a semester, students testified that they were significantly influenced by the implicit peer pressure to come to class every day without fail. They also like seeing and learning each other's names, something I was eager to have them do.



### **Prior Initiatives in Chemical Education**

Education and outreach have been integral components of my independent academic career. Since starting at Duke in 2011, I have been teaching an introductory freshmen course in organic chemistry, a research course for undergraduate independent study in lab, and an advanced level course in chemical biology for both undergraduate and graduate students. I participate in Duke's Service-Learning program to connect the undergraduate curriculum to civic engagement. I also received the David L. Paletz Fund for Innovative Course Enhancements to promote active and inquired-based learning in my courses.

Within the Duke community, I have mentored 14 Duke undergraduate students in my lab, including seven women. Eight of them are currently studying in graduate and medical schools (Duke, Emory, Harvard, UNC, Vanderbilt, and Washington Universities). I have also served as a mentor in 81S "Introduction to Research in Chemistry," a unique lab course for talented first-year undergraduates who want exposure to research early in their careers. In our educational outreach to local communities, my lab sponsored North Carolina high school students for summer research, encouraging them to continue study in STEM and mentoring them to conduct hand-on experiments in lab. Among three students working with my lab, one is currently studying at UNC Chapel Hill, and another two at MIT. It is a joy to work with these enthusiastic and bright young students, as they are quite adept at learning lab techniques and absorbing a lot of information, and they are thrilled to be part of a bigger research problem. Most of my undergraduate and high school students have presented their research on both regional and national conferences. Several undergraduates are contributed as co-authors (even one first co-author) to our research projects. Finally; I have assembled a research group of graduate students and post-docs encompassing a broad range of backgrounds (>50% of my graduate students are females and minorities). In the coming years, I will continue to devote to the education in chemical science. My activities are based on a teaching philosophy that strives to combine excellence in research with excellence in teaching, and is manifest in the overall mission of Duke, which "seeks to engage the mind, elevate the spirit, and stimulate the best effort of all who are associated with the University".

### **New Initiatives in Chemical Education: An Enriched Coursework-Based Training Foundation Integrating Interdisciplinary Research and Active Learning**

Global societies are facing some of the most complex challenges in the history, including disease prevention and treatment, economic development, social inequality, and global climate change. All of challenges increasingly require interdisciplinary research and collaborations. Today's education requires an improved training platform that prepares students to address complex scientific and social questions through collaboration and innovation. Toward this, I propose that one of the best ways to equip students with the necessary skills is to incorporate active engagement in the frontier of interdisciplinary research into their coursework. The value of interdisciplinary research in scientific discovery and educational training is reflected in the statement from the committee on Science, Engineering, and Public Policy: "Interdisciplinary research can be one of the most productive and inspiring of human pursuits—one that provides a format for conversations and connections that lead to new knowledge. As a mode of discovery and education, it has delivered much already and promises more – a sustainable environment, healthier and more prosperous lives, new discoveries and technologies to inspire young minds, and a deeper understanding of our place in space and time." Along with my own research program across organic synthesis and molecular imaging in lab, my goal in chemical education is to develop innovative teaching that integrates chemistry knowledge into solving interdisciplinary problems and to provide students an enriched interdisciplinary learning experience, reflecting the diverse aspects of chemistry research and its impact on real-world problems.

The specific objective of my educational plan is to establish an enriched coursework-based training foundation that will equip students with indispensable experimental and innovative thinking skills to undertake complex interdisciplinary scientific and social challenges as well as motivate them to actively inquire knowledge and to pursue science-related careers.

To achieve the above educational objective, my efforts will focus on **developing an organic chemistry lab section with an emphasis on neurologically active molecules** “From bench to neurologically active molecules”. This new lab section is expected to engage students in an interactive, collaborative and creative learning environment, improving how organic chemistry classes and labs are taught, and potentially serving as a basis for launching a neurochemistry concentration for chemistry majors. The selected emphasis on neurologically active molecules originates from emerging interests in neuroscience at Duke University and rich history of Durham evolving from the city of Tobacco to the city of medicine today. Considering a large enrollment in organic chemistry, the development of the new lab will be initiated as a pilot section (e.g. 10~20 enrollment), for which students will register on a voluntary basis. Through the pilot section, 1~2 new labs will be introduced and evaluated each year. The reforming of the complete curriculum will build with the collaboration and input of teaching staff. The selection of target molecules and synthesis in this organic lab will be aligned with key organic chemistry concepts, such as substitution, oxidation, and reduction reactions as well as the latest transition metal chemistry. The synthesis designed for the new lab section will leverage the new chemistry developed in my lab and will center on neurologically active molecules, such as aripiprazole (Abilify®), a leading antipsychotic drug (Note that similar projects has been successfully achieved by undergraduate students in my own lab). In all projects, the final compounds will be sent for activity evaluation through the NIMH Psychoactive Drug Screening center at University of North Carolina, where my group has established the collaboration. The students will be in communication for the results for the compounds on which they have worked. By exposing students to real-world problems, the research-based lab will foster an inquiry-based learning environment that encourages and enhances innovation and creativity. I also hope to develop an outreach component associated with this new lab section, to foster the development of undergraduate students as future teacher-scholar. Students are encouraged to self nominate as “chemistry ambassadors”, to present their work and their chemistry experience at local high schools and local conferences, and to provide personal inspiration to younger minds on the path to pursue scientific discovery as part of their community service-learning experience. In the longer term, the new lab section can be integrated with lectures to create an advanced neurochemistry course across the areas of chemistry, pharmacology, and disease, serving as a basis for launching a neurochemistry concentration for chemistry majors.

In classroom, I will continue emphasizing active and inquiry-based learning. My teaching will be not only aligned with key concepts in each course but also beyond textbook and in response to student’s interests. In the course of organic chemistry, I arranged regular in-class discussions on the course topics and encouraged students to make personalized video to explore the connection between these topics and their life. In the videos contributed by the students in this course, the properties and reactions of organic molecules are linked to energy (e.g. explosion), medicine (e.g. stereochemistry), personal activities (e.g. breathalyzer, alcohol oxidation), and more. Such exercises motivated students to think actively and creatively across different scientific areas, offering an active and enriched learning experience beyond simply working on practice problems. For the advanced course of chemical biology, my course syllabus is tailored on the basis of student’s interests, with ~30% topics in response to the requests from enrolled students. The dynamic incorporation of diverse teaching formats from lectures, literature discussion and research proposal will greatly enhance self-motivated and inquiry-based learning. Meanwhile, students are introduced to the frontier research in this course and are encouraged to find solution to real-world problems and unsolved challenges in human disease along with their learning in this course.



**Emily Weiss**  
Chemistry  
Northwestern University



I have been teaching Chemistry 101 for four years. Chem 101 is the first quarter in the sequence of General Chemistry (Gen Chem), the major entry point into the Science, Technology, Engineering, and Mathematics (STEM) curriculum at Northwestern. Retention in this three-quarter sequence (Chem 101, 102, 103) – that is, the percentage of the 450-500 students who enroll in Chem 101 that complete Chem 103 – is only 52% for all students, and 43% for under-represented minorities (URMs). The percentage of students who complete the sequence and go on to get degrees in STEM fields is 44% for all students and 31% for URMs. Some of the students who only take one or two quarters of Gen Chem are using it to satisfy a distribution requirement and never intend to major in a STEM field. Many of the remaining students, however, are initially interested in science, but do not finish the Gen Chem sequence and do not remain within a STEM field because they lose interest, lose confidence, or perform so poorly in Chem 101 that they cannot move forward in the sequence. Perhaps the most troubling implication of these statistics is that we, a faculty who spend a large portion of our time articulating our fascination with science and its societal importance, do not effectively transmit this enthusiasm when introducing our field to freshmen – potential future scientists and the constituents of our future electorate. I and others in my department have been working hard to change the course, and changes these outcomes.

In my first two years of teaching the course I observed that: 1) We design the quizzes and exams such that we obtain an approximately Gaussian distribution of grades at the end of the quarter, but the population of Chem 101 students is certainly bimodal with respect to their abilities and background in Chemistry. Roughly speaking, two-thirds of the class has the tools to comprehend the material in the time given and apply their knowledge to solve single-concept or multi-concept word problems. The weaknesses of the bottom one-third of students include both a lack of familiarity with the material (maybe they did not have chemistry in high school) and a lack of problem-solving skills. 2) The vast majority of the students at all levels are determined to “learn” by memorizing equations and facts, and are staunchly resistant to presentations of the material designed to help them develop intuition that is broadly applicable to solving problems they have not already seen and memorized. 3) Largely due to the way textbooks are organized, we present topics in what I believe to be a haphazard and non-intuitive order, and we are too ambitious in the quantity of facts that we present. More importantly, instead of bringing each topic to its logical conclusion, we give the students part of the story (sometimes with a misleading level of simplification), and then pick up the story later in the sequence. This practice is confusing, unsatisfying, and inefficient because it requires a re-teaching of the topic “the right way” in later courses. My hypothesis was that, at a place like Northwestern, the students will be inspired to continue in a subject if they feel like they have gained some intuition about the subject, and not just memorized uncontextualized facts.

To address point (3), I reorganized the course such that the topics from the most microscopic to the most macroscopic (the “atoms-first” strategy). We start with quantum mechanics, then move to electron configurations and the periodic table, then bonding, then structures of molecules and solids, and finally reactivity and ensemble thermodynamics. This reorganization resulted in a 50% decrease in the number of drops/fails in Chem 101. We are cheating the system a bit, however...most students drop after the midterm because they did poorly. Because we cannot teach quantum mechanics and bonding to freshmen with much mathematical rigor, the “atoms-first” version of Chem 101 is front-loaded with more conceptual topics. The biggest problem for the students in the course is problem solving and quantitative analysis, so the scores on the midterm were, on average, higher than they have been in past years since there were more conceptual questions and fewer problems. The average score returned to normal by the end of the course, since the course was back-loaded with more quantitative analysis than usual. We may have gamed the system, but doing well on the first midterm inspired confidence in a lot of students who otherwise would not have had enough to try and finish the course, so I believe the atoms-first curriculum has a favorable side-effect of holding onto students longer, until they can get their footing in the new world of college courses!