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How organic chemistry became one of UCLA's most popular classes

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Organic chemistry has a bad reputation, despite having a tremendous impact on our everyday lives. It has remained a notorious "weed-out" class for decades—striking fear in the hearts of students—and has long been viewed as a gatekeeper course for those interested in pursuing a career in medicine or other health-related professions. This personal account examines the underlying teaching philosophies that transformed organic chemistry into one of the most popular classes on the UCLA campus. Special emphasis is placed on ways to increase engagement and help students feel connected. Educational initiatives, including organic chemistry music videos and various online resources created in partnerships with students, will be discussed. It is hoped that this account will stimulate ideas that transcend scientific disciplines all for the benefit of student education.

I grew up in a small town called Fishkill, New York. When I was growing up, I did not have a clue about what I wanted to do in the future. I did not think about becoming a teacher, a researcher, or an organic chemist. Instead, I was mostly looking to have a good time with my friends and make enough money to enjoy my high school days. I was actually a door-to-door knife salesman at one point. Later, I helped conduct the dog census for the town of East Fishkill. Yes, I walked door-to-door asking people how many dogs they had, collecting a modest 75 cents per dog uncovered. Last, I secured a job at Blockbuster Video helping customers select movie rentals.

When it came to academics, I naturally gravitated toward the sciences. My older brother was on track to be become a medical doctor, and I was ultimately encouraged to do the same. Thus, when I began my undergraduate studies at NYU, I took premedical requirements early on, such as biology, general chemistry, calculus, and physics, with the hope of one day acing the MCAT exam. My first year in college went relatively smoothly, but as I began my second year, I braced myself for the class everyone dreads: organic chemistry.

For decades, organic chemistry has been reputed as being a gatekeeper class. Without scoring an A grade in this class, it would supposedly be impossible to secure medical school admission. It is interesting to note that nowhere along the way did anyone explain to me the relevance of organic chemistry, or that it was really just a class about creativity and problem-solving. It was not until my first day of organic chemistry class that I heard this perspective. Rather than diving straight into the material, Professor Yorke Rhodes III spent the entire first lecture giving us a pep talk. "Do not try to memorize and regurgitate information," and "this class is all about critical thinking" are the messages he conveyed. I remember leaving class thinking that this class would be *different* from all of the other science classes I had taken so far, and I was excited.

Despite how good it all sounded, the pace of the course picked up considerably over the next few weeks. With our first midterm around the corner, I began to panic. Rather than trying to truly understand the course content and use it as a vehicle to solve problems, I resorted to what I had become quite good at: brute-force memorization. I do not remember anything about the exam itself. What I do recall is that I thought I scored better than my close friends in the class, based on our conversations and viewing the exam answer key. I ultimately scored something on the order of 55%, which I thought was awesome, given that the exam average was roughly 25%.

Professor Rhodes happened to notice that I was "celebrating" my grade of 55%. With a serious squint, he turned to me and said (paraphrased): "Neil, that's a good score, but you can do better." My first reaction was to be defensive and wonder why Professor Rhodes would be critical after I had done so much better than the class average. However, I soon began to realize that this common pre-med mentality of just wanting to beat class averages and celebrating a grade of 55% made no sense. I began studying more seriously, both independently and in groups, building a relationship with Professor Rhodes, and working diligently to improve my problem-solving skills. I ultimately mastered the course material and properly earned the A grade I was striving for. Overall, the experience changed my perspective on learning in general, but also set me on a path toward studying and practicing organic chemistry for the long haul.

Several important lessons can be gleaned from the aforementioned anecdote. One is the simple reminder that the student path of study is not straightforward. At least 75% of students will change their major at least once during their time in college. The other takeaways, which will be discussed in more detail below, center around topics in education. We should never underestimate the importance of how a subject is taught. For example, whether a class requires brute-force memorization or focuses on critical thinking skills has a profound impact on the student educational experience and what students ulti-

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mately learn. In addition, we should be aware of the incredible influence our teachers have. Just a few words of encouragement or inspiration can change the student mentality, as it did when Professor Rhodes changed my life with a single sentence and a facial expression.

From student to organic chemistry professor

Exactly 10 years after Professor Rhodes's organic chemistry course, I began my independent career as an Assistant Professor at UCLA (in 2007). Before that, and aside from some minimal time spent serving as a teaching assistant, the bulk of my time was devoted to conducting research studies, both at Caltech (Ph.D. studies with Professor Brian Stoltz) and UC Irvine (postdoctoral studies with Professor Larry Overman). When I began at UCLA, my mentality was to focus on building my research program and earning tenure. The research expectations were daunting. UCLA is a campus with 13 Nobel Prizes awarded between faculty and alumni. Seven of those are from my home department of Chemistry and Biochemistry.

I was "spared" from teaching introductory organic chemistry to undergraduates for the first 3 years of my independent academic career. However, in 2010, there was an opening to teach "Chem 14D: Organic Reactions and Pharmaceuticals." This is the last class in a fast-paced sequence designed for "life science" majors who need to fulfill general chemistry and organic chemistry requirements in order to pursue health-related professions (*e.g.* medicine, dentistry, physical therapy, optometry, etc.). Whereas most schools would offer such a sequence over the course of two full academic years, the "14 series" allows students to complete chemistry lecture requirements in four academic quarters (or the equivalent of 1⅓ years). The Chem 14D course typically has high enrollments, approaching 400 students in a given lecture period. It is also worth noting that most students view this class as a final lower-division requirement, rather than an exciting educational opportunity. Based on student surveys, the vast majority of students (>65%) indicate a low interest in organic chemistry at the start of the course each year.

Before discussing teaching practices, it is worth commenting on what organic chemistry is and what makes it a challenging course. Simply put, organic chemistry is the chemistry of molecules made of carbon. The applications of organic chemistry are vast, and span medicine, agrochemistry, cosmetics, food science, and cutting-edge technologies, just to name a few areas. Most molecules in our bodies that are responsible for genetics and various physiological events are organic compounds (proteins, DNA, RNA, etc.). Regarding the difficulty associated with organic chemistry, a primary challenge is that most students simply do not learn about it until their first introductory organic chemistry course, typically in their second year of college study. However, a new student will quickly have to learn how to decipher shorthand chemical structures, recognize functional groups, visualize two-dimensional structures in three dimensions, and assign stereocenters. As they are just absorbing the basics of chemical structure, they begin to learn about chemical reactions, where students learn how to transform certain functional groups into others. For each reaction, there is a logic associated with how and why the reactions take place. Accordingly, students will learn "arrow-pushing" mechanisms. For each reaction, there is inevitably some memorization regarding reagents, solvents, reaction names, and various acronyms. Last, students will typically learn how to perform chemical synthesis using an intellectual tool called "retrosynthetic analysis." Here, students are provided with the structure of an organic molecule and must propose a means to synthesize that molecule using much simpler compounds through a series of functional group conversions. To solve such problems requires a command of the course material, creativity, and impeccable critical thinking skills. Although this sounds intimidating, I would offer that our students are highly innovative and generally enjoy solving problems, if they have a good support system in place.

Do students feel connected?

There are many things teachers can do to create a positive and impactful experience for our students. Under the broadest terms, I always ask myself if the teaching tools and resources I offer to my students help them feel *connected* to the course. If students feel connected, they are more likely to attend and participate in class (and office hours), and even to study. Of course, the opposite also holds true. A disengaged student is less likely to participate, study, or succeed. In the worst case, a disconnected student will fail or drop a course. If such problems permeate to more than one class, this may lead to a student withdrawing from a school entirely.

Teaching tactics and philosophies

There is no "one-size-fits-all" model when it comes to teaching (1). I have found it is best to experiment in order to identify those teaching practices that work best for me and for my students. However, I hope it may be helpful to briefly describe some of the "best practices" used in my UCLA Chem 14D course, which were also validated during my recent sabbatical stint as the Robert Foster Cherry Professor at Baylor University. The notions described, albeit in the context of organic chemistry, can be generally applied to other courses.

Help students understand the value

It is important to establish value on the first day of class and continue to do so throughout a course. In the case of organic chemistry, there are several key points I emphasize. 1) Most importantly, the class is ultimately about problem-solving and critical thinking. No student can dispute the value of learning these life-long skills. 2) Success in future coursework, such as biochemistry, will likely require a strong foundation in organic chemistry for a student to be successful. 3) Some professions (and associated education), including medicine, will expect students to understand organic chemistry. 4) Last, it can only help to have students appreciate the relevance of organic chemistry in everyday life. For example, I devote some time on the first day of class to describing biomolecules, such as DNA, organic light-emitted diode (OLED) technology used in modern displays, fabrics and dyes in our clothing, polymers used in movies, like Yoda from Star Wars, and countless human medicines that are made by organic chemistry.

Level the playing field

In the case of Chem 14D, this is the final course of the general and organic chemistry sequence. Many students have struggled to get this far and are just hoping to withstand the final course, rather than achieve excellence and understanding. As such, I remind students that their prior history in chemistry courses at UCLA has little bearing on how they will perform in my class, as long as they are willing to learn. I help them recall that they are academically well-qualified to excel just based on their admission to the university. Last, I give them something new to look forward to. For example, in many lower-division science classes, exams may involve the regurgitation of information, often done in multiple-choice format. Instead, I foreshadow that the most difficult problems will be more open-ended, with many possible correct answers and ample room for student creativity.

Vocabulary before problem-solving

I will not extensively detail organic chemistry specifics, but my general strategy centers on the notion that most students do not have a firm organic chemistry vocabulary at the start of the course. This holds true even if students have taken a prior organic chemistry class. Thus, I spend the first 2 weeks of the 10-week course teaching and emphasizing the fundamental vocabulary. This includes the recognition of certain functional groups and the rules or patterns of chemical reactivity (*i.e.* nucleophiles, electrophiles, arrow-pushing mechanisms, etc.). Rather than focusing on the exceptions, it is important to focus on the generalities. By laying a strong foundation, students become well-equipped to learn new chemical reactions and the mechanisms by which they occur. Last, as students further progress, we introduce reactions they have never seen before and ask them to propose mechanisms. In addition, we show them molecules they have never seen before and ask them to propose a way to make those molecules in a very open-ended way. I generally aim to have at least half of my course be focused on such advanced problems (5–6 weeks), which gives students time to practice and embrace the challenge.

Demonstrations, visual aids, and clickers

One of the prime challenges associated with lecture courses, in general, is finding ways to make the lectures more engaging. Performing in-class demonstrations provides a timeless means to liven up a science classroom. In the case of Chem 14D, perhaps the most well-appreciated demonstration is the classic "breathalyzer" test to check for alcohol consumption. Thanks to the modern age of technology, it is also straightforward to incorporate visual aids into lectures, such as images and videos. In my case, I use such things routinely to complement my more traditional style of writing on a chalk- or whiteboard. Overall, this allows me to teach at a reasonable pace, which, in turn, gives students time to get confused, ask questions, and learn how to draw chemical structures as if doing so was second nature. Last, I am a strong advocate for response polling devices, or "clickers" (2, 3). By posing questions in class through a polling system, one keeps students engaged and obtains invaluable real-time feedback on whether or not students are learning.

Show students we care

Faculty tend to be very busy people, but for success in undergraduate teaching, it is important that students still see that faculty care and are approachable. After teaching the same course many times, I have heard the same questions from students repeatedly. I will admit it takes some effort to show enthusiasm when answering repeat questions, but I remind myself that the material is completely new to the students. Showing complete care and enthusiasm goes a long way to positively impact students. Likewise, it is important for teachers to take the time to prepare their lectures and put effort into their courses. If the teacher appears not to care, the students will pick up on this and are likely to adopt a similar sentiment.

Be available

If one is intent on offering a challenging course, it is also important to provide a superb support system. It is crucial to advertise and repeatedly remind students of one's office hours. In addition to offering regular office hours, I will respond to questions daily via an online office-hours type system. I will also meet with students through individual appointments throughout the term.

Offer rewards

It is critical to recognize students when they are improving, participating, or performing at a very high level. Such recognition can be achieved in many ways, such as offering handshakes, writing supportive notes on exams, or providing a "gift" of some variety. In my class at UCLA, I have given out periodic table beach towels to students who volunteer to solve a difficult problem in front of the class. The students who have received these towels have been seen wearing the towels (*e.g.* as a cape) in class and even just while walking across the UCLA campus. As an alternative form of recognition, I have treated students to meals on campus, local restaurants, and in my home.

Avoid the curve

Grading with a "curve" is incredibly common in lower division classes. Even the first time I taught Chem 14D, I "curved" the class because it was convenient for me to be vague in my syllabus and I just did not know any better. I later realized, however, that the "curve" created a fierce and undesirable sense of competition, which was counterproductive toward learning and collaboration. The goal should also be for students to learn, and it is best to provide grading transparency whenever possible. As such, I ultimately switched to offering a set grading scale, where we set grading cut-offs. For example, a weighted average of exams and other assignments that exceeds 95% will guarantee a student an A grade. I reserve the right to lower the cut-off to make the grading more generous, but I promise the students that I will never raise the cut-off. By setting high expectations, but making the expectations clear, the students can set personal goals and comfortably study with their peers.

Create a teaching team

At UCLA, the students sign up for "discussion sections" (also known as "recitations") when taking large lecture classes. These are taught by graduate student teaching assistants and provide a forum for students to meet in groups of 20–30 to clarify concepts and hone student problem-solving skills. In addition, we have several means to allow undergraduate students who have previously done well in the course to help teach discussion sections. Formally, the undergraduates are termed "learning assistants" or "undergraduate assistants," and they can even earn course credit for studying pedagogy. In a recent offering of Chem 14D, nine undergraduates joined the teaching team to provide the enrolled students with an incredible support system and a stellar active learning environment.

Learn student names

Especially when teaching large classes, making an effort to learn student names can have a tremendous impact (4). If I am teaching a class of 400 students, I learn at least 200 names during the term. The effort alone means the world to students and can help students make a reciprocal effort in the course.

Never blame the students

It is critical for teachers to accept responsibility for every aspect of their course. Thus, when a student may appear distracted in class, I ask myself what I could do to better engage that student. Likewise, when writing exams, it is my responsibility as the teacher to make sure the content and difficulty level are commensurate with the class materials and the level of support and resources I have provided. Otherwise, exam averages can be low, and this can be extremely disheartening to both the students and the professor. If an exam average turns out to be low in my class, I make it a point to let the students know that I made some judgment errors, as it is highly unlikely that ~400 students performed poorly on a "fair" exam.

An opportunity, not a burden

Countless times, I have heard faculty describe teaching as being a burden and something that stands in the way of one's research objectives. This mentality is unfortunate, but ultimately a result of the academic system where faculty promotions are generally tied to research publications and funding. Nonetheless, it is important that teachers adopt the mentality that teaching is not a burden. Rather, teaching is an incredible opportunity to educate the future leaders and problem solvers of the world, while sharing one's passions. For the vast majority of academicians, the true legacy we leave behind lies with our students, not our publications or H-index.

Creativity through music videos and retrosynthetic analysis

The creativity displayed by my organic chemistry students has been nothing short of inspiring. I have seen student creativity take many forms, including through an unconventional assignment I first began offering in 2010. More specifically, I offer my students the chance to make organic chemistry music videos, which are parodies of their favorite songs, but with a chemistry theme. This type of assignment has become commonplace, but in 2010, it was new. The students can work on their own or in small groups. They post their final videos on YouTube.com, where they are immediately available for grading and for their peers to enjoy. The teaching assistants and I then grade each of the videos and award extra credit. Despite the amount of extra credit being minimal, students are always eager to complete the assignment. It offers a chance for students to do something unusual and highly creative, enjoy an activity with their friends, and even learn some organic chemistry in the process. More than 1300 of my students have teamed up to make hundreds of music videos. They have collectively been viewed many hundreds of thousands of times around the world, spreading the love for organic chemistry. The best videos are available online in our "Hall of Fame."

Perhaps the most powerful outcome of the music video assignment is that it helps students become more engaged in the course and empowered to succeed. My goal is always for students to do extraordinary things and learn to solve the hardest problems I can offer. On exams, students will be asked to solve the notorious retrosynthesis problems, where they encounter molecules they have never seen before. They must propose a reasonable chemical synthesis of the molecule using much simpler compounds as the starting materials. At the end of my course, over two-thirds of the class can solve these problems. What is also striking is that the students show impeccable creativity in their solutions, often providing reasonable responses that bear no resemblance to what is shown on the answer key (thus, still earning full credit). Bear in mind that the students in my Chem 14D class are never chemistry or biochemistry majors; instead, they are typically second-year life science students who are not likely to further pursue organic chemistry after taking my class. I should also note that I did not learn to solve problems of comparable difficulty until my first year of graduate studies at Caltech.

Metrics and organic chemistry love

Student surveys about the Chem 14D course and organic chemistry have been overwhelmingly positive. Of note, at the end of the course, more than two-thirds of the students rate their interest in organic chemistry as "high," whereas only <4% rate their interest in the subject as "low." This is a dramatic shift from the start of the course, where <10% indicated a "high" rating and >60% rated their interest as "low." The course has been featured in various UCLA Newsroom stories as "UCLA's Most Beloved Class," in Buzzfeed as the second "coolest class at UCLA," ahead of actor James Franco's class on creative writing and screenplay, and in *LA Weekly* magazine as one of the "Best Classes in LA."

There are two lessons that stand out most to me. The first is that students can learn to love a class as dreaded and as notorious as organic chemistry. This notion applies to thousands of students, even if one only considers the students I have taught at UCLA. The second lesson has to do with the innovation and creativity shown by students. Whether we think about organic chemistry music videos or the unique solutions students devise in solving retrosynthesis problems, it is clear that our students are capable of doing extraordinary things. Educators should be mindful of this and should aspire to draw out a spirit of creativity and innovation from their students when teaching.

Collaborating with students to create educational resources

Inspired by my students, I have enjoyed the opportunity to create educational resources for organic chemistry, including online resources (5–7), that are currently being used around the world. Each of the following projects has involved extensive collaboration with students.

The Organic Coloring Book is a self-published coloring book, co-authored with my daughters. The book allows students of all ages to appreciate the vast impact of organic chemistry in our world (10).

Biology and Chemistry Online Notes (BACON) is an online website that provides concise written tutorials on organic chemistry (8). The tutorials connect common topics in organic chemistry with medicine, other aspects of everyday life, and even pop culture. BACON is used all over the world and has been used by nearly 50,000 students to date.

Backside Attack is a free iOS smartphone application that teaches organic chemistry in a fun, gaming-type environment. The game focuses on the bimolecular substitution reaction, which proceeds by "backside attack," and provides a learning tool for many fundamental organic chemistry concepts.

QR Chem is a free online teaching resource that ultimately allows students to interact with three-dimensional chemical structures on their own smartphones (9).

RS Chemistry provides a free online forum for students to learn and practice the skill of assigning stereocenters of organic molecules, but in the context of medicines and other life-impacting molecules.

More than 50 brilliant students have been involved in the creation of the above-mentioned resources or other collaborative teaching-related activities. They deserve to be mentioned individually. They are: Sarah Anthony, Emma Baker-Tripp, Joyann Barber, Timothy Boit, Jason Chari, Grace Chiou, Michael Corsello, Jacob Dander, Johnny Dang, Noah Fine Nathel, Adam Goetz, Liana Hie, Alexander Huters, Francesca Ippoliti, Tara Kappel, Vandan Kasara, Andrew Kelleghan, Junyong Kim, Brian Lin, Crystal Lin, Stacy Ma, Ali Mally, Jose Medina, Milauni Mehta, Preeya Mehta, Lucas Morrill, Jesus Moreno, Melinda Nguyen, Lauren Ogata, Karen Anne O'Laco, William Parsons, Krishan Patel, Jonathan Pham, Lee Pham, Stefan Prisacaru, Stephen Ramgren, Melissa Ramirez, Johnny Randhawa, Shawn Schwartz, Nikhil Shah, Rishabh Shah, Emily Siegler, Amanda Silberstein, Bryan Simmons, Ganeev Singh, Ernst Schmid, Tejas Shah, Joel Smith, Justin Soffer, Robert Susick, Evan Styduhar, Nicholas Weires, Julia Yuan, Jimmy Zheng, and Julia Zhu.

The other major player in the above-mentioned projects who deserves special attention is Dr. Daniel Caspi (Element TwentySix). Daniel and I were project partners in graduate school. We have enjoyed many opportunities to collaborate on science and educational initiatives in recent years. Daniel has led the computing aspects of all of the projects mentioned, while bringing countless innovative ideas to each initiative.

Closing thoughts

Students want to learn, and we must never lose sight of this fundamental reality. With so much knowledge and information available online, teachers must be careful to ensure the highest standards of intellectual rigor when teaching. However, there is no reason one cannot provide an enriching educational experience that is also fun and relevant, with ample opportunities for students to exercise their creativity and critical thinking skills.

It is also important to ensure that our students feel connected to our courses. There are countless opportunities for this. For example, it can only be beneficial to establish relevance. In the case of organic chemistry, many students taking the course are interested in health-related professions and appreciate learning about the critical role organic chemistry plays in the discovery and manufacturing of life-changing drugs. Alternatively, some students will engage with a course on an intellectual basis and may cherish the opportunity to learn how to solve difficult problems. Another opportunity for students to feel connected is through human interactions. Team-based activities, like the music video assignment, provide an opportunity for students to connect with one another, form study groups, and build lifelong relationships. Similarly, students may develop a bond with their teaching assistants or the professor. To this day, I stay in touch with several students who took chemistry with me when I was a teaching assistant at NYU ~20 years ago, and I am actively in touch with many hundreds of my UCLA students. It is likely that the connections I made with these students in the classroom were meaningful at the time but also helped to pave a long-term mentor-mentee relationship. Of note, the burden for creating an engaging classroom environment where students feel connected lies with the teacher, not with the student.

So, how did organic chemistry become one of UCLA's most popular classes? The answer is, "It's complicated." Nonetheless, I hope this personal account provides food for thought for anyone interested in teaching. Most importantly, remember that teaching is all about the students. We must challenge them, support them, make them feel connected to the class, and give them opportunities to do amazing things.

Educational resources

- TED^{X} and Breathalyzer Demonstration, https://www.youtube.com/watch?v=cs95YQLpSj0
- Music Video Hall of Fame, https://garg.chem.ucla.edu/music-video-hall-of-fame
- Biology and Chemistry Online Notes (BACON), https://learnbacon.com/
- Backside Attack smartphone application, https://apps.apple.com/us/app/backside-attack/id1278956096
- QR Chem website, https://qrchem.net/
- RS Chemistry website, https://rschemistry.com/

Media resources

- UCLA Newsroom, http://newsroom.ucla.edu/releases/has-organic-chemistry-become-ucla-s-most-beloved-class

- Buzzfeed, https://www.buzzfeed.com/ucla/the-8-coolest-classes-to-take-at-ucla-sw50
- LA Weekly Magazine, http://digitalissue.laweekly.com/publication/index.php?i=128971&m=&l=&p=201&pre=#{%22page%22:200,%22issue_id%22:128971}

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