Organic chemistry can sizzle

Tejas K. Shah and Neil K. Garg

Experienced chemists know that chemistry is all around them. Helping students to see the connections between real life and concepts of organic chemistry is the driving force behind the development of a set of online resources pioneered at UCLA.

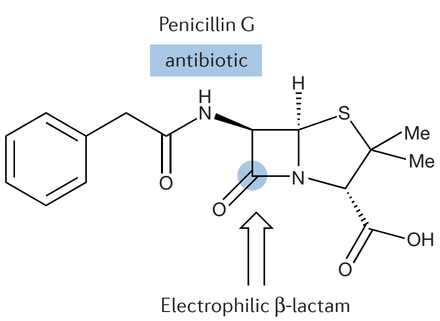
It is widely accepted that graduates in science, technology, engineering and mathematics (STEM) fields are vital to the continued development of the economy, healthcare, the environment, and countless elements of our everyday lives. According to the Science and Engineering Indicators 2012, roughly 1.75 million students enter colleges in the United States each year with the intention of pursuing a STEM major. However, the attrition statistics are striking. Nationwide, according to the President's Council of Advisors on Science and Technology (PCAST), only 40% eventually graduate with a degree (or concentration) in one of these fields. Therefore, it is essential that academics devote time and resources to the development of innovative solutions to the growing problems surrounding STEM education.

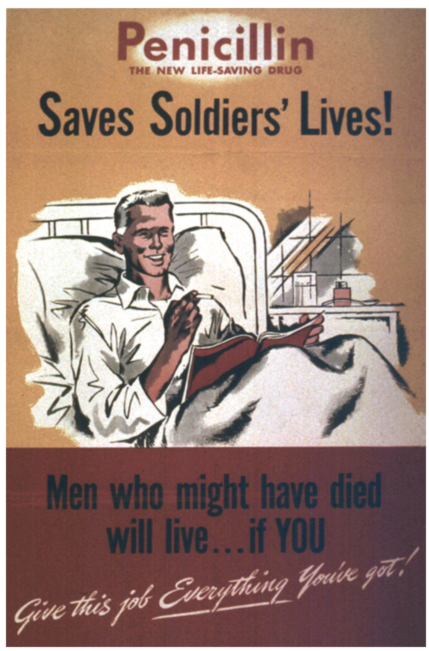
One of the most daunting topics for college students is organic chemistry. This topic, along with general chemistry, has been associated with the departure of students from STEM fields. A report from the Ohio University Office of Institutional Research shows that chemistry has one of the lowest first year retention rates. What is it about organic chemistry that makes it so difficult for our students? Several variables are responsible:

- Organic chemistry is a challenging subject. It requires students to think abstractly, while using analytical skills and problem solving techniques not found in other topics.
- Organic chemistry is not routinely taught at the high school level.
- The general perception of organic chemistry leaves much to be desired. Prior to attending college, many students hear rumours that organic chemistry is a 'weed-out' class requiring extensive memorization. This hampers student interest in the subject (*Attrition in STEM Fields at a Liberal Arts College: The Importance of Grades and Pre-Collegiate Preferences* Cornell Univ. ILR School; 2010).
- Chemistry has largely been taught in the same way for decades, with courses passed down from generation to generation. Experienced professors may be reluctant to change, especially if they are concurrently running a research group that requires external funding.
- Students seldom have an understanding of the important role that organic chemistry plays in society. Understanding and improving this situation is an important goal for all of those involved in the practice of teaching chemistry (*Improving Performance in First Year Chemistry* Thesis, Texas Tech Univ.; 2005).

We have long thought that students should be taught to enjoy organic chemistry, or perhaps even be inspired to love it. With this in mind, and with the key goal of helping students succeed in their organic chemistry coursework and persevering in STEM subjects in general, we have developed a series of online learning modules we affectionately call BACON. BACON stands for Biology and Chemistry Online Notes and is intended to arm students with organic chemistry knowledge, reinforce key concepts, and illustrate the relevance of organic chemistry in medicine and other aspects of our everyday lives, including popular culture. Herein, we describe the creation and content of BACON, its expansion to engage thousands of students worldwide, and its impact and future prospects.

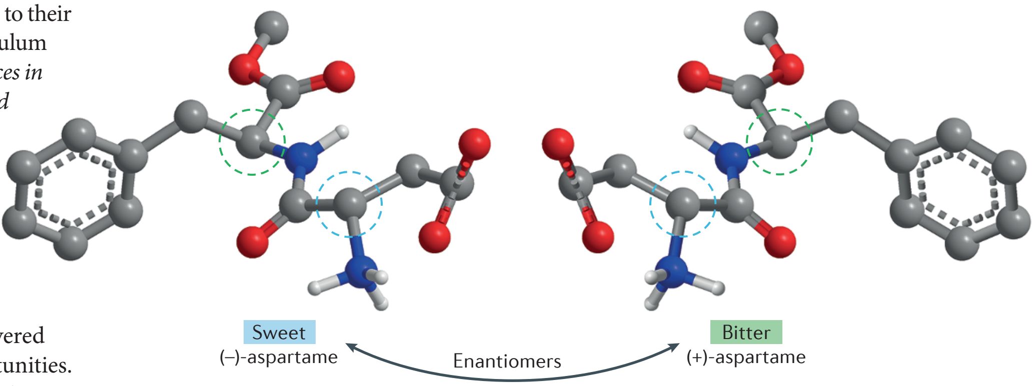
The BACON project was first launched at UCLA in early 2014. At the time, one of us (N.K.G.) was instructing a sophomore-level organic chemistry course and was asked by a life sciences colleague: "How much time is spent making connections to medicine and biology?" Although links between these topics were considered highly valuable, the intense course curriculum and the time constraints of the 10-week quarter system rendered it challenging to include such material in the usual lectures. We reasoned that providing these materials as an online supplemental resource would solve this issue as well as providing other advantages (*Make it Stick: The Science of Successful Learning* Harvard Univ. Press; 2014 and *Science* **304**, 521–522; 2004). For example, the online environment provides a vehicle for making extensive connections between organic chemistry and popular culture (such as movies, TV shows and sports) as a means to engage the 'YouTube generation' of students and help them recognize that chemistry is all around them. Additionally, it allows instructors with established lecture-type curricula to readily





Rachael Tremlett/Macmillan Publishers Limited/War posters/Alamy Stock Photo incorporate BACON as a supplement to their teaching. This type of blended curriculum *(Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies* US Department of Education; 2010) featuring conventional teaching and BACON modules was considered ideal to enrich the student learning experience.

The creation of BACON has involved a spirit of collaboration, layered with mentoring and learning opportunities. Initially, it involved a close collaboration between a graduate teaching assistant at the time (T.K.S.) and the principal investigator (N.K.G.). Over the course of several lively meetings, we conceived the necessary tutorial topics and key concepts, as well as the connection between organic chemistry and medicine, everyday life and popular culture. The student involved (T.K.S.) had countless opportunities to be creative, hone written and presentation skills, and learn many important aspects of pedagogy.



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> "The online environment provides a vehicle to make extensive connections between organic chemistry and popular culture"

Ultimately, ten interactive BACON tutorials, each 15–20 minutes long, showcasing current events, visual aids and video clips were created. For example, one tutorial focuses on radical reactions, a popular topic in most organic chemistry courses. The BACON tutorial provides a 'refresher' on the key concepts of radical chemistry before giving real-life examples, such as how oxygen radicals can react with cells and DNA, and are thus associated with cancer, Alzheimer disease and Parkinson disease. The tutorial goes on to explain that antioxidants can help to prevent the damage in our bodies and shows which foods and vitamins contain antioxidants. It even asks students questions about how antioxidants protect our bodies when they react with oxygen radicals. Finally, the tutorial further engages students by making connections to popular culture by, for example, discussing Muhammad Ali's battle with Parkinson disease and the progression of Alzheimer disease seen in the hit film 'Still Alice'. The corresponding text contains hyperlinks to other informative websites, primary research articles and videos throughout the tutorial, so that students can learn more, if they desire.

Here, two additional examples of BACON content are depicted. One connects the concept of electrophilicity to the remarkable antibiotic penicillin and its use on the battlefield in the Second World War. The other demonstrates that enantiomers of a given compound may interact differently with our taste receptors, as is the case for the two enantiomers of the popular artificial sweetener aspartame. Other BACON tutorials feature revolutionary organic materials being used to construct sports arenas, the chemistry behind transition lenses, and numerous examples of how organic chemistry is used to prepare the vast majority of life-saving medicines available to humans.

BACON was piloted on 375 UCLA undergraduates in 2014. Their post-course evaluations — completed with a response rate of >95% — demonstrated that the union of typical course content to real-world applications and popular culture provided a highly effective way to engage students. BACON was viewed as being 'fun and informative' (4.3/5.0 rating), and helpful in letting students see connections between chemistry and biology not covered in the lectures (4.4/5.0 rating). The majority of students indicated that BACON helped to increase their general appreciation of organic chemistry (4.3/5.0 rating) and that it should be used in future course offerings (4.6/5.0 rating). Lastly, students suggested that resources analogous to BACON would be welcomed in other STEM courses (4.4/5.0 rating).

Encouraged by these reviews, we devoted considerable effort to refining the BACON content the following year and subsequently obtaining additional assessment data beyond satisfaction-based surveys. Further mentoring opportunities were created by the involvement of a second graduate student and three undergraduates, the latter of whom were able to receive UCLA course credit for working on educational resources. The BACON team met weekly as a group and in smaller groups in which the students worked collaboratively through a vertical mentoring system. Ultimately, we were able to refine the prior tutorials, create additional tutorials, introduce several sections on modern organic chemistry research, and introduce quizzes for students to take before and after completing the tutorials. The new and improved version of BACON was used by 1,500 students in 2015 by five classes. Although student quiz scores prior to completing BACON tutorials averaged around 50%, these rose to 90% after the completion of the BACON tutorials. This data in combination with the satisfaction-based surveys encouraged us to further expand the project.

With the goal of making the BACON tutorials widely available, we developed a new website: learnbacon.com. The website allows for multiple 'BACON courses', which are custom compilations of specific BACON tutorials chosen by professors, to be run simultaneously. In this way, professors can choose the tutorials that they deem to be appropriate for students based on their own course content. The tutorials that are currently available are: functional groups and reactivity fundamentals; stereochemistry and chirality; radical reactions; substitution reactions; elimination reactions; alcohols and epoxides; alkenes and alkynes; Diels–Alder and pericyclic reactions; aromaticity and electrophilic aromatic substitution; enols and enolates; aldehydes and ketones; carboxylic acids and derivatives; polymers; cross-coupling reactions; mass spectrometry; and NMR and IR spectroscopy.

Blended online and face-to-face courses often struggle with faculty resistance to using new technologies, (*Managing Technology in Higher Education: Strategies for Transforming Teaching and Learning* Jossey–Bass; 2011); therefore, we made efforts to design the BACON interface with features to simplify the experience for both students and faculty. For example, the platform e-mails reminders to students when tutorials become available (and when coursework is due), as well as providing an array of easy-to-use grading functions. How to make use of the BACON grades (for example, as a requirement or for optional extra credit) is left to the professor.

Learnbacon.com was launched in early 2016 and adopted by several schools as part of our initial expansion efforts. This phase proceeded smoothly, so we have now increased the availability of BACON to instructors and students worldwide. So far, the organic chemistry BACON tutorials have been used as supplemental materials for more than 150 courses, spanning at least 75 colleges and universities in the United States, Canada, Europe, Mexico, Japan, India and the Middle East. Nearly 15,000 students have been educated by BACON tutorials to date.

The benefits of the BACON project on STEM education can be seen from several viewpoints. The project has given numerous undergraduate and graduate students the unique opportunity to be involved in the creation of educational content. Writing instructive content of any variety is challenging, but combining this with connections to modern research and popular culture adds significant complexity to the process. What is perhaps most striking about BACON is the sheer number of STEM students that have been reached and can be positively affected in the future. We expect that it will enliven organic chemistry for tens of thousands of students in the upcoming years. We are optimistic that these efforts will ultimately help to shatter the negative perception of organic chemistry amongst students, and perhaps even the general population, over time, while also providing the impetus for other academics to develop BACON-like resources for other STEM fields.

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Competing interests
The authors declare no competing interests.

FURTHER INFORMATION
N.K.G. teaching website: http://www.chem.ucla.edu/dept/Faculty/garg/Garg_Group/Teaching.html
Ohio University Office of Institutional Research Report: https://www.ohio.edu/instres/retention/RetenAthens.pdf
President's Council of Advisors on Science and Technology (PCAST): https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf
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