frontiers | Frontiers in Education

TYPE Editorial
PUBLISHED 11 March 2025
DOI 10.3389/feduc.2025.1578608



OPEN ACCESS

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RECEIVED 18 February 2025
ACCEPTED 20 February 2025
PUBLISHED 11 March 2025

CITATION
Wackerly JW, Zingales SK, Wentzel MT, McCollum BM and Bhattacharyya G (2025) Editorial: Organic chemistry education research into practice. *Front. Educ.* 10:1578608. doi: 10.3389/feduc.2025.1578608



# Editorial: Organic chemistry education research into practice

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KEYWORDS

**organic chemistry, undergraduate curriculum, chemistry education research (CER), practice, learning, instruction**

Editorial on the Research Topic
Organic chemistry education research into practice

Scholarship in chemical education has grown in remarkable ways over the past century. What started with a focus in primary and secondary education soon spread to first-year courses in higher education. By 2008 there was enough research on topics beyond the introductory undergraduate level, that the Royal Society of Chemistry's *Chemistry Education Research and Practice* dedicated a Research Topic to "advanced courses" (Bodner and Weaver, 2008). Along with the expansion into all levels of education, scholarship in chemical education has advanced to the point that journals devoted to chemical education are now dominated by theory-grounded research studies using quantitative, qualitative, and mixed methodologies (Cooper and Stowe, 2018)!

Ostensibly, chemical educators worldwide use the resulting bodies of research to inform, and reform, their instruction. However, these innovations are infrequently reported because of the absence of peer-reviewed journals in which the associated scholarship can be published (Sweder et al., 2023). We are excited to provide this forum for presenting evidence-based instructional practices in organic chemistry. To use an analogy from organic synthesis, CER articles are equivalent to methodology articles; and evidence-based practice articles—like the ones in this special issue—are like total syntheses. Just as we recognize the importance of total syntheses in showcasing and extending/refining respective methodologies, the articles in this issue, similarly, expand the knowledge base of CER and are clearly a valued form of scholarship in chemical education.

The contributions to this special issue of *Frontiers in Education* share several key attributes. First, each group of authors designed learning experiences that are grounded in research literature and/or theoretical frameworks from social sciences and philosophy. Second, the articles include detailed descriptions of the context in and methods by which the authors implemented their developed learning materials. Third, the authors demonstrate the efficacy of their evidence-based course innovations. Critically, all the presented data in this issue are consistent with one or more levels in St. John and McNeal's (2017) strength of evidence pyramid.

This Research Topic contains 12 articles, divided into three themes: (1) generally-applicable instructional strategies; (2) imaginative repurposing of instructional agents and virtual platforms; and (3) innovative approaches to assessment. In the brief descriptions of the contributions in the following paragraphs, we use one of the following abbreviations after the authors' names to designate the *Frontiers* manuscript category to which the article belongs: Curriculum, Instruction, and Pedagogy (CIP), Hypothesis and Theory (HT), Original Research (OR), Perspective (P), or Review (R).

Each of the contributions to the first theme, generally-applicable instructional strategies, presents concepts that are applicable to teaching across the spectrum of topics in organic chemistry. Popova (P) describes how research-practitioner partnerships can be used to create more effective course materials and, therefore, pedagogical implementation of research findings. Using representational competence as an example, the author explains how one such partnership was used to explicitly address an area of learner skill development that is often left implicit. MacNeil et al. (CIP) follow with a report on instruction in metacognition delivered concomitantly with course content. Using seminal works from cognitive and educational psychology, the authors developed a combination of learning task inventories, confidence self-assessments, and performance predictions and post-dictions. They found that learners improved their ability to engage cognitive processes involving planning, monitoring, and evaluating knowledge acquisition. Wackerly et al. (HT) then propose that abductive reasoning skills, essential in scientific problem-solving and medical diagnosis, are crucial for career interests of students that present in the 2$^{nd}$-year undergraduate course. The authors provide examples of how instructors can integrate abductive reasoning into their teaching and, thereby, enhance students' problem-solving abilities. Concluding this section, Graulich and Lieber (R) assert that effective chemistry learning requires engaging students in meaningful tasks that go beyond rote exercises. They explain that contrasting case comparisons are meaningful because they tend to induce students to use multiple cognitive operations simultaneously, which helps in their overall problem-solving ability.

The authors for the second theme, imaginative repurposing of instructional agents and virtual platforms, meticulously describe their adaptations and successful creation or adaptation of instructional methodologies for virtual and in-person learning. Schuessler et al. (OR) present their conversion of assessment tasks from pencil-and-paper formats into a digital ones. In their multi-institutional study, the authors demonstrate how these types of transitions need to be carefully and purposefully executed. Using cognitive load theory, the research team used several cycles of implementation and feedback to identify and minimize extraneous cognitive load resulting from the change in medium. Griffin et al. (CIP) describe their use of chemical education and peer-learning research literature to simultaneously design a new lab curriculum alongside a new Learning Assistant (LA) program in which undergraduate students worked with the graduate teaching assistants (GTAs). The authors discuss how interactions with LAs positively impacted several affective factors for students in non-majors courses. Additionally, the students found LAs to be especially helpful when their GTAs were working with other students. Ward et al. (CIP), explore how an augmented reality (AR) app, H NMR MoleculAR, helps students understand proton NMR in organic chemistry labs. The study highlights the challenges and benefits of using AR tools in different learning environments. In the final article of this section, Gallardo-Williams and Dunnagan (P) present their use of extended reality to address factors related to access to instructors during introductory-level organic chemistry labs. Initially developed for virtual instruction, the authors provide a research-based methodology for fostering constructive and thoughtful interactions between students and their lab instructors in research-focused institutions.

The articles in the final theme, innovative approaches to classroom assessment, offer compelling evidence demonstrating the potential of non-standard methods of assessment. Mio (CIP) reviews alternative grading methods, such as "ungrading" and standards-based assessments, and describes how these can reduce students' stress and anxiety while improving their metacognition. Gaines and Burrows (CIP) implemented oral examinations in two different classrooms during the disruption in educational settings caused by the pandemic. They found that oral exams allowed students and instructors to collaboratively identify strengths and weaknesses. Moster and Zingales (CIP) describe specifications-based grading in an online graduate organic chemistry course, wherein students earned grades by meeting specific learning objectives rather than accumulating points. The flexible system allowed students to choose assessments, work at their own pace, and use tokens for extensions or retakes, leading to more content-focused interactions and a slight increase in pass rates. This Research Topic concludes with Ferguson and Bonner (P), who share their perspective on "ungrading" across the curriculum and how they implement it in their organic chemistry courses. Like Mio, they propose "ungrading" as a promising strategy for increasing student metacognition.

Above all, we would like to thank the more than 30 authors who contributed to this Research Topic. The authors afford readers unique opportunities to learn about new and effective instructional strategies, some of which may have been previously unknown. Furthermore, several manuscripts demonstrate how creative adaptation of existing resources can lead to ground-breaking change.

As co-Editors, we recognize that a single Research Topic, cannot comprehensively alter the landscape of teaching and learning in organic chemistry. Rather than being definitive or prescriptive, our main hope is that this issue will stimulate healthy debates in the global chemical education community about ways to improve the student experience. Though we may have differences in approaches and proposed remedies, as instructors of organic chemistry we can certainly agree that there is room for improvement.

Finally, we strongly feel that the contributed articles demonstrate the immense value of practice-focused, evidence-based scholarship in chemical education, and the clear need for more venues to publish articles like the ones in this issue. In fact, the American Chemical Society Statement on Scholarship (American Chemical Society Committee on Education (SOCED), 2010) exhorted, *"the chemistry community* [to] *accept and act upon* *a broader definition rewarding faculty for the wide range of activities needed to bring about a modern and effective research and education infrastructure."* To that end, journals need to establish clear and consistent guidelines for evidence of instructional efficacy that do not mandate research studies. We hope that the readers will join us in advocating for these future opportunities.

## Author contributions

JW: Writing – original draft, Writing – review & editing. SZ: Writing – original draft, Writing – review & editing. MW: Writing – original draft, Writing – review & editing. BM: Writing – original draft, Writing – review & editing. GB: Conceptualization, Writing – original draft, Writing – review & editing.

## Acknowledgments

We would like to express our heartfelt gratitude to the authors, for sharing their innovative work, the reviewers for their thoughtful evaluations of the manuscripts, and the *Journal's* editorial staff for making this Research Topic a reality.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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