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Bridging chemistry education research and practice through research-practice partnerships

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This perspective article is a call to establish research-practice partnerships (RPPs) to foster collaborations between instructors and education researchers to tune into the needs of practice, share evidence-based practices, and solve modern organic chemistry education problems. I begin the article by discussing some limitations of the traditional approach of "translating" research *into* practice and suggest RPPs as an alternative model for "bridging" research *and* practice. Importantly, RPPs have been shown to address persistent problems of practice and improve educational outcomes. While more common at the secondary level, RPPs are rarely leveraged in post-secondary chemistry education. The article goes on to provide a concrete and relevant context for potential future RPP efforts to improve aspects of organic chemistry education—RPPs between education researchers and organic chemistry instructors to work toward designing, administering, and testing interventions to support learners' representational competence (RC). RC is a set of skills that allow for the reflective use of a variety of representations to think about, communicate, and act on chemical phenomena. Current instruction often falls short of effectively supporting learners in developing RC. It is often tacitly assumed that learners will develop RC without explicit instruction that scaffolds the development of the RC skills. While it is important to improve the teaching about and with representations, implementing innovative pedagogical approaches can be challenging, particularly when instructors feel isolated in their efforts within their work environments. The RPP model could catalyze solutions to these challenges by pooling diverse expertise, thus enabling more robust and sustainable educational innovations.

KEYWORDS

post-secondary education, organic chemistry, representational competence, professional development, research-practice partnerships

1 The problem with traditional approaches to translating research into practice

In the ever-evolving landscape of higher education, the importance of implementing innovative, evidence-based pedagogical approaches cannot be overstated. Educators must continuously seek out and apply the best available evidence to their teaching practices, thereby enhancing the quality of education they provide to improve student learning outcomes. At the same time, implementing innovative pedagogical approaches can be challenging, particularly when instructors feel isolated in their efforts within their work environments. Even if instructors recognize the potential benefits of a particular innovation, the absence of support can impede their well-intentioned curricular reform efforts or efforts to improve their teaching practices (Fairweather, 2008). These barriers can result in a lack of motivation needed to initiate change within their instruction (Shadle et al., 2017). To mitigate these barriers, educators and curriculum developers require knowledge, skills, resources, and support. This need has been previously emphasized by the National Research Council:

> "*The translation of research findings into forms useful for educational practice… will require large-scale, systematic experimentation and demonstration to transform knowledge about human learning and the development of competence into the working vocabulary of teachers…*" (Committee on a Feasibility Study for a Strategic Education Research Program, National Research Council, 1999, p. 3).

Today, one of the most common mechanisms to provide such support is faculty professional development initiatives that typically involve structured programs, workshops, or seminars, where education researchers directly impart knowledge to instructors in a one-directional manner. A significant limitation of such traditional professional development lies in the assumption that knowledge transfer is straightforward and that teaching practices can be directly informed and transformed by simply exposing instructors to new educational theories or research findings. The conventional "translation" metaphor of research into practice provides an impoverished way of understanding the complex relationship between research and practice (Penuel et al., 2015). While effective to a degree, the "translation" approach overlooks several critical aspects that are essential for meaningful pedagogical growth as it fails to account for the specific contextual challenges and opportunities within different teaching environments and results in a lack of instructors' engagement and ownership, missed opportunities for collaboration between educational researchers and instructors, inadequate attention to implementation challenges, and issues with the sustainability of instructional innovations (Burbank and Kauchak, 2003; Chicoine, 2004; Webster-Wright, 2009; Coburn et al., 2013; Penuel et al., 2015; Coburn and Penuel, 2016; Rodriguez and Towns, 2019; Johnson, 2022).

Major task force reports have called for changes in how we conceptualize the "translation" of research into practice (National Research Council, 1999; Donovan et al., 2013). Researchers, administrators, and stakeholders need to better account for the complex challenges researchers and practitioners face when using research to drive educational improvement (National Research Council, 1999; Coburn and Stein, 2010; Donovan et al., 2013). These efforts should go beyond the predominantly used "teaching as telling," "one-directional," or "one-shot" professional development models, especially given the evidence of the failure of some of these professional development approaches (Lovitt and Clarke, 1988; Fullan and Stiegelbauer, 1991; Johnson, 1998). The evolving landscape of higher education and the diverse needs of modern learners call for more innovative, flexible, and inclusive professional development approaches, as well as for a broader range of mechanisms through which faculty professional development can emerge. This perspective article is a call for the chemistry education community to consider an alternative faculty professional development model that has the potential to address the limitations described above—research-practice partnerships (Coburn et al., 2013; Penuel et al., 2015).

2 Research-practice partnerships as an alternative model for bridging research and practice

Research-practice partnerships (RPPs) are long-term collaborations, often between educators and education researchers, that have been shown to address persistent problems of practice, and improve educational outcomes (Tseng, 2012; Coburn et al., 2013; Donovan et al., 2013; Fishman et al., 2013). RPP members establish an external community of like-minded colleagues outside of one's institution which becomes an important force in promoting educational innovation. RPP members engage in processes of collaboration and exchange that are both messier and often more transformative than the traditional "one-directional translation" of research into practice. RPPs are characterized by mutual goals that focus on problems of practice rather than gaps in research and theory. Importantly, these goals and efforts often evolve through interactions between RPP members, rather than being defined fully ahead of time (Penuel et al., 2015).

RPPs offer opportunities for growth and development not only for instructors but also for education researchers. By working closely with practitioners, researchers gain direct insights into the problems of practice. This deep engagement with the realities of educational settings fosters a richer understanding of the context-dependent nature of learning and teaching, enhancing the relevance and applicability of research findings. Effective RPPs establish shared authority where goals, work, and interactions are jointly negotiated, with carefully elaborated roles, routines, and protocols for engagement (Coburn and Penuel, 2016). Ultimately, this symbiosis between research and practice enriches the academic and research communities, fostering an environment where knowledge creation and pedagogical excellence coalesce more effectively.

While there is promising evidence on the impact of RPPs' interventions on student learning at the secondary level (Fishman et al., 2003; Yarnall et al., 2006; Geier et al., 2008; Snow et al., 2009; Barab et al., 2010; Booth et al., 2015), RPPs are uncommon in post-secondary chemistry education. Below I propose a potential direction for future RPPs to improve aspects of post-secondary organic chemistry education.

3 Representational competence as a potential context for future research-practice partnerships to improve aspects of organic chemistry education

Organic Chemistry is known for its high attrition rates (Lovecchio and Dundes, 2002; Jones and Gellene, 2005; Grove et al., 2008). It is imperative to rethink and redesign the curriculum, instructional, and assessment strategies used to teach this course. To effectively transform organic chemistry education, it is necessary to forge effective professional development programs to equip instructors with literature-based resources and support that could meaningfully affect instructors' pedagogical knowledge and teaching practices (Gess-Newsome et al., 2003; Henderson et al., 2011; Talanquer, 2014). One critical direction for these initiatives is in the area of representational competence (RC), as learning and communicating with visualizations is an essential component of chemistry instruction (Kozma and Russell, 2005; Ainsworth, 2006; Gilbert, 2007; Stieff, 2007; Keehner et al., 2008).

The development of RC has been positioned as one of the chief goals for STEM education by the National Research Council (2012). Chemistry is one of the main STEM disciplines where learner success is significantly impacted by RC because many of the fundamental concepts and processes in chemistry cannot be directly observed or experienced in the physical world (Kozma and Russell, 2005; Ainsworth, 2006; Gilbert, 2007). Kozma and Russell (2005), p. 131 define RC as "a set of skills and practices that allow a person to reflectively use a variety of representations, singly and together, to think about, communicate, and act on chemical phenomena in terms of underlying aperceptual physical entities and processes." This set of skills includes the ability to interpret, translate, generate, and use representations, among others. At the same time, one can develop these foundational RC skills without understanding the 'why' behind engaging in tasks that require these skills. This is problematic because instruction and tasks that do not make sense to learners undermine their motivation to continue work in science (diSessa, 2004). Meta-RC "may be precisely what makes learning representations sensible to students" (diSessa, 2004). Meta-RC is a subset of RC that allows for the reflective and purposeful use of representations and includes skills such as the ability to describe affordances and limitations of various representations or select an optimal representation for a particular purpose. Therefore, effective support for developing RC requires a comprehensive approach that targets both the foundational RC skills and meta-RC skills.

Although a wide body of literature has focused on exploring organic chemistry students' learning about and with representations (Bodner and Domin, 2000; Cooper et al., 2010; Grove et al., 2012; Stull et al., 2012; Popova and Bretz, 2018a,b,c), less is known about organic chemistry instructors' approaches toward developing learner RC. Literature in this domain shows that even though conventional teaching approaches in chemistry incorporate a wide variety of representations, they are not frequently guided by learning objectives that explicitly target RC (Talanquer, 2022). It is often tacitly assumed that learners will develop RC without explicit instruction that intentionally scaffolds the development of the various RC skills. Recent studies from our research group found that neither chemistry instructors (Popova and Jones, 2021; Jones et al., 2022) nor chemistry textbooks (Gurung et al., 2022) support learners in developing higher-level meta-RC skills that allow for the reflective and purposeful use of representations. Moreover, currently, no professional development opportunities exist focused on improving how instructors support learner RC, despite chemistry instructors reporting wanting to learn about (a) finding quality representations to use in their teaching (e.g., animations, simulations), (b) effective teaching about representations, (c) proper assessment of student mastery of representations, and (d) expert-novice differences in understanding representations (Popova and Jones, 2021). The lack of such domain-specific professional development is problematic, as learners with developed RC are better set for building conceptual understanding and acquiring scientific practices (Lansangan and Orleans, 2007; Sim and Daniel, 2014; Lansangan et al., 2018; Dickmann et al., 2019; Herunata et al., 2021).

4 Hypothetical five-year RPP between organic chemistry instructors and education researchers

RPPs could be established to fill this gap in domain-specific professional development. Here, I present an outline for a potential five-year RPP between organic chemistry instructors and education researchers, aiming to improve organic chemistry students' RC. Importantly, should RPP work be externally funded, it is imperative to ensure that appropriate funds are allocated to compensate for the work of not only the researchers but also the practitioners. Securing external funding is crucial not only for the operational needs of the RPP but also to honor the significant contributions of each participant. Appropriately allocated funds will ensure that instructors are compensated for their time, particularly for tasks that extend beyond their usual teaching responsibilities. Proper compensation would acknowledge instructors' essential role in the partnership.

The RPP work could be partitioned into six main stages (Table 1) following the application process to express an interest in participating. The application process for the RPP should be intentionally designed

TABLE 1 Timeline and the main stages for the proposed five-year research-practice partnership.

Year	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
0										start	application process	
1			Teaching pre-RPP				f2f meeting			Stage 1		
2										Stage 2	f2f meeting	
3		Stage 3					f2f meeting			Stage 4		
4		Stage 5								Stage 6	f2f meeting	
5			Teaching post-RPP				f2f meeting		finish			
Legend: start; f2f meeting; finish	Stage 1: Discussion of readings to generate ideas for RC interventions based on research and theory			Stages 2 and 4: Design, development, and refinement of RC interventions; CITI, IRB, and plans for collecting and analyzing data			Stages 3 and 5: Administering interventions in Organic Chemistry I and collecting student outcomes data			Stage 6: Dissemination via publications, including journal author guidelines, organization of a manuscript, etc.		

to select instructors who demonstrate a clear commitment to engage in a long-term collaboration. The teaching pre-RPP and post-RPP periods in Years 1 and 5 (Table 1) could be used for collecting various data (e.g., video observations, course artifacts, interviews) to evaluate the impact of RPP on the Pedagogical Content Knowledge (PCK) and practices of instructors over time. Recognizing that RPPs generally involve establishing an external community of like-minded colleagues outside of one's institution, ideally, the RPP work should start at an in-person gathering to help the RPP members more effectively build rapport with each other. Additionally, the RPP members should have an opportunity to come together at least yearly (e.g., at conferences). At the same time, consideration should be made for allowing for hybrid attendance of the in-person meetings, recognizing potential diverse needs and constraints of RPP members (e.g., funding limitations, teaching commitments, and personal health and well-being). Outside the occasional in-person meetings, the RPP members should meet periodically during remote meetings (below, I propose a monthly schedule of meetings).

The RPP work could start with presenting the instructors with the "representational dilemma." The representational dilemma refers to the idea that learners are expected to understand abstract concepts and reaction mechanisms using various representations before they have fully learned how to interpret and use these representations. This is analogous to using a complex map to navigate a new city without the necessary practice in map reading. Just as learning to read a map requires practice, learners also need support in using representations to understand new concepts and mechanisms. This dilemma could be used to outline a very general and broad goal for the RPP—to collectively brainstorm and generate practical solutions for this challenge, which could include designing and testing interventions in authentic classroom settings. At this first meeting, it is also critical to jointly discuss and negotiate roles, routines, and protocols for engagement as an RPP (Stage 1).

At the subsequent monthly remote meetings, RPP members should discuss literature related to theory and research around supporting learner RC (Stage 1). This literature could include (1) primers on RC and meta-RC (diSessa, 2004; Kozma and Russell, 2005), (2) relevant theories of learning including constructivism (Novak, 1993), dual-coding theory (Paivio, 1986), and the information processing model (Baddeley, 2003), (3) Johnstone's chemistry triplet (Johnstone, 2006; Taber, 2013), (4) multimedia and visualization principles (Mayer, 2002; Tasker, 2015), (5) the key factors affecting learners' ability to reason with representation (Schönborn and Anderson, 2006, 2010), (6) assessment including the use of representations to promote equitable assessment design (Towns, 2014; Ralph and Lewis, 2020); and (7) design frameworks for developing educational interventions (Branch, 2010; Rau, 2017). At each remote monthly meeting, the discussion should focus on deriving insights for interventions aimed at improving RC.

Next, the RPP should leverage their knowledge of the (1) needs of their learners, (2) relevant research and theory, and (3) design frameworks to develop interventions to support learner RC (Stage 2). RPP can work collaboratively to review and refine the developed interventions (including student and instructor implementation guides). At this stage, the RPP should also make concrete plans for gathering and analyzing any necessary student data, including, when applicable, completing the Collaborative Institutional Training Initiative (CITI) and submitting Institutional Review Board (IRB) applications to ensure the ethical administration, testing, and evaluation of developed interventions.

The next stage would involve administering interventions in Organic Chemistry I and collecting student outcomes data (Stage 3). Each RPP member administering interventions in their classroom should be able to select a set of newly developed interventions that are best aligned with their learning objectives and the needs of their students. During this stage, RPP members should collect, analyze, and reflect on student data to evaluate the success of the administered interventions. In Stages 4 and 5, RPP members refine, develop (if needed), and readminister interventions in organic chemistry classrooms, emulating Stages 2 and 3. Finally, the RPP members should work on disseminating their work at conferences and via publications (Stage 6). Time should be set aside for planning, writing, and revising publications at the end of the project.

To mitigate the potential burden on instructors, the RPP should be structured to foster a collaborative environment where responsibilities are shared among all partners. This should include substantial support from education researchers in managing the collection and analysis of data, and the administrative tasks associated with IRB approval and funding applications. Leveraging the diverse expertise within the RPP could help enhance the sustainability and effectiveness of the interventions without overburdening any of the members.

5 Discussion, implications, and concluding remarks

While the section above outlines the timeline and main stages for a hypothetical RPP, it is important to tailor this plan to the unique context and needs of each specific project or collective of RPP participants. For example, while Table 1 proposes that in-person meetings occur in March and July, to coincide with the National Meeting and Exposition of the American Chemical Society (ACS) and the Biennial Conference on Chemical Education (BCCE), RPPs based outside of the United States should consider holding in-person meetings in accordance with the timelines of local chemistry education conferences.

Additionally, while this perspective article presents a hypothetical RPP for supporting learner RC, RPPs could be leveraged to address other important problems of organic chemistry education, such as developing student mechanistic reasoning in lecture courses or scientific practices in laboratory courses—other areas identified as particularly difficult for both teaching and learning (National Research Council, 2012; Graulich, 2015).

Finally, research on RPPs in education is very sparse, especially at the postsecondary level. More research is needed to understand the influences of RPPs on instructors and researchers (Coburn and Penuel, 2016). For example, there are several studies that provide evidence that RPP participation is associated with increased access to research (Bickel and Cooley, 1985; Kerr et al., 2006), but little is known about whether it is also associated with greater use of research for making instructional decisions (Coburn and Penuel, 2016). Comprehensive evaluations are necessary to assess RPP contributions to educational improvement. For example, studies are needed to characterize and evaluate (a) the dynamics of RPPs and the mechanisms by which they may foster educational improvement, (b) challenges associated with RPPs at the postsecondary level, (c) how RPP participation might influence instructors' PCK and practices and researchers' insights, (d) whether RPPs foster greater capacity and uptake of research in classroom decision-making, and (e) the extent to which RPPs help improve student learning and RC. By diving deeper into these aspects, we can pave the way for RPPs to not just be a theoretical ideal but a practical vehicle for driving improvements in the quality of chemistry education.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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