EDITORIAL

More Rethinking of Chemical Engineering Education

Part 2: The Forming of Chemical Engineers

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In the previous issue of this journal, we looked to add to the conversation that was started by six chemical engineering scholars [1] on reimagining the curriculum of our discipline. In that editorial [2] we focused on curricular content as well as the constraints within the education system. However, we noted that such a conversation is incomplete without consideration of how chemical engineers are actually *formed*, and the professional development chemical engineering educators receive to facilitate such student growth. We shift to such a proposition here.

Chemical engineering educators are typically well-qualified in the technical aspects of the field, with most disciplinary courses being taught by those who have earned the doctorate or equivalent degree – often with extensive, cutting-edge research experience. However, while such a technical foundation may be considered a necessary condition for teaching in this discipline, instructors' pedagogical knowledge and subsequent implementation can have a large influence on student learning. Ideally, all chemical engineering educators would be formally trained in teaching. Accordingly, we advocate for a shift in importance where chemical engineering educators are encouraged to pursue professional development in teaching, and for the percentage to grow and approach 100% over the next decade. The American Society for Engineering Education, under whose banner this journal is published, is currently framing a structure that provides recognition for such professional development in teaching for engineering and engineering technology faculty members.[3]

As part of our advocacy for professional development in teaching, we encourage chemical engineering educators to design curricular activities that more closely align with those of professional engineers. In other words, we need to consider not only those aspects of students' learning that were discussed in the first editorial [2] but also those aspects that address the disciplinary practices in which students engage. Such a shift in focus touches on both the kind of work that we ask students to complete and the classroom norms where that work is done.

Why should considerations of practices go hand-in-hand with content in the formation of chemical engineers? Recent video research studies find that students will commonly engage in their core chemical engineering course assignments in ways that do not translate well into the practices of professional engineers. Often, problem sets and exams reward algorithmic solution procedures that lead students to develop problematic *schooling* practices.[4, 5] Such practices can include equation shopping in the text, the web, or other places; looking for a worked example to parrot; mining the assignment for clues to instructor expectations and then "backwards engineering" a solution to match; and structuring group work where a dominant leader controls the decisions. This form of engagement leads to solutions that are characterized by certainty, where authority derives from what the instructor is "looking for," and speed and accuracy are foregrounded over deep understanding and collaborative sense-making, a hallmark of a positive team attribute that is valued in practice.

As is well known, engineering "in the wild" is not conducted through a linear process where step-by-step algorithms can be followed. Rather, engineering involves complex, iterative approaches, where conceptual, material, and social elements are intertwined. Engineers' work is influenced by history, as the problems we focus on and the tools we use are shaped by past scientific and engineering advances. Additionally, engineering work involves learning how to negotiate social discomfort by managing uncertainty and balancing conflicting goals and values from different stakeholders or team members.

Accordingly, we advocate for standard course assignments to increasingly reflect these characteristics – ones that are complex, open-ended, and contain multiple, legitimate solutions. When engineering learning is conceived as an evolving set of interrelated practices, students can then learn when and how to use those practices. Through experiencing the regularities and variations in the ways that engineers pose questions, design experiments, construct models to make progress on their engineering designs, troubleshoot, and work through the inevitable confusion and failure, students not only

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come to understand engineering work better but also become more likely to see themselves as engineers. Indeed, such an approach is also encouraged in the *Nature Chemical Engineering* article [1] by David Shallcross, who mentions that real chemical engineering practice necessitates multiple competencies thereby expanding students' notions of who has access to the profession.

Of course, initiating an activity that has the desired characteristics mentioned in the above paragraph is not enough. These activities need to be supported by a concurrent change in classroom norms. Instructors should work to cultivate a classroom environment that supports constructive confusion and productive failure. Current educational practices tend to view confusion and failure as obstacles to be avoided, which can lead to stress and sometimes behavioral difficulties when students face these challenges.[6] This perspective likely stems from an emphasis on content acquisition and retention, often measured through large-scale assessments that prioritize mastery. However, progress in real engineering project work is seldom so straightforward. Confusion can be productive towards professional formation when students take up authority to answer questions, when they hold themselves accountable to engineering disciplinary norms, when participation allows for equitable input, and when reasoning and sense-making processes use big ideas from their courses. By incorporating complex, open-ended problems and creating a classroom culture that embraces confusion and recognizes failure as an inevitable precursor to success, we can better prepare students with the cognitive and emotional tools they need in the profession.

To conclude, the future of chemical engineering education must necessarily reflect the needs of the profession. But such needs go beyond just content coverage – as educators we need to prepare students to engage in the practices of real engineering work. To do this, all faculty in our discipline (and all engineering disciplines) require professional development in teaching, including strategies that allow instructors to create and assess activities and create a classroom culture that better mimics engineering "in the wild." Admittedly, a shift to more chemical engineering practices in a course or across a curriculum would likely require a prioritizing of concepts since these approaches, while more realistic, are time consuming. But such experiences would allow students to develop more accurate ideas about what counts as engineering and be better prepared to engage in the profession upon graduation. In this way, chemical engineering faculty will be better able to support the *formation* of chemical engineers that can attend to the broad needs of our world, now and in the future.

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