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Pedagogy in bioengineering: pipettes, practice and patience

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Strategies for hands-on and hands-off teaching, coupled with dynamic adaptation to students and science, enable effective pedagogy in bioengineering.

I grew up attending ten schools across three continents. In a childhood defined by new schools and new teachers, learning was not a linear process – I once finished 5th grade in one country a week before I started 3rd grade in another! As I navigated the nonlinearity of my unusual education, I was comforted by the aspects of school that transcended international boundaries. In particular, I valued how science teachers around the world taught me the value of using the scientific method to ask and answer new questions.

Over the years, as I skipped grades, repeated grades, learned new accents and made new friends, one thing stayed constant: my interest in growing up to speak the global language of science (and wearing a white lab coat, of course). In 2021, I was delighted to take a big step towards this goal by starting my own lab as an assistant professor at the Massachusetts Institute of Technology (MIT). Although building a research group from scratch was a daunting task, a decade of training as a scientist made this challenge feel addressable. By contrast, nothing in my prior education had prepared me to stand in front of hundreds of undergraduate students and attempt to make core engineering concepts accessible and engaging.

To tackle this challenge, I reflected on how I learned to learn as a child navigating dynamic environments, using these insights to inform the teaching techniques I have practiced in my first few years as a professor. Although my pedagogy is still very much a work in progress, my current philosophy involves three main factors: pipettes (knowing when to put on some gloves and teach hands-on); practice (learning when to step aside and enable independent exploration); and patience (centering optimism in my view of students and science).

Pipettes: strategies for hands-on pedagogy

My undergraduate and graduate training were in mechanical engineering departments, where 'getting your hands dirty' in machine shops was (and still is) an established part of the academic culture. I started at MIT by teaching mechanics of materials for undergraduate mechanical engineers, and I found particular joy in the 'guided discovery labs' in our curriculum, originally designed by Professor Ely Sachs. In these weekly sessions, students are guided through an experiment that enables empirical discovery of a fundamental principle of mechanics before the topic is covered in lecture. Students are encouraged to predict the outcome of the experiment beforehand (an exercise that often sparks spirited debate between groups), which seems to promote retention of the content regardless of the correctness of the prediction.

I was eager to test out this guided discovery approach in bioengineering. In a class on biomechanics and mechanobiology, we presented students with muscle cells growing on a soft hydrogel and asked them to record a video of how the tissue responded to the addition of two 'mystery liquids', Agent X (RNA lysis buffer) and Agent Y (Triton-X), that caused substantial changes in cell morphology and matrix tethering (Fig. 1). Students were then taught to leverage an open-source computational framework[1] to perform automated cell tracking over time and use these data to predict the identities of Agent X and Agent Y on the basis of their functional impact.

This lab proved to be an exciting way of exploring cell-matrix adhesion, and the success of our initial pilot has inspired me to design other bioengineering labs that enable students to connect theoretical concepts from lectures to empirical phenomena that can be observed and controlled in real time.

Practice: creating space for self-directed learning

Outside of the classroom, makerspaces offer experiential learning and skills development that are crucial to improving individual agency and engineering identity, and have the potential to improve the retention of marginalized students in science, technology, engineering and math[2–4]. For example, recent studies have shown that makerspaces can have positive impacts on the self-efficacy of women from marginalized backgrounds, highlighting a need to build welcoming environments that encourage active participation by a range of students[3,4]. Luckily, the start of my faculty career coincided with the launch of a new BioMaker Space at MIT, and I have enjoyed leveraging this space to help students explore independent projects in bioengineering.

Inspired by findings in the field of problem-based learning[5], I previously helped design a biofabrication course at the University of Illinois that enhanced learning outcomes by letting students practice solving ill-structured problems in bioengineering, such as improving the strength of tissue-engineered muscle[6]. Building on this experience, I have worked with MIT BioMaker Space staff and student mentors to teach ~4-week tissue-engineering workshops on building muscle-powered robots[7]. At the end of these workshops, students have the requisite technical skills and makerspace access needed to design and execute independent experiments in biofabrication. As most students come to our workshops without wet-lab experience, there is a lot of room for error. Failed experiments caused me a lot of stress in my early days of teaching, but I soon discovered that student enjoyment and motivation in these contexts are not tied to the success of their first foray into a biosafety cabinet. Instead, students enjoy the opportunity to practice new skills, make mistakes and explore creative directions with minimal intervention.

My current efforts to encourage self-directed learning in bioengineering are focused on developing a 3D bioprinting-focused makerspace at MIT, with the goal of giving trainees from a range of academic and demographic backgrounds access to next-generation biomanufacturing technology.

Fig. 1 | Ritu Raman (right), Eugene Bell Career Development Assistant Professor of Mechanical Engineering at MIT, guiding a student in the laboratory. Image credit: Tony Pulsone.

Patience: adapting to the dynamics of people and science

Students often take different paths to reach the same academic program, particularly in multidisciplinary fields such as bioengineering. Most experiments do not generate the predicted outcomes, particularly in emerging disciplines with limited prior knowledge. Developing patience with myself and with students in the face of dynamic scientific challenges has thus been one of the most necessary (and most rewarding) parts of my teaching efforts.

As an example, my class on biomechanics and mechanobiology drew undergraduate and graduate students from a range of engineering and biology departments. Owing to the various academic backgrounds of these students, I spent half the lectures at the chalkboard teaching fundamental mechanics of biomaterials and the other half presenting emerging research in mechanobiology. Although this may have been the fairest approach, it came with the tradeoff of occasionally boring students who had previously been exposed to some of the concepts in previous classes. For example, my mechanical engineering students had already covered linear elastic materials in their prior curriculum, and my biological engineering students were already familiar with the fundamentals of mechanotransduction. To address this issue, I encouraged students to form project groups that emphasized their shared scientific interests, rather than their shared academic background. This restructuring led to an exciting and multidisciplinary array of final projects and launched a partnership with the Boston Museum of Science, in which students developed an open-source online resource for others exploring molecular, cellular and tissue mechanics for the first time.

Learning to adapt to student feedback, while acknowledging that universal approval is a futile goal, has been a challenging exercise. By centering patience and dynamic adaptation in my approach, however, I am optimistic that each semester will bring new insights and new improvements to my teaching.

Taking small steps forward

As with many things in life, getting started is the hardest part of teaching. For others taking their first steps into bioengineering pedagogy, I would recommend first observing and learning from peer and senior mentors who are effective teachers. If you decide to make changes to a class, design your test run just like an experiment in the lab: change one variable at a time and embrace failure. When you inevitably make a mistake, apologize and make amends. And finally, remember the student you once were, and be kind to the people in your classroom who are still growing as engineers, scientists and newly independent adults.

My perspective on teaching in bioengineering is based on the experience of a new professor at a research-intensive institution with minimal formal training in pedagogy. As I deepen and broaden my experiences, I hope to continue evolving my philosophy on bioengineering pedagogy to dynamically adapt to the changing needs of future generations of students. With pipettes, practice and patience, I hope to embrace and enjoy the nonlinear nature of teaching and learning.

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Competing interests

The author declares no competing interests.

Related links

3D bioprinting-focused makerspace: https://shed.mit.edu/
BioMaker Space: https://biomakers.mit.edu/about-us/hhbms/
Open-source online resource (Molecular, Cellular, and Tissue Biomechanics Quizlet): https://www.mos.org/quizlet/molecular-cellular-and-tissue-biomechanics-quizlet