Best Practices in Robotics Education: Perspectives From an IEEE RAS Women in Engineering Panel

By Shawna Thomas

Educators everywhere are reexamining and reinventing their teaching approach to meet the challenges of delivering a high-quality education in this unprecedented time [1]–[3]. The coronavirus outbreak brought significant disruptions to higher education. In April 2020, higher education institutions were closed in 185 countries, representing nearly 90% of enrolled learners worldwide [4]. Many are revisiting established best practices while others are looking for new ways of reaching students [5].

In robotics education, we are facing many difficult questions:

- How can we best engage students in robotics material in the current teaching environment?
- How can we overcome perceived limitations when teaching robotics content online, especially when hardware is involved?
- What should be the focus of robotics education research to address these issues head on?

To facilitate a conversation around these important questions, in December 2020, the IEEE Women in Engineering/IEEE Robotics and Automation Society (RAS) hosted an online panel on best practices for teaching robotics. The diverse panel boasted a group of experts in robotics education from a variety of disciplines, institutions, and areas of expertise:

Carlotta Berry, Rose-Hulman Institute of Technology, USA.

Cecilia Laschi, National University of Singapore.

Katie Driggs-Campbell, University of Illinois Urbana-Champaign, USA.

Iolanda Leite, KTH Royal Institute of Technology, Sweden.

- Carlotta Berry, Electrical and Computer Engineering, Rose-Hulman Institute of Technology—passionate about robotics education; increasing underrepresented populations in science, technology, engineering, and mathematics; and enhanced human-robot interfaces
- Katie Driggs-Campbell, Electrical and Computer Engineering, University of Illinois Urbana-Champaign—explores safe and interactive autonomous systems through modeling human behavior, designing robust decision and control frameworks, and developing multi-agent validation schemes

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- Cecilia Laschi, Mechanical Engineering, National University of Singapore—interested in biorobotics, soft robotics, humanoid robotics, and neurorobotics
- Iolanda Leite, Division of Robotics, Perception, and Learning, KTH Royal Institute of Technology—develops social robots that can capture, learn from, and respond appropriately to the subtle dynamics of real-world situations
- Karinne Ramirez-Amaro, Electrical Engineering, Chalmers University of Technology—advances artificial intelligence and robotics research in semantic representations, decision making, and human activity recognition and understanding.

The panelists have taught a variety of undergraduate and graduate courses, ranging from introductory robotics and applied programming courses to project-based design courses to specialized courses on human-centered robotics, autonomous decision-making, human perception for information technology, and intelligent robotics, to name a few.

All of the panelists shared their experiences in best practices for robotics education, provided strategies for applying these practices to new courses, discussed major challenges in online robotics education and how they have overcome them, and talked about where they see robotics education headed. This article shares their perspectives.

Robotics Must Remain Hands-On

Robotics, at its heart, is a multidisciplinary, hands-on field [6]. It invites people to get their hands dirty, persevere through trial and error, and experience the thrill of success. These experiences are fundamental to the field and to the way students acquire a deep understanding of robotics concepts [7], [8]. Education research shows that concrete experience helps students transfer learning to new contexts and makes their knowledge more "flexible" [9], [10]. According to Karinne, "It has to be a balance between the theory that they see and the practice they need to do." This tenet has always been true in traditional in-person classrooms (it is why many robotics courses have physical labs associated with them) and remains true in our new teaching climate—with a variety of environments, from fully in-person to fully remote to a hybrid model in between.

Karinne Ramirez-Amaro, Chalmers University of Technology, Sweden.

Shawna Thomas, moderator, Texas A&M University, USA. Thomas is the author of this column.

Carlotta, who has taught courses ranging from mobile robotics to human robot interaction to electrical design, finds that there is no substitute for "tinkering and hacking and making mistakes with wiring things wrong and seeing things smoke. So, no matter how it is, get their hands on something, even if it's just to see a motor spin." This can be more challenging in virtual learning environments but is well worth the effort.

How can robotics educators facilitate these types of experiences for their students, especially in remote and hybrid classrooms? Carlotta ships low-cost kits to students' homes and has students ship them back in a self-addressed envelope at the end of the course. Cecilia, a pioneer in soft robotics research and a long-time educator, points out that, compared to teaching even a decade ago, there are many cost-effective robotics kits available: "My suggestion is to definitely invest in this part of the course and try the many robotics kits that are available today. They're very, very helpful."

In hybrid learning environments, where some students are in-person and some are remote, panelists have used a buddy system to get students to work with equipment. In this model, students work in teams to complete lab assignments and projects, with one part of the team physically in the lab handling the equipment and the other part participating virtually. Katie, who teaches both introductory robotics courses and special topics graduate courses, finds this model to work well for her. "Students who are signed up for the remote labs—they're doing the simulation," she notes. "They buddy up with someone who actually comes into the lab and works with the robot." They can transport what they developed in their simulation to the real world and still get that experience by working with others. "This sort of buddy system helps ground and engage the students."

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Karinne has also piloted a web-based solution for students to smooth out issues with different hardware platforms, configuration settings, and computing resources: "We keep finding out that everything is perfectly installed in the lab, but now that they have to do it at home, then we have to be creative." She has her students log into a web computer connected to the physical lab equipment. "Students don't need to even install anything; everything is already there," she says; they can actually control the real robot in the lab from the web computer. "I think that's a good solution

in this perspective, when we cannot guarantee that every student has the same hardware."

Ignite Students' Passions by Allowing Them to Explore on Their Own

One of the best ways to engage students is to give them learning experiences they can take ownership in, tapping into their intrinsic motivation [11]–[14]. Cecilia captures students' interest by first showing them some phenomena she wants them to understand later. "I challenge them to find the explanation, to propose their own idea, their own view, even with some fast search on the Internet," she explains. "If you engage them in forming their own idea, and then, after that, you discuss and compare, and you finally give the correct explanation and answer, I think that this is more effective in educational terms because of their engagement." She even finds this compelling in remote learning: "Even with remote teaching, such an engagement can help them stay focused and listen more and learn more." The power of such active learning techniques to facilitate learning has long been supported by a large body of work in education research [13]–[18].

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Carlotta uses weekly readings to spark interest in her students. "Every week, I have them read a paper on some topic that's state of the art," she says. "They are undergrad, so I try to pick some of the lower level ones related to what I'm teaching them." She also uses this as a recruitment tool: "By the end of the quarter, I can kind of see who comes to me after class and says, 'Hey, that paper was kind of cool,' and I say 'Ooh, I need you to do some research with me next quarter.' That's how I find my students: by seeing the ones who go above and beyond the assignments I give them and want to continue to engage with the topic."

Katie uses free-form projects in her robotics classes so students can really customize and take ownership of their learning. With free-form robotics projects, there is always an element of uncertainty, especially when creating something innovative. This can be a source of stress for students, particularly undergraduates. Katie tackles this challenge by giving students a pathway to success, even if their robot is not successful: "If they can tell me why it fails and really dive into the challenges and explore those, they will get equal credit for talking about how their robot failed or how their robot completed the task. I think having some expectations that basically are not just about success but about the exploration and having really thorough rubrics … decreases some of that stress." This has the added benefit of supporting learning through self-explanation [19]–[21].

Engage Students' Voices Early and Often

Research and experience show that giving students space to provide feedback on their learning and adjusting their learning experiences based on that feedback significantly improves student agency, engagement, and retention [13], [14]. Now that many classrooms have moved partially or fully online, this is more important than ever. Iolanda suggests to "constantly get student feedback, not wait to the end of the semester to understand their ideas on how the assignments were." This can be a simple poll of the class or having students fill out a short questionnaire that asks which point was the muddiest. "Stop, start, continue" surveys are also effective. They ask three simple, free-response questions:

- What should the instructor stop doing?
- What should the instructor start doing?
- What should the instructor continue doing?

Keeping feedback anonymous gives students a safe space to respond. Acting on that feedback communicates to students that they have a voice that is heard.

Building a safe community allows instructors to experiment with new techniques in a lower-risk environment. Many were thrust into new types of classrooms and learning environments amid the pandemic, which required trying out new approaches to teach students. Instructors who pointed out to their students that they were going to try something new found that students are very forgiving and appreciate the effort made. Successful roboticists know how to "fail forward." Robotics educators have an opportunity to model that for students by explicitly telling them when they are trying something new and why. Karinne explains, "I try to get feedback, and I always inform students, 'Today I will try something different. Let's see how this works.'" It is that same attitude that our community wants to instill to empower each student for success in robotics.

Looking to the Future of Robotics Education

All of the panelists agree that the future of robotics education holds more opportunities than challenges. New hardware kits and software simulation tools are now available, and even the rapid shift in learning environments during the pandemic has launched new teaching tools and approaches in robotics. "The current situations forced us to get out of our comfort zone," notes Karinne, "and that allowed us to also learn new things, and these improve, somehow, our teaching in robotics because we have to now be creative." Many techniques can carry over to "normal" teaching again. She continues, "Once we are back, and, hopefully, everything is resolved in the near, near future, I think we are going to learn from that, and we are going to start doing flipping of the classroom: more active learning and all these buddy systems in the lab."

Robotics has the wonderful problem of rapid growth in popularity as it is becoming more accessible to students at different institutions and from more diverse backgrounds. One of the

challenges, as voiced by Iolanda, is "How do we keep the content personalized and engaging, and we can really address students, when we have 400 students in the class?" Scaling to a broad student audience poses a challenge but also presents an opportunity to innovate in the way we educate—both in robotics and in general. While we don't yet have answers to all of these questions, we are on the path to find them. It is certainly an exciting time for robotics education.

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Deadline for RAS Local Chapter Initiative Grants

The RAS Member Activities Board (MAB) awards a limited number of Chapter Initiative Grants to local RAS Chapters for professional development, educational outreach, and other programs. Grant proposals will be reviewed by the MAB at its meeting in late May 2021 and funds up to US$2,000 will be awarded on a competitive basis. The deadline for proposals is 15 April 2021. For submission details, please visit: https://www.ieee-ras.org/chapters/support-for-chapters.

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