Robotics Education for All Ages

Maja J Matarić
Computer Science Department
Center for Robotics and Embedded Systems (cres.usc.edu)
University of Southern California
Los Angeles, CA 90089-0781, USA
mataric@usc.edu, http://robotics.usc.edu/∼maja

Robotics is a growing field that has the potential to significantly impact the nature of engineering and science education at all levels, from K-12 to graduate school. In this paper I briefly survey my experiences, as a robotics researcher and educator, of teaching robotics and using robotics as an educational tool at all those age levels.

Since 1995, I have been developing and teaching robotics courses at the university level, and in the last two years, I have also been engaged in bringing the robotics curriculum to the K-12 audience, including both students and teachers. My experiences are based on the process of designing and implementing a lab-based hands-on undergraduate Introduction to Robotics course, several graduate seminar robotics course with a hands-on robotics projects, writing a (truly) introductory textbook on robotics, and working with K-12 teachers to bring a robotics curriculum to their students. Next I briefly summarize some of the key highlights of these activities, focusing on what may be the most valuable general lessons.

Teaching introductory robotics at the undergraduate level

Robotics is a naturally compelling subject for engineering and computer science undergraduates, but never more so then when coupled with hands-on lab work. I designed an undergraduate Introduction to Robotics course that consists of a regular lecture (3 hours per week) and a lab (another 3 hours per week). Details about the course and the lab can be found at http://www-scf.usc.edu/ csci445. Each portion of this course presented its own challenges. The lecture immediately posed the need for a truly introductory textbook, one that covers robotics at breadth and without a particular bias. I found that such a textbook is lacking, while there are several excellent options for secondary texts (e.g., AI Robotics by Robin Murphy, Behavior-Based Robotics by Ron Arkin, etc.). After putting together detailed course notes and refining them over four years, I was finally talked into writing such an introductory text. The book, whose working title is "The Robotics Primer: A Gentle Introduction to the Art, Science, and Engineering of Robotics," will be published by MIT Press in 2004. The book is written in informal style and covers the broad range of robotics topics, including: what is a robot, where do robots come from, sensors, effectors, actuators, manipulation, locomotion, navigation, control architectures, representation, behavior coordination, emergent behavior, robot learning, team & swarm robotics, humanoid robots, robotics today, and emerging directions. I am willing to share components of the book and I welcome feedback, especially while it is still in press and can be improved.

The lab portion of my undergraduate course is based on the well-known MIT 6.270 model, and uses the same LEGO kits and Handey boards (distributed by Pitsco and Gleason). I designed the course just as LEGO Mindstorms was emerging as a product, and I elected not to use that platform as it provided too little I/O capability. Robotics is fundamentally about coupling sensing and action, and Mindstorms processors could not take in much external input from sensors. Furthermore, Handey boards are more capable and general, allowing more advanced computation, which is appropriate at the university level. (At the K-12 level Mindstorms would be fine and they are in fact what I am using for those curricula, as described in more detail below.) While designing the course I was also in touch with Fred Martin, who was working on his LEGO-based book, "Robotic Explorations; A Hands-On Introduction to Engineering", for which I provided a brief entry on control architectures. I chose that book as the text for the LEGO-kit lab. It is an excellent resource for high-school students and above who are learning about simple robotics (mostly robot building and simple control, not any AI-level work). The lab is structured based on weekly exercises involving the concepts learned in class and extended in the lab. The lecture and lab texts are used in a complementary fashion; the former provides a broad coverage of robotics topics, while the latter focuses on a few lower-level areas and puts them in the context of LEGO robots. The course syllabus clearly outlines which sections of each book are read for which lecture and lab.

Lab work is structured in teams of two students, to foster collaboration and ease some of the challenges and frustrations inherent to working with physical hardware. The semester culminates in a public contest with some appropriately challenging but doable theme (for example finding and hoarding as many objects/pucks/balls as possible, etc.). The contests provide a wonderful opportunity for the students, who spend unlimited hours on their robots, and bring friends to show off. To spread the benefit, we hold the contest in public venues, such as the local science museum, so more kids, in particular those in the K-12 age group, can see the process and get involved in related activities in their schools or elsewhere. This course received a teaching award at USC, as no doubt most hands-on robotics courses do. The award also included a small grant, which helped to provide funds toward the development of a comprehensive web site, which includes links to general robotics Web resources and pointers to current relevant articles in the popular press. However, implementing the lab portion of the course involved raising about $10,000 (twice, as the class grew) from the Dean of the USC School of Engineering. I found USC administration to be helpful in this process, but it is still a challenge requiring a great deal of initiative on the part of the designer of the course. Furthermore, the lab requires dedicated space for robot development, testing, and storage, another resource that is often scarce at universities and may require political finagling to obtain. Fortunately, the course and the associated contest provide true inspiration for students, while serving as good retention and showcase tools for the university, and a forward-looking administration should recognize this and nurture it.

Teaching robotics at the K-12 level

Given the testing-based mandate imposed on today's K-12 educators, robotics will need to be used not (only) as a topic in itself, but primarily to help K-12 teachers to convey the key concepts from math and science (on which the students will be tested and test scores used to determine the the schools' future funding). Working with K-12 teachers is not simple, as they are overworked, generally have few resources at their disposal (except for the very few working for wealthy private schools), and have a broad range of educational backgrounds. An excellent avenue for pursuing an interaction with K-12 teachers is the NSF Research Experience for Teachers (RET) Program, which allows *every* NSF-funded PI to submit a simple 5-page FastLane proposal describing how a K-12 teacher would spend some time with the PI learning about current research, and can in return get up to $10,000 per teacher and work with up to 2 teachers per grant. I am currently working with two LA middle school teachers to develop a hands-on lab-based robotics curriculum for their students. They are learning about some of our research, but we all care most about setting up their robotics classes, so they can impact many future generations of K-12 students (instead of learning about some high-level and more esoteric research topic). The teachers are using my textbook for their teacher training, but will have to develop lessons and materials on their own.

In general, and to a great frustration of the underpaid and overworked K-12 teachers, there is a dearth of age-appropriate robotics teaching materials for the K-12 age group, even more so than for the university level. Some such materials are available for purchase, but they are typically limited, narrow in scope, and largely consist of pointers to web pages, instead of topics and lesson plans that teachers desperately need. Such materials will likely be developed in various schools and by various teachers, and we as a community should foster this process (and not only focus on the university level), by making the results publicly available on the Web. We plan to put all lessons and materials we develop as part of our NSF RET-funded project on the Web by the end of Summer 2004, in order to help others in the process integrating robotics into K-12 education. While publishing these results in conferences, magazines, and journals may be helpful to our careers as academicians, it completely fails to reach the K-12 teacher audience, since these teachers have no time or access to those publications. They do, however, have access to the Web, and are typically very Web-savvy (since they quickly learn to be savvy about free resources, given how little they have at their disposal).

I urge NSF-funded PIs to take the time to apply to the NSF RET program. NSF program directors are very receptive to these proposals (and if sluggish, the person worth contacting is Dr. Mary Poats of the Engineering Directorate at NSF), and the money, while small for research purposes, is astonishingly large for K-12 teachers, many of whose schools have annual budgets on the same order. Thus, we can really make a difference at the K-12 level, and should do so. By introducing robotics at this younger age group, we will have better prepared students in our undergraduate and graduate courses, and make more research progress in the long run as well. More importantly, given how appealing robotics is as a pedagogical tool, we will succeed in recruiting more students into engineering and science, in particular from the otherwise underrepresented groups (e.g., women and minorities). These are worthy goals.

Teaching lab-based robotics at the graduate level

While lecture courses at the graduate level serve an important educational purpose, my experience is that seminar courses focused on reading original papers from the field and implementing a focused major project are very popular with graduate students. This framework allows the students the freedom to choose a topic they are most interested in within the scope of the course, and to apply themselves with dedication (even without a contest to drive them). To facilitate hands-on learning, I leverage research robot platforms for their use. Most recently, I have begun using Evolution Robotics SDK robots, with significant success, in large part because these are equipped with sophisticated off-the-shelf vision capabilities that students have not had a chance to experience before. I am also using ActivMedia Pioneer robots and requiring the students to implement and test their algorithms on Player/Stage (http://playerstage.sourceforge.net), a high-fidelity simulator and device driver, which allows for code to be ported directly from simulation to Player-compatible devices without much if any tuning. Only once the simulations work properly do the students move on to the physical robot platforms. At the graduate level, the textbook issue is no longer acute, as there are plenty of texts and original papers that can be used. This is really the level where we as educators have perhaps the easiest time, having to do the least after the reading list is set up. The students, once allowed to make informed choices, and implement and discuss them, are truly in their element and thrive on the process.

In summary, robotics is an excellent tool for teaching science and engineering, and it is a compelling topic for students of all ages. However, the art, science, and pedagogy of teaching hands-on robotics is still in its infancy, and we are all pioneers in this field. This workshop provides an opportunity to share our experiences and expertise. I urge the participants to consider robotics education as a broader goal, not just limited to the university level, in order to set the stage and establish a pipeline for a truly technology-savvy future for our kids, undergraduates, and graduate students.