Some thoughts on robotics for education

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Abstract

In this paper we formulate some thoughts about use of robotics in education, in particular at college and university level. We argue that, although robotics is used in many universities and courses, its advantages are not necessarily as obvious as we would like to believe. There is an apparent need for analysis that would provide more convincing data supporting use of robotics for educational purposes.

Introduction

Since late 1980s, beginning with the famous 6.270 course at MIT, robotics is used in education in many forms, at many levels and with many purposes. These proceedings are a good example of variety of educational contexts that the robots might be useful in. Although the majority of documented courses using robotics in an instrumental way while teaching other topics are at the college and university level, robots have been used at the K-12 level education as well. Most of the activities at this level are a form of outreach program, aimed at raising interest in higher engineering education among selected group of (usually high-school) students, but there are also activities aimed at students from socially deprived areas, where the main objective is to attract those students to some form of education at all.

Although usually the experiences from this form of education are very positive, if not enthusiastic, it is sometimes very hard to pin-point the actual benefit of using robotics in particular curriculum. There are many reasons for such fuzziness of opinions. In this paper we will try to look at some of them by formulating them more clearly and suggesting further studies that would hopefully resolve at least some of the open questions related to how should one use robotics in order to achieve particular educational needs.

The paper is divided as follows. In the first section we state our concerns about how use of robotics is motivated. Then in the next section we provide a short overview of the kinds of courses that more or less successfully employ robotics as an educational medium. After that we state further questions regarding the actual benefits of using robotics. The following section presents our experiences in robotics-based higher education, with some brief comments about the courses described. The paper ends with short conclusions.

The typical motivation

Robotics is used in education in a variety of ways and for a multitude of purposes. However, one can probably classify the way such use is motivated into one of the following two (fortunately overlapping to a large extent) classes:

1. "Robotics *in* education": Robotics, besides being engineering and science, is fun. Let us convince our students that indeed it is so and, besides that, teach them something useful.
2. "Robotics *for* education": Robotics is useful in the educational process. Let us teach whatever we have to (or like to), but using robotics as one of the educational tools.

Please note that the first type of motivation, although quite common in personal communications, occurs very seldom in written form. But its importance shouldn't be underestimated.

The first statements is hardly debatable, especially if one is a roboticist. But "fun" is not a sufficient motivation for including a topic in a curriculum. Our sponsors (usually college or university authorities) need more arguments for accepting a new course as useful from the educational point of view. Therefore we usually rephrase it in the second form, independently on the actual motivation.

However, the second claim needs justification. There is little doubt that playing with robots is fun. It is very common that students get enthusiastic about robot-based courses. But proving that robots are useful in a particular educational context is much harder than that. What we need is hard data that can be used to support the thesis that a particular course, with a given educational goal, indeed benefits from using our favorite approach.

How are robots used?

In this section we would like to provide an overview of how robots are used in college-level education. The list below is not intended to be complete, but should rather be treated as an inventory of typical uses. This technical report contains many more examples from each of the categories and some other as well.

- **Design** (considered to be the major engineering activity). Many courses, including the 6.270, allow the students to gather hands-on experience of the design work. There is vast literature on this topic, beginning with Martin's PhD thesis (Martin 1994), and describing design (in particular engineering design) at various level of detail, see e.g. (Beer, Chiel, & Drushel 1999). I do not think there are any doubts about the utility of robotics in such course.
- **Teamwork** (considered as the major engineering capability). As in the case of design above, there is no controversy about using robotics projects for enhancing the students' teamwork capabilities.
- An introductory course in **Electrical Engineering** (Computer Science, Control). Here the students use robots as yet another kind of artifact exemplifying the ideas they learn during the course. Here building a robot is not the goal of a project, but may be a medium for learning basics of circuit theory, introduction to control, basing programming concepts, etc. Usually the students are very glad of being able to use "real robots" instead of watching yet another simulation on the computer screen. Some statements though about such courses, made during the Workshop, were the following:

  > The coolest thing is that the students get something done.

  and

  > I am sure they got a lot out of it. I am not sure what, though.

  Apparently there is some problem with such courses. How do we assess whether and what do the students learn by using robots? Are robots really better medium than the tools we were using previously? Had the students learned what we really wanted to teach them? Taking slightly another perspective we might discuss what are the appropriate examination forms for such courses? The example taken from one of the presentations at the Workshop ((Hobson 2001), by no means meant to criticize this particular case, but just to illustrate the point): In order to build some particular circuit used later on the robot the students need to use the Ohm's law.

  1. Do the students really know the Ohm's law after the experiments?
  2. Do they *understand* the Ohm's law (with all its ramifications)?
  3. What do they learn more about the circuit theory besides the Ohm's law?
  4. What do they learn that they wouldn't have learnt without the hands-on robot experience?

  The first three questions might be answered rather easily by subjecting the students to standard examination procedures. The fourth question, however, would require extensive statistical data gathered throughout many years of experience with such course given in two versions: robot-based and non-robot-based, in order to produce a justified answer. Even then, one may ask whether we indeed test all the options that might be tested?

  My main point here is that although we are enthusiastic about using robots, we cannot be sure that this approach is actually better that some other one. Therefore, until we get more sound evidence, we should be careful with advocating our solution as a panaceum for all educational problems.
- Introductory courses in **programming** (and other introductory Computer Science courses). Are the robots necessary to enhance students' understanding of the issues involved? (Definitely not.) Are they useful for this purpose? (Maybe.) Is robotics just a fashion tool that might be replaced by other controllable physical device? (This would be my guess.)

  My conclusion in this case would be that robotics might be used, but we shouldn't overestimate its power, both illustrative and attractive. As in the previous case, without proper data one cannot draw any strong conclusions.
- Advanced CS courses related to **Artificial Intelligence**. Robots seem to be in this case an ideal tool to illustrate the concepts and how they may be used in practice. They also are a very good tool to introduce the complexity and unpredictability of the physical world to students, a property often forgotten within more theoretical paths through Computer Science education. (I often get the comment "This was the most useful course I have taken throughout my studies." However, this comment often comes /when I can pinpoint the author - usually the course evaluation is anonymous/ from a science student, not necessarily computer science, but usually not engineering, realizing for the first time during his education that the abstractions he is using are just abstractions and do not correspond one-to-one to the real world problems.)

Some further questions

There is a number of issues requiring further discussion. Most, if not all of them, have already been raised during the Workshop:

- Should the courses using robotics be contest-based or not? Originally, the majority of the courses were graded partially on the basis of a final contest (usually a participation in the contest sufficed to get a pass). Some examples quoted in literature (Beer, Chiel, & Drushel 1999; Murphy 2000) advocate contests as means for motivating the students to harder work. This strategy succeeds, but the students not necessarily work hardest on topics we would like them to work with: the pressure to get their contest entry to score best makes them neglect other, more relevant questions. This problem has been observed even more drastically in the RoboCup simulation context (Kummeneje 2001), where following up the students' progress is less easy than in case of physical robots. Definitely, leading students through such projects requires knowledge and much work from the educator's side.

  There have been many voices raised during the Workshop, stating that a final exhibition at the end of a course is a better solution than a contest. In some cases (Turbak & Berg 2001) this has been verified in practice. However, the motivational value of a contest should not be underestimated.

Probably this issue might also be affected by the kind of students taking the course: are they engineering, science, or maybe art students? What is the proportion of females in the class? What is their purpose of taking the course?

- Another issue that has to be solved with care is grading. If the course ends with a contest, should the grading be based on contest results? Such an approach would probably be unjust but, on the other hand, not taking the results of a contest into account is unjust as well, or at least is perceived so by some course participants! This is usually solved by appropriate weighing of many factors, like daily/weekly reporting, design, possibly exams, deadline maintenance, etc. However, this might be a very complicated issue for the teacher.
- How do we guarantee that the students learn what we want them to learn? This is usually achieved in a number of ways.
  - Tests and homeworks focusing on the important topics.
  - Appropriate construction of tasks and problems to solve. The main issue here is to stress that the problem to solve just illustrates the principles and is not the goal in itself. Otherwise there is a risk that the students loose the proper perspective.
  - Assessment of the course contents: The balance between theory and practice must be appropriately chosen. The contest-based courses tend to focus on practice and often loose the necessary theoretical background. Usually this loss is involuntary, but the educator should be aware of such danger. Even if we present the necessary theory in advance, it is seldom used to a larger extent. On the other hand, what can we do or expect more? We are giving a course in order to present the students with some piece of knowledge and to demonstrate how it may be used in practice.
- What robotic platform to use? Probably there is no universal answer to this question, as different courses have different needs that might be best met by different technologies. LEGO Mindstorms is very popular and useful tool, but probably not for engineering majors. LEGO robots with custom control board like Handy Board (Martin 1999) or the new one being currently developed at MIT (Bajracharya & Olsson 2001) provide a more sophisticated alternative from programming point of view while retaining the attractive price tag. Some other robots like Pioneer or Khepera may be considered a viable option if price of the equipment is not of primary importance. But it usually is.
- As educators we should be aware of issues that we are usually not taught about. Some of the robotics-based courses have as their explicit aim the intention to attract more women to engineering or science. First of all, there have been many reports during the Workshop stating that this aim has not been achieved in any substantial way. Again, in order to be able to be conclusive, one would need to do research on this topic. A good example of such research is presented in (Fossum *et al.* 2001). However, these studies that exist usually address outreach programs and do not analyze higher educational levels like college or university courses.

  Personally, I have not realized until the Workshop that even the language we use while formulating course descriptions and other related documents, play role in attracting or repelling some students to/from the course and that this difference might be to some extent gender-based. Of course, this is a sign of my ignorance. But I want to present it here as an example of issues that one does not necessarily think of while preparing a new course. Possibly a good guide written by a pedagogical expert would be of great help to all of us ignorant in those matters.
- Finally, I would like to point to the fact that the robotics-based courses are much more resource demanding than the usual ones. A good description of the typical problems has been given in (Congdon 2001). These courses require more financial support, more space, usually more assistants and, last but not least, more work from our side. In most cases this work is not properly acknowledged by our employers, colleges and universities, therefore leaving just satisfaction as the major reward. But in order to draw attention of our sponsors to this problem and to convince them that some extra measures are appropriate we need convincing data that this type of education is indeed beneficial.

Our experience

The courses I have given using robots (real and simulated) are the following:

- **How to build and control your own mobile robot**

  A summer course, given twice (1996 and 1997); discontinued due to financial cuts. Undergraduate, aimed at a broad spectrum of students. Very similar in spirit to the MIT 6.270 course (from which the idea has been taken). LEGO + 6.270 board-based (in the second year the Handy board was used). Intended to pass the introductory knowledge in robotics, reactive systems, design methodology, cooperative project work. Some video documentation of the course exists.
- **Situated robotics**

  A graduate course, given once (1996), aimed at computer science students. Focused on reactive, embedded systems and on discrepancy between symbolic models and reality as perceived by the sensors. LEGO + Handy board-based. No remaining documentation.
- **Artificial Intelligence Programming**

  An undergraduate course, given (in its current form since 1998) until today (see `http://www.ida.liu.se/~TDDA14`). Based on RoboCup, simulation league. Intended for Computer Science students that have completed Introduction to AI. Its main goal is to illustrate AI in practice and stress the necessity of balance between reactivity and deliberation. A preliminary analysis of the first year of this course may be found in the paper (Coradeschi & Malec 1998).

- **Multi-agent systems: RoboCup**

  An undergraduate course, given for Computer Science and Computer Engineering students that have completed Introduction to AI. It focuses mostly on the notion of agency and multi-agent systems, in particular agent coordination, and cooperation. Based on RoboCup, the simulation league. Documented.

- **AI for robots**

  A course first given in November-December 2000. Intended for Computer Science students that have completed Introduction to AI. Its main goal is to illustrate AI in practice and stress the necessity of balance between reactivity and deliberation. However, a substantial part is devoted to multi-agent systems and agent cooperation. The course is based on experiments with Khepera robots. The course homepage may be found at `http://www.cs.lth.se/~jacek/dat125/`.

My experiences, as shown above, are mostly with Computer Science students, either at undergraduate or graduate level. The main aim of most of my courses was to teach applications of AI. The robots (either real or simulated) proved to be a very good tool for that purpose. However, they may be exploited in many more contexts and for other educational purposes. E.g. one of my students has experimented with LEGO robots used for teaching "technology" classes in some secondary schools in Sweden. Unfortunately, his sample was too small to draw any scientifically valid conclusions.

Conclusions

The question I am looking an answer for is whether and how can we capture what do the students learn during courses incorporating some form of robotics. Although most of the courses get enthusiastic evaluations, it's often hard to say whether all the knowledge defined in the curriculum has been assimilated by the participants. Is this a wrong way of thinking about the problem? Maybe we should change curricula instead?

Another important issue that should, in my opinion, draw more attention, is some form of certification or assessment that can guarantee our employers and our students that a course we give fulfills its promises. One can either do it locally, at a university level (the standard procedure, probably specific to each educational institution), or refer to some external organization, like ABET (American Board of Engineering and Technology) mentioned during the Workshop, in order to obtain such certification. This way we may guarantee that the contents of our courses meet the demands of good academic education.

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