Robotics: a pedagogical tool in the field of computing

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Abstract: this article discusses the use of robotics as a means to increase motivation, creativity and interdisciplinary thinking. In order to exercise these skills in this particular context, the students must apply precise concepts from different subjects and, at the same time, must have the maximum freedom to explore alternative solutions to each assignment. These contrasting objectives must be balanced to guide the class through a series of feasible tasks, making the planning of a laboratory of robotics to be a non trivial task. We focus on computer science courses, but the approach can be extended to other areas. One of the objectives of the present research is to define and document a series of activities and assignments, forming the backbone of a practical approach. We analyse the main aspects of the methodology and report the preliminary results of its application.

Keywords: robotics, computer architecture, creativity, motivation, interdisciplinary approach.

1. Introduction

Contemporary professional education faces the challenge of preparing students for a new, multicultural reality. Interdisciplinary abilities and technological knowledge are key qualities required by the industry. In this context, there is a need for educational methodologies that enable the development of complex thinking and that put into context the acquired knowledge.

Unfortunately, the fragmented organization of curricula does not correspond to these expectations. It is a known fact that the classic, compartmentalized nature of curricula in university respond to administrative needs, but is not adequate to reveal the interwoven character of subjects studied. While there are attempts to solve the roots of the problem, there are no signs that the situation will be modified in the near future. As a consequence, teachers must explore alternatives to circumvent these difficulties. In the case of computer science and system
analysis courses, robotic present characteristics that can make it a viable solution to increase interest on the subjects considered as abstract and difficult: computer architecture, electronics and logic of programming.

Robotics is a rich subject taught in engineering courses, involving contents from several areas like Mechanics, Physics, Electronics and Computing. Certain aspects like dynamics and nonlinear control can make Robotics a daunting subject. Nonetheless, by avoiding complex issues it is still possible to take full advantage of its interdisciplinary character, in order to bring to the class situations that bridge different contents. This can be done with the help of practical activities that lead to the creation of actual mechanisms by the students. The experimentation opens the way for a creative and motivating environment, also with a positive impact on the assimilation. Overall, the introduction of this type of activity can provide a rewarding experience to the class.

Despite all the potential advantages, the use of robotic in classes is quite limited. Besides the cost of equipment, an important factor is the lack of training of teachers. Much of them do not feel confident to adopt these tools.

The article describes an attempt to fill this gap, by means of the creation of a minimal laboratory of robotics and the description of activities performed with the class. The activities are organized with a ludic focus and anchored on pedagogic principles. The purpose of the laboratory is to show the students immediate relations between different contents, as well as their practical application in an unusual, yet significant way. The subjects covered are part of the curriculum of a Computer Technology degree.

2. Literature review

The pedagogic roots to the use of robotic at school may be traced back to two teaching-learning theories: the constructivism, whose main proponent is Jean Piaget; and the constructionism, developed by Seymour Papert upon principles laid by Piaget's work.

2.1 A brief overview of learning theories

The foundations of the development of the constructivist theory can be found in the investigation of knowledge acquisition, with a focus on children behavior. According to constructivism, knowledge is not simply transmitted, but constructed in a process that requires the active participation of the learner. The acquisition of knowledge occurs through the creation of mental models, which are the result of combining previous information with new ones. Acting upon reality is the primary mechanism for children to learn. New information can also be obtained in a
cognitive manner, by analysing, comparing and combining previous available information (Ben-Ari, 1998).

Another important facet of the theory is the framework describing how children assimilate formal operations. According to constructivism, this process follows a series of stages increasingly sophisticated, accompanied by the growing ability to apply formal thought to real problems (Piaget, 1999). This establishes a strict temporal sequence and also a parallel between intellectual and corporal development. Abilities like the use of symbols, making classifications and recognizing relations begin to be acquired at early ages and remain essential through all academic life. Difficulties with abstract contents, logical thinking and planning are indeed recurrent among computer science students (Mow 2008). There is some evidence that these signs of incomplete developmental level may be somewhat generalized (Kuhn et al, 1977).

Seymour Papert, mathematician and psychologist at the MIT (Massachusetts Institute of Technology) founded his work on the grounds of Piaget’s theory. Papert created the neologism ‘constructionism’ to distinguish his view on the subject. The difference between the approaches is significative, yet subtle; it can be summarized by this extract:

“Constructionism – the N word as opposed to the V word – shares constructivism’s view of learning as “building knowledge structures”through progressive internalization of actions... It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it’s a sand castle on the beach or a theory of the universe” (Papert, 1991).

Papert valued experimentation and the discovery of facts by students that are engaged in the activity. While motivation can be cited as an obvious requirement for learning, Papert did a brilliant job on discussing this issue and on showing ways to create conditions for it to occur in class. His ideas and solutions for this problem avoid ordinary persuasion methods and strive to create an authentic exploration environment, which motivates children to build things, test hypothesis and learn on their own. Indeed, his research of using robots with those purposes date back to late 1960’s (Martin et al., 2000).

### 2.2 The place of robotics in education

A fundamental prerequisite to assimilate a subject is to stay focused. During classes and oral expositions, students tend to be less attentive over time and finish retaining less information. Teachers can use several methods to deal with the problem; Felder (1999) proposed to substitute the traditional lectures where students passively listen to the teacher, with what he called active learning. According to this view, students must be engaged in activities that require higher-order thinking skills. Some examples are:

- requiring the students to take notes and present their comments;
• involving the class in discussions;
• constantly proposing problems to be solved by groups.

A laboratory provides a natural environment for active learning; students are pleased with the autonomy to use equipment and materials and are more willing to participate. Moreover, they feel rewarded by seeing the functioning of their own projects. Robots can be used as a pretext to create this atmosphere and involve the students in the activity. Howell et al (2006) give an excellent example:

“...we are not using the lab to teach students about robots, per se, but rather to develop lab modules that will use the excitement and interaction with the robots to reinforce other concepts, especially key concepts in bioengineering...”

The same concept appears in the use of the LOGO language by Papert (Frangou et. al 2008). The software provides a micro-world where children are free to explore geometrical constructions and programming logic. The research conducted by Papert and Mitchel Resnick in the MIT Media Lab lead to the creation of Lego Mindstorms, a robotic kit with educational purposes (Martin et al, 2000, Beland, 2000).

Experiences with educational applications of robots have been conducted in various situations, from primary education up to university (Cardoso 2005; Istenes and Pásztor 2007a). Besides acting upon motivation, robotics has also an impact on creativity, cooperation and communication among students. These aspects have been assessed and positive results were found (Nagchaudhuri et al. 2002).

While Lego is certainly a significant reference on the subject, many other pedagogical alternatives have been developed. There are innumerable off-the-shelf products as well as specially designed robots. Howell et al (2006) proposes a solution aiming communication capabilities. Medeiros Filho and Gonçalves (2008) describe a robot assembled with spare parts, costing US$ 25 and featuring a microcontroller and light sensors. A similar approach is described by Takahashi et al. (2007) to train teachers.

Despite the interest that robots can raise, a negative aspect may also be present in class: students may be afraid of the possible complexity of the tasks. Anderson et al. (2007) suggest a series of assignments that conduct the class through tasks of increasing difficulty, trying to palliate the problem. Alimisis et al. (2007) study specific teaching methodologies; preliminary results were reported by Papanikolaou et. al. (2008).

Hsin et al (2007) describe the use of Lego Mindstorms in a computer architecture course. The students could see concepts in practice and also learnt assembly programming, a subject originally not present in their curriculum. Teixeira (2006) describe the use of robotics to present and exemplify Physics concepts and also computer programming. A similar approach is described by Yang et al. (2007), joining digital logic, assembly, computer architecture and robotics. The use of robotics to motivate the study of the programming language C is presented by Istenes and Pásztor (2007b). Van Lent (2004) discusses the use of a robotic lab in the first semester of a computer science degree.
3. A proposal for robotic in Information Science

The present study is being carried out with 25 students of the undergraduate degree of Informatics at FATEB, Faculdade de Telêmaco Borba, Brazil. The research aims to organize and document a series of activities involving robotics, allowing other teachers to use the material as a reference on their own courses. The specific objectives of the project are:

- identify opportunities for activities and assignments with an interdisciplinary character;
- analyse issues concerning prerequisites, motivation and other difficulties of the students;
- define a series of activities that will form the backbone of the course.

In the current phase of the research, a one-semester laboratory of robotics is proposed in parallel with disciplines of the regular curriculum, in order to evaluate the strengths and weakness of the proposed programme. The results of this experience will direct the proposal of a computer architecture syllabus, merging the current contents with practical activities involving robotics.

3.1 Account of the laboratory programme

The contents of robotic in the course were roughly scheduled according to steps that are now described.

The subject of robotics started with a presentation covering a brief historical view, significant examples of contemporary applications and relations with several professions. The class was randomly divided into groups that received a research assignment on these subjects. In the sequence, the students participated in oral expositions and debates. Videos showing examples like the NASA robot Spirit sparked the curiosity and strongly motivated the discussions.

The next step consisted of presenting basic material, to allow the students to plan a prototype. It began with a classification of example robots according to their mechanical structure, followed by descriptions and discussions on projects that could be constructed with the available hardware. In our case the Lego Mindstorms NXT was available. It is worth noting that a very low cost alternative consists of using the PC parallel port to drive step motors through power transistors, like the BD135 or the TIP31. Old printers are a source of motors that can be used in projects like simple plotters, cranes and moving robots. The construction of initially simple projects will allow the teacher to reuse them in more complicate designs, in subsequent editions of the course. More advanced features include light sensors, digital logic to replace the compute control and the addition of microcontrollers.

The class also reviewed concepts of kinetics with a Physics teacher. This included calculations of speed and time, in linear and circular motions. Since the
students can see an immediate practical use for this information, there is a better assimilation of the concepts.

In the next step, the students started sketching their own designs, using graphical software. This was done under teacher guidance, to ensure the feasibility of the projects.

The fourth step consisted of the actual assembling and initial testing of a robot. This task was divided in several sub-steps. It began with the identification of mechanical and electronic components, followed by the test of the components, in order to get used to electric measurements. The Physics teacher also accompanied this activity. Once the robot was assembled, it was verified with diagnostic tests. The photos on Figure 1 captured two moments of these activities.

![Figure 1 – photos of the students participating in the assembling of the robots.](image)

The programming of the robots was done in the fifth step, using the LabView graphical programming language. It uses icons to describe logic structures as decisions and loops and input/output commands. The lack of debugging facilities in the LabView tool demanded a careful planning of the algorithms. The value of techniques like stepwise refinement (Wirth, 1971) source code inspection and structured walkthroughs (Yourdon, 1989) become more evident to the students. The possibility of damaging equipment can be gently used to emphasize the importance of quality assurance. This aspect also contributes to keep the students alert and give them a sense of responsibility and satisfaction for successfully accomplishing their tasks.

The next step is the transfer of the software to the robots, using a cable or a wireless network. An overview of computer networks and protocols was presented in order to show how this was physically implemented by the hardware. This task also motivated discussions about security, like the possibility of altering the programming of an industrial robot from a remote location.

In the final step, a survey will be conducted to gather student’s feelings about the experience. All annotations in class, students’ writings and other materials will be analysed in order to organize a new edition of the course.

The Table 1 summarizes the sequence of activities and subjects studied.
Table 1. Summary of initial programme for robotics laboratory.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Possible objectives and contents covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction and Motivation</td>
<td>General introduction and motivation. Examples of application and research assignments.</td>
</tr>
<tr>
<td>Review of subjects</td>
<td>Review of kinetics and electronics. Overview of mechanical structures as joints and components as step motors and microcontrollers. Review of computer interfaces, signals, serial and parallel transmission, CRC.</td>
</tr>
<tr>
<td>Software implementation and revision</td>
<td>Codification. Use of cross inspections and structured walkthroughs between different teams.</td>
</tr>
<tr>
<td>Software upload and testing</td>
<td>Overview of networks and protocols and discussion of security issues. Transfer of the software to the robot. Run the diagnostic tests and quality control checks planned by the teams. Preparation of the corresponding formal reports.</td>
</tr>
<tr>
<td>Survey</td>
<td>Discuss the overall experience with the students.</td>
</tr>
</tbody>
</table>

Most of the activities described in the table require the students to work autonomously. This corresponds to one of the most important objectives of the study, which is to reduce the intervention of the teacher to a minimum. Since the dynamics of laboratory of robotics is quite different from the rest of the disciplines, the students take some time to get used to it. As a result, during its initial stages the course still makes use of expositions and classical lectures, to gradually replace these methods with tasks that the students must execute themselves.
4. Conclusions

Teachers and students in undergraduate courses frequently find themselves locked into a paradox. The university is a rich intellectual and cultural environment, but a significant amount of time is spent in static, tedious lectures. High order thinking, communication, collaboration and abilities as organizing and executing plans are fundamental qualities in the everyday practice of technological professions; nonetheless, they are seldom exercised in class. Many teachers simply do not find the means to explore and encourage the application of these skills, especially in those subjects where a theoretical treatment is the path traditionally followed.

In the case of computer science, robotics can function as a catalyst for the mobilisation of the class. The students feel curious about the subject and tend to be very participative. They are pleased to manipulate the different equipment, carrying on unusual assignments and applying concepts that, generally, remain theoretical and pointless.

The activities in a laboratory of robotics can be organized so that the use of methods and concepts acquire foremost importance. The teacher can use the construction of the robot as a means to review subjects and lead the students to apply their knowledge and skills. Simple electromechanical designs can be used to achieve this objective. For instance, a small assignment like using a computer to accurately control the position of a single motor, can give rise to all activities enumerated in the Section 3.

The implementation of a similar experience does not require expensive investments or even modifications to the curriculum. It is possible to organize the laboratory activities as extra-time assignments and limit the complexity of the tasks to a minimum. This can be useful to evaluate the approach before deciding to adopt it in a more extensive manner and dedicating more resources.

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