Application of an Educational Strategy Based on a Soccer Robotic Platform

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***Abstract*—In this paper we describe the design and implementation of an educational methodology based on a robotic platform used for the small size league (SSL) challenge of the RoboCup initiative. The methodology is based on three main aspects of the learning process, namely classical conditioning, reinforcement learning and cognitive learning. This is achieved through the combination of robotic concepts applied to the soccer problem; a highly interesting topic to the students, together with skill oriented modules. We show practical results achieved after applying this methodology in specific courses in an undergraduate electrical engineering program. Our initial results demonstrate that it is possible to attain significantly better results in terms of learnt concepts and motivation when using our robotic soccer based strategy.**

I. INTRODUCTION

Robotics is nowadays considered as a high impact research topic in academia due to the large amount of projects carried out all around the globe aiming at solving important industrial and social needs. For this reason, it has become of paramount importance not only for the further development of technology but also for a wide variety of aspects in human life, especially in teaching and learning processes. In this field, robotics has become a key aspect for new educational methodologies that include laboratory courses and robotic challenges that encourage the learning of numerous concepts in science and engineering [1].

Under this scenario we propose a new methodology that builds up from a previous work from [2] that aimed at showing the first prototype of a robotic football player specifically designed for educational purposes. This platform has shown to be a suitable tool not only for general entertaining but also for research and education in engineering and science.

This paper focuses on the development of the specific educational subjects covered by the proposed methodology as well as its impact on the students from an electronic engineering program. This process is assessed by showing quantitative measures on the competencies and disciplines developed by the students when exposed to such methodology. The results shown throughout the paper are the result of performing experiments and collecting data from a typical academic term.

The main strengths of the proposed methodology can be summarize as follows: the students achieve a hardware software integrated solution for the proposed challenges, the development and management of distributed systems, cooperative and coordinated systems and the manipulation of the robotic platform among multiple work environments.

This paper is organized as follows: Section II shows works performed by others related to the use of robots for educational purposes, Section III shows a detailed explanation of the development process followed to conceive the educational robotic platform. Afterwards we show the areas of knowledge and developed modules of the proposed methodology and finally Section IV shows quantitative results of applying such methodology to students during a four-month period.

II. RELATED WORK

In this section we briefly show the work carried out by others related to the development of educational robotic platforms and methodologies. We use this to assess and compare the methodology proposed and applied during the development phase of our methodology.

In [3], the authors proposed a methodology based on learning stages where undergraduate students use robots in a mixed reality environment to improve their own skills. The virtual environment allow them to be highly flexible in terms of the challenges that can be proposed. However, their approach is highly oriented to sophisticated control algorithms in the field of robotics.

In [4], the authors proposed the design of a course for teaching science and technology topics for secondary education students. Although our methodology has been designed for an undergraduate level, their methodology and ours share some specific characteristics such as the fact that both promote the use of robotics to teach and reinforce subjects other than robotics. Also, their methodology relies on the cooperation of teachers and students to solve practical problems in what they call workshops.

Similar to our work, in [5] the authors proposed *Robotic Autonomy*, a seven week course taught at the Carnegie Mellon West campus, located within NASA/Ames research Center. Although this is also a high school student initiative, their approach also strives at teaching lessons beyond the scope of robotics. In [6] we appreciate that through the use of robotics as educational tool, it is possible to develop in the students cognitive structural developments. This is achieved by designing exercises to make the students plan, build and

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program their own robots. Other research efforts aligned with this philosophy include the work of [7] in what they call problem-based learning.

These past works show that robotics has played a significant role in education, especially for science and engineering. According to [8], the education in engineering should be in continuous evolution with the aim of improving the social and economical development and furthermore, the sustainable development of our society. In this context, it becomes of high importance the development of novel methods in education capable of developing in the future engineers with strong theoretical and practical skills. Our proposal is aligned with the previous works in the sense that strives at searching for improved results and learning strategies in students of undergraduate engineering programs. This is achieved through the use of platforms that encourage competitiveness in the students and that include practical and methodological developments.

III. Soccer Robotic Platform as a Didactic Learning Methodology

As shown above, robotics has shown to be a suitable tool for undergraduate level education, especially in the fields of engineering and applied sciences. The idea is to use robotic challenges and platforms not only to teach the basic concepts of robotics itself and other important engineering concepts, but also to strengthen the student's background on subjects that are usually identified as difficult and abstract. Important concepts in mathematics, control theory and physics are typically included in this set of disciplines and constitute key aspects of several engineering and science undergraduate programs.

We have identified three main arguments that show the benefit of using robotics to leverage the learning experience of undergraduate students, especially, the one proposed here of soccer player robots, namely:

- We argue that **Classical conditioning** plays an important role in the learning process when using robots and especially, soccer player robots, as we have proposed. The robotic platform itself and its association to the soccer creates on the students an attraction incentive that significantly boosts the learning process of all the elements associated with it.
- The field of robotics has been historically geared by competitions or contests. Usually, these competitions aim at showing and rewarding the best robotic design under a set of rules common to all the participants. In their way to obtain the greatest recognition and awards, the students are capable of achieving outstanding results. This process known as **reinforcement learning** allows students to incorporate new concepts, knowledge and experiences within the process.
- Finally, challenges in robotics usually allow the students to experience a process of **cognitive learning**. During this process, the students learn by solving problems and making important design decisions on a very specific subject. Instead of learning by recalling previously given concepts, the students recall their own experiences. This is similar to a project-based learning.

Fig. 1. SSL-based robotic platform to be used in the proposed educational methodology.

Under this approach, we have proposed an educational methodology based on the small size league (SSL) challenge of the RoboCup initiative. The SSL challenge of RoboCup consists on a domain where a variety of elements such as electronics, mechanics and software design interact with each other to create highly coordinated autonomous robots to achieve the main objective: winning soccer games. The creation of the mechanical structure of the robots, the acquisition of the data by artificial vision and its interpretation, the creation of the software framework, the control of the robot kinematics and the establishment of an appropriate communication between the computer and the robots are some of the key elements that make this league an ideal candidate for our educational framework in engineering and applied science students.

In the following subsections, we briefly discuss the architecture of the educational robotic platform. Then, we show the proposed methodology and its execution sequence on a real course of an undergraduate engineering program. Finally, we relate the execution of such methodology to the areas of knowledge and skills developed by the students in the process.

A. *Architecture of educational robotic platform*

The architecture of the robotic platform employed in this work was based on the characteristics of those at the Small Size League of RoboCup. In overall, it consists on a set of cameras attached to a camera bar located 4m above the field. The data provided by the cameras are used to keep track on all the objects within the field (players and ball). This information is processed by off-field computers that play the role of coaches and communicate wirelessly to all robots the actions that each one should execute.

The physical aspect of each robot is usually defined by the technical specifications of the league in terms of size, speed and shooting features among others. Figure 1 shows the mechanical prototype of the robot.

The main parts of the robotic structure include the locomotion system, holonomic wheels, a motor control module, a chip and a flat kicker and a communication system. Additionally, the SSL challenge include the development of an artificial vision system, an artificial intelligence system and a simulation software. In [2], the authors show an exhaustive description of the main characteristics of a typical SSL robot and all its systems.

B. Modules, skills and knowledge areas

As the key aspect of the educational methodology we have proposed the creation of modules, specifically tailored for the educational task at hand. Each module consists on a set of particular activities that strive to strengthen certain set of **skills**, **competencies** and concepts related to a given area of knowledge. The main objective is that after visiting all the modules, the students should have reinforced basic concepts in areas such as mathematics and physics as well as developed new abilities in other engineering and science fields such as artificial intelligence and control systems.

We have proposed 18 modules overall, each with a specific engineering and/or scientific topic and each based on a specific functional requirement of the SSL challenge. We briefly describe each proposed module:

- **Module 1:** The students learn how to utilize some basic tools required cutting, shaping and folding certain materials used to build the mechanical structure of the robot.
- **Module 2:** The students review some fundamental concepts of electricity and electronics to finally weld components in printed circuit boards.
- **Module 3:** The students review the basic concepts from the field of power electronics (DC motors, servo motors, H bridge, etc) together with the use of actuators and later perform tests with the boards that control the electrical motors.
- **Module 4:** Some types of sensors are studied to facilitate the analysis of the environment perception of a robot.
- **Module 5:** The students initially study concepts from mobile robotics, reactive and deliberative robotic systems, together with their features and working elements. Finally, they implement a reactive platform through the use of exteroceptive sensors.
- **Module 6:** The students study the basic concepts on cooperative robotics and we present a brief explanation of the requirements and dynamics of the Small Size League from RoboCup.
- **Module 7:** The students perform an analysis of the omnidirectional locomotion system and the manufacturing process of the required wheels of these types of systems.
- **Module 8:** We define degrees of freedom regarding the movement of the system. Then, students perform the necessary calculations of the inverse and direct kinematics of the platform.
- **Module 9:** We study the main concepts of mobile and industrial robotics so that students can use these concepts to analyze and propose multiple applications in a variety of fields within industry.
- **Module 10:** The students carry out programming developments in C language, strengthen their knowledge and make themselves aware of possible applications using this tool.
- **Module 11:** The students learn certain types of control systems for electrical motors by developing a digital control for the robotic platforms.
- **Module 12:** We study location and path planning methods for robotic devices together with obstacle avoidance.
- **Module 13:** In this module we study the parabolic motion and the uniformly accelerated movement in the context of robotics platform for the kicker devices within the robots.
- **Module 14:** The students perform calculations of force, hit and velocity of the ball for a pass in a range of distances within the field and also for shots at goal.
- **Module 15:** Lead by the tutors, the students perform the set up and implementation of the systems that form the robots to later perform tests to verify that the platform behaves as expected.
- **Module 16:** We implement a cooperative robotic system for a multi-agent application using the robotic platform..
- **Module 17:** study the basic concepts of programming, focused on image processing.
- **Module 18:** In this module, some concepts from programming and artificial intelligence are reviewed. Then the students are required to write a deliberative program with a basic development of artificial intelligence using the robotic platforms.

The modules were designed to be strongly oriented to cognitive learning experiences. In this way, all modules include challenges that the students are required to solve by making use of the skills provided in other modules and abilities such as creativity and resourcefulness. We have clustered the skills developed within each module into groups of skills and competencies according to its nature in the following way: **a) hand skills:** it is related to dexterity in handling mechanic materials and tools, **basic cognitive competencies:** it is related to the actual knowledge obtained during a lecture or a practice class, **c) higher order competencies:** related to develop structural thinking and decision making processes and **d) soft competencies:** related to social abilities such as leadership and teamwork. Table I relates the competencies and skills developed in each module of the proposed methodology.

In addition to the skills and competencies developed within each module, a specific set of knowledge areas that range from mathematics to artificial intelligence are tackled. We have identified 9 areas for which the proposed methodology enhances the learning processes for specific topics. Below, we show each of these areas and some of the topics that are addressed in typical problems related to the robotic soccer platform.

- Mathematics: Concepts of trigonometry applied to the kinematics of the platform. Also, some concepts in linear algebra (matrix operations) in order to apply a state space control.
- Physics: Direct application of linear and parabolic movement to generate a ball pass.

TABLE I. RELATIONSHIP BETWEEN MODULES AND COMPETENCIES DEVELOPED BY THE METHODOLOGY

Competencies and skills developed in the modules	**Modules developed in each phase of application of methodology.**				
	Phase 1	*Phase 2*	*Phase 3*	*Phase 4*	*Phase 5*
Hand skills	1			13,15	
Basic cognitive competencies	1, 2, 3	5,6,7	9	14	
Higher order competencies	4		8, 10, 11	12	16, 17,18
Soft competencies				15	18

- Electronics: Identification and possible improvements in the electronic circuitry of the robots. Identification of the main digital and analog circuits to achieve control, communication and power system handling.
- Hand skills: Learning of new concepts in the field of mechanical design through the use of CAD software as well as cutting, shaping and folding certain materials.
- Programming: Concepts of object-oriented and distributed software architectures applied to the control of each robotic player.
- Social framework: Revision of concepts in the field of cooperative robotics and nature-inspired behaviors in multi-agent environments.
- Control systems: Basic designing and tuning of PID controllers to guarantee stability, velocity and accuracy of the robotic platforms.
- Artificial vision: Basic concepts and improvements in the processing of images, feature extraction and pattern recognition among others from data collected by the video cameras.
- Artificial intelligence: Methods and theories regarding the design of autonomous agents capable of making intelligent decisions, path planning, obstacle avoidance, among others.

Table II explicitly shows the areas of knowledge included within each module.

C. Methodology

Taking advantage of the diversity of disciplines that the SSL challenge provides, we have designed and carried out an educational methodology for a group of 30 students of an undergraduate program on electrical engineering. The students were selected from two groups at a different stage of their careers. The first group is composed of students that have just began their second year; while the latter group is made of students studying fourth year.

Each module was designed to be carried out in one week. The total time of the whole course was 72 hours and it was carried out in 18 weeks (4 hours per week). Each module was divided in three parts: **a)** a 2–hour lecture to cover the specific concepts and requirements of the module, **b)** a 2–hour guided practical class where students were required to achieve a specific goal that usually included some part of the robotic platform and **c)** a 6–hour period of individual work to reinforce the concepts of the module. The period of time designed to perform hands-on activities was carried out in groups of 3 students.

In order to execute the proposed methodology, we proposed a 5–phase schedule. In each phase, a different set of modules is executed depending on which abilities or skills are required to be taught. Phase 1 took place in 4 weeks, the second phase took 3 weeks, third phase was scheduled for 3 weeks. The fourth phase was designed for 4 weeks and the last phase was developed in 4 weeks for a total of 18 weeks. Table I shows the modules developed within each phase.

Additional to the low-level skills and concepts reinforced with the methodology, the students will learn complex and difficult engineering tasks such as integrate hardware and software solutions, manage distributed systems, design and develop cooperative-coordinated behaviors, among many others.

IV. RESULTS

In this section we show quantitative results of applying the proposed methodology to a group of students of an electrical engineering program. The procedure consisted on replacing an elective course on fundamental robotics usually taught in the traditional way with the proposed methodology and compare. In this sense, the traditional course is our baseline implementation.

For this purpose, we have extracted 4 important measures that could provided us with the most vital information regarding the learning process of the students under this methodology. Figure 2 shows the average score of the whole class in the current semester where our methodology was applied and also for the two previous semesters where a traditional methodology was utilized. It is noteworthy that a significant improvement in the student's grades was achieved when using the proposed methodology going from an average grade of 70% approximately to an average grade of 82%. It is important to mention that the evaluation for both, the proposed methodology and the traditional one is based on the same tools, namely exams and assignments regarding robotic concepts and problems. The distribution of such grades in the course is shown in Figure 3.

Figure 4 shows the student's attendance for the proposed methodology. This result shows a large attendance in a course that has traditionally low attendance levels. Finally, Figure 5 shows a motivation surveyed that demonstrates the impact that such methodology generates on undergraduate level students.

V. FUTURE WORK

Future work of this project consists on making improvements on the model through the implementation of more courses. This will allows us to tune specific topics and activities within each module. It will also allows us to evaluate in a more efficient way each of the skills and competencies developed by the students and obtain more and better quantitative measures.

TABLE II. AREAS OF KNOWLEDGE REINFORCED WITHIN EACH MODULE

	Mathematics	*Physics*	*Electricity*	*Hand skills*	*Programming*	*Social Framework*	*Control Systems*	*Artificial Vision*	*Artificial Intelligence*
Module 1				X					
Module 2	X	X	X						
Module 3		X	X						
Module 4		X	X	X					
Module 5					X	X			X
Module 6	X	X	X		X			X	X
Module 7		X	X	X			X		
Module 8	X	X			X				
Module 9	X	X			X		X		
Module 10					X	X	X		X
Module 11		X	X		X		X		
Module 12					X	X	X	X	X
Module 13			X		X	X	X	X	X
Module 14		X							
Module 15			X	X		X			
Module 16					X	X	X		X
Module 17					X		X	X	X
Module 18					X		X		X

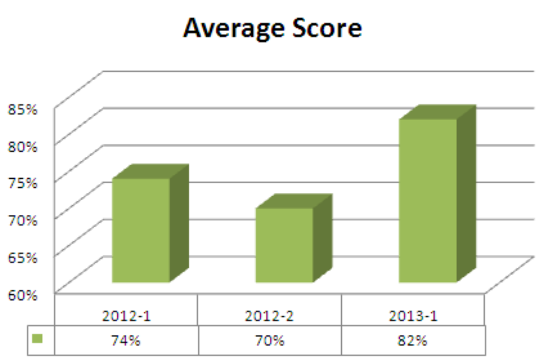

Fig. 2. Average score per student in the current semester (2013-1) and the two previous semesters (2012-1 and 2012-2).

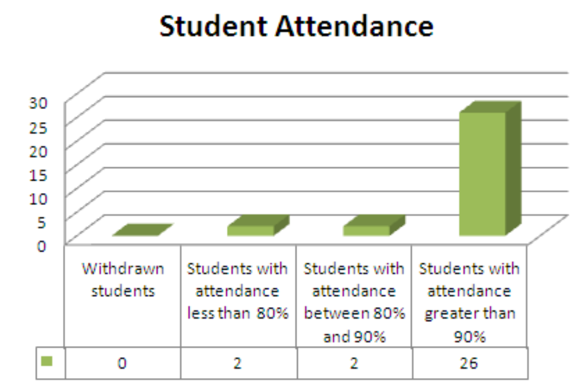

Fig. 4. Students attendace during the development of the course.

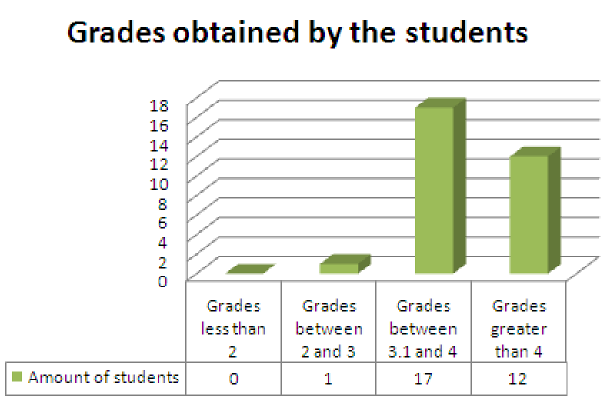

Fig. 3. Grade distribution at the end of the course.

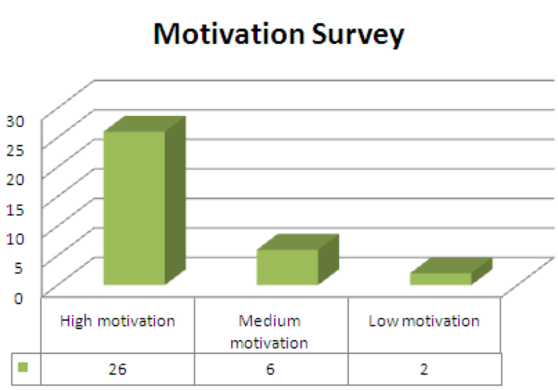

Fig. 5. Results of the motivation survey taken by the students.

Finally, we plan to migrate the current model at different levels of education in a way that it can be applicable to middle school, high school and college. For this task, some of the knowledge areas will have to change and some modules will need to be re-design to meet the needs of younger students with the final objective of encourage them to study engineering and science programs. Furthermore, there will be the need to increase the importance and intensity of some of the modules compared to the undergraduate methodology.

VI. Conclusions

Robotics applied to education is a field that has gained popularity in the last decades. Researchers and academics have found that its use in different level of education in subjects related to science and engineering has a significant impact in the learning process of the students. A key aspect within this phenomena is the fact that problems in robotics are heavily based on a hands-on philosophy ecnouraging what is known as cognitive learning: the students are capable of remembering concepts that they learnt through an experience easier than those learnt by memoristic procedures. This concept, together with the concept of soccer player robots allowed us to create an educational methodology based on modules for undergraduate level students.

After applying this methodology into a group of 30 students from the electrical engineering at Universidad Santo Tomás we have verified the increase in motivation experienced by them in subjects that were considered to be most difficult for them under the common approach. This motivation can be reflected in higher grades and attendance to the classes compared to previous semesters. Also, we have verified that the implementation of the module-based methodology allows students with varied capabilities to deepen into already gained abilities as well as to visit and experience new challenges in topics that may be unfamiliar to them.

During the development of the course we combined students in their first year with third year students. We have found that our methodology allows this variety of technical levels by reinforcing the basic science concepts used in robotics for the older students and introducing new concepts of more advanced engineering topics to younger students. This variety also allowed us to develop interesting experiences in terms of team work within the groups.

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