The potential of a robotics summer course On Engineering Education

N. M. Fonseca Ferreira[1,2,3,4,*], André Araujo[5]
M.S. Couceiro[5] and David Portugal[5]

[1]*Engineering Institute of Coimbra (ISEC)*
[2] *RoboCorp, I2A, Polytechnic of Coimbra (IPC),* Portugal
[3]*Knowledge Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development (GECAD) of the Institute of Engineering, Polytechnic Institute of Porto, Portugal*
[4]*INESC TEC – Instituto de Engenharia de Sistemas e Computadores, Tecnologia e Ciência (formerly INESC Porto), Portugal*
[5]*Ingeniarius, Coimbra, Portugal*

[*]*nunomig@isec.pt*

Abstract

RobotCraft is an international internship with a summer course in robotics designed especially for BSc to PhD students. The students attending this 2-months program have the opportunity to work in robotics, focusing on several state-of-the-art approaches, technologies and learned how to design, build and program their robots throughout multiple activities, carefully prepared to provide a wide range of skills and knowledge in the topic. This paper describes the methodology used to introduce participants to a hands-on technical craft on robotics and to acquire experience in the low-level details of embedded systems.

Keywords*: Engineering education, Project-based learning, educational robotics.*

1. Introduction

Robotics is a very attractive subject in the field of engineering. More frequently, educators find robotics a suitable project-based learning tool. Using robots as a teaching tool, can lead to the acquisition of knowledge and skills in several engineering areas, such as electrical, mechanical and computer engineering areas. As can also provide the students with problem solving, teamwork and self-taught skills. With the educational benefits in mind, world-widely, some educators have been creating for students extra-curricular activities involving robotics, such as Robotics Summer Camps and Robot Competitions [1-5]. Robot contests present several successful designs for projects surveyed by students in universities, colleges and schools. These contests can offer engineering assignments of different levels, from a high-school competition [6-7] to advanced research programs such as the robotic soccer initiative, or pose a challenging problem, designing a robot that can navigate autonomously through a maze, find a lit candle, and extinguish it in minimum time.

As a multi-disciplinary subject, robotics involves physics, mathematics, control, programming, computer-aided design and hands-on technical skills. The primarily focus of the robotics programs are different, while a Computer Science robotics program may focus on the high-level algorithms used for image recognition and navigation, a mechanical engineering program may focus on the manipulation of servos and motors to complete specific tasks. For college students looking to become involved in robotics, however, it can be difficult to find an introductory course that empowers them with the knowledge to construct and operate their own autonomous robots. The RobotCraft is an international internship with a summer course in robotics designed especially for BSc to PhD students. The students attending this 2-months program have the opportunity to work in robotics, focusing on several state-of-the-art approaches and technologies. The summer course, now in its second edition and entitled as the 2nd Robotics Craftsmanship International Academy.

RobotCraft 2017 received around 100 applications, but just 84 attended the summer course. The attendants came from a wide range of countries, namely Egypt, Spain, Jordan, Lebanon, Palestine, Portugal, Sweden, Turkey, Germany, Algeria, Estonia, Finland, United Kingdom, Greece, Hungary, Italy, Morocco, Malaysia, Netherlands, Romania, Russia, Kazakhstan Syria and Kosovo.

2. International Summer School Program

This summer school program designed to bring engineering students from all over the world as a way to experience life and learning hands-on technical skills. The program provided a solid learning opportunity for international students and presented two challenges. The first challenge was the wide range of educational backgrounds from the students. As a result, this course had to be accessible to students who had never worked with embedded systems before, while at the same time, it needed to engage and challenge those students who already had some robotics project experience. This was the second major challenge faced; all of the presented material had to be interesting and engaging enough to keep participants interested on the course subjects, meeting the different needs of the international students.

In order to support the wide range of background and skills level of the students, the course was layout into six different topics, each with the duration of approximately one week. The topics are summarized in Table 1. For each of these topics, the participants attended a seminar, lectures and several practical sessions (Table 2.) The seminars presented were on enthusiastic topics and this learning activity allowed the participants to have contact with researchers referred to each expertise field. Also as part of their learning activities, as shown on Table 3, the existence of practical assignments, in order to see results early on in the learning process, while introducing concepts, allow the more advanced participants to customize their systems [8-9]. The methodology used on this course allowed participants to accelerate their learning processes, and also the development of systems thinking and the skills of intensive purposeful teamwork; reducing the gap between background, theoretical and practical activities.

Table 1. Course Schedule and Outline

Schedule	Topic	Brief Description
First and second week	Introduction to Robotics	✓ History of robotics and its evolution
		✓ Mobile robot morphologies (namely sensors and actuators)
		✓ Brief literature review (basic theoretical concepts)
Third week	Computer-Aided Design (CAD)	✓ 3D modelling tools
		✓ 3D printing
		✓ Model a 3D structure for the mobile robotic platform
		✓ 3D print the personalized 3D structure
		✓ Assemble the mobile robotic platform
Fourth week	Arduino Programming	✓ C language applied to Arduino programming
		✓ Features of Arduino solutions (e.g., hardware architecture, cycles, communications)
		✓ Identify different wireless communication technologies
		✓ Low-level algorithms, flowcharts and pseudocode
		✓ Develop a typical differential kinematic application
Fifth and sixth week	Robot Operating System (ROS)	✓ ROS features (e.g., packages publish-subscribe, topics)
		✓ ROS-compatible simulators (Stage)
		✓ High-level algorithms, flowcharts and pseudocode
		✓ Develop a typical remote sensing application
Seventh and eighth week	Artificial Intelligence (AI)	✓ Different paradigms and some real applications
		✓ Integrating biologically-inspired models
		✓ Formalizing a biologically-inspired approach
		✓ Develop a streaming architecture to exchange all necessary data (e.g., sensor readings, encoder's readings, actuators control, etc.)
Last day	Competition	✓ Mobile robot platform maze competition
		✓ Mobile robot Patrol competition: algorithm testing
		✓ Prize delivery

The practice is fundamental in the learning process and can offer educational advantages: the participants acquired skills are required in many professional fields and various science methods studied, can be apply on robot navigation and other functions. The assignments provided to the students were creative and involved instructive activities. The course schedule planning accounted the following factors: Each topic should be preceded by its prerequisite topics; Each topic should be learned in parallel with the linked topics; Combination of subjects and balance of theoretical, seminaries and lab studies are desired; Seminaries presented by researchers in the specific field of each workshop is extra motivation to the participants, this stimulate the creative and guided by innovation, which suggests a professional who is capable of maintaining the skills and knowledge updated to recent scientific–technological advances. The team assignments given in each week, allowed the participants to cooperate as a team and to work more independently. Table 3 shows the learning activities used to achieve the objectives described.

The final competition, in the end of RobotCraft, had two different goals: maze solving and patrolling attributes. In the maze scenario, the robot needs to find its way through the maze; where the evaluation contemplates several conditions: the distance to the maze's exit elapsed, the time and the number of wall collisions.

Table 2. Seminar, lectures and practical sessions

	Description	Methods used	Objectives	Assessments
Seminar	Invited Talk (45 min + 30 min)	Audio and visual materials. Discussion between Oral Speaker and participants.	Engage students to this particular area of knowledge. Provide students with the state-of-the-art developments.	Feedback from the audience. Pertinent questions and students interaction . Interest shown during the presentation.
Lecture (theoretical lesson)	Talk given by one of the resident teachers (1hour + 20 min)	Content well organized and structure. Audio and visual materials. Discussion between teacher and participants.	Provide students with the basic theoretical contents. Promote parallel learning with linked topics.	Oral Questioning. Tutorial exercises.
Pratical sessions (lab practice)	4 to 8 hours per day of Lab practice, supervised by 2 to 4 teachers	Active involvement, through hands-on projects. Challenging team assignments.	Emphasize concept application. Foment team-learning activities. Foster and develop critical thinking.	Oral Questioning. Team and individual capabilities on solving problems and developing critical thinking.

Table 3. Learning Activities.

Objectives	Learning Activities
Implementation of basic system functions	Work with instructional modules. Lectures provided in the context of each module and the tutorials provide structured information for the participants.
Design and construction of the system	Teamwork on practical project assignment.
Implementation, control and communications	Work on research and Lab practice. Participants need to develop the proposed assignments and to conclude the final project. System of extra point's reward, to increase motivation and development of all the proposed tasks.
Adaptation of the system to the real environment and prepare to the competition	Lab practice and assignments.

And in the patrol mission, the robot needs to patrol, cooperatively, a given region, minimizing the idleness of all points of interests; therefore, the evaluation of this patrol mission is on the average idleness. Table 4 shows for each subject approached during the course, the intended learning objectives and the observed outcomes, as well as an example of a proposed assignment given to the participants.

Table 4. Subjects - Learning Objectives, Assignments and Outcomes.

Subject	Intended Learning Objectives	Proposed Assignment	Observed Learning Outcomes
Robotics	Identify mobile robot morphologies Implement, develop for functional architecture to a mobile robot.	Simple tasks where both circuit and program needed to be changed, e.g. modifying the communication protocol start code.	All the participants achieved the intended learning objectives. All groups completed the assignment with good remarks by the teachers.
Computer-Aided Design (CAD)	Identify 3D modelling tools and printers Execute a 3D modelling tool (FreeCAD) Create and print a 3D structure	Participants must design a creative robot housing. The robot housing should hold the 2-ultrasound sensors (left and right sensors), 1 infrared sensor (front sensor) and 4 LEDs.	All the participants achieved the intended learning objectives. All teams showed creativity in the design of the 3D structure.
3D mobile Robot	Assemble the printed 3D structure Assemble all mechanical components	Participants must follow a given hardware architecture in order to construct their mobile robot platform	All groups assemble their mobile platforms. All participants understood the hardware architecture.
Arduino Programming	Apply C language in Arduino programming Create the interface to link the Arduino board with the sensors and actuators	Create a function that reads the ultrasound sensors and converts its measurements in millimeters. Create a function that reads the difference between the numbers of pulses counted by the encoders on each wheel since last request.	The participants shown good response to the Arduino module. All groups were able to plan, organize and execute the tasks.
Kinematics and Control	Relate kinematics with the robot control system Create and implement a kinematic model of a differential drive robot	Adapt and merge the codes to the real hardware, comprising linear and angular velocities on the control of speed and the direction of both wheels.	The evaluation of all participants was positive, highlighting the interpersonal help between each team.
ROS Architecture	Interpret and operate in a ROS environment Explore ROS features Relate Arduino task with ROS architecture	Create a ROS package, that contains a node capable of subscribing 3 topics provided by the code developed in the previous task in Arduino.	All participants shown some difficulties upon the introduction of ROS. The assistance and help of the teachers were fundamental and on this module, they overcome most of their drawbacks by team interaction.
Simulating with Stage and ROS	Sketch a robotic simulation setup and implement the mobile robot platform in ROS. Execute Stage software in ROS and evaluate the mobile robot performance.	In a ROS package, create the needed files to simulate a virtual world with a robot in Stage. The extra goal is to have the robot mapping the environment with laser scans, in parallel with other tasks.	Almost all groups achieved the intended learning objectives. Robot design creativity used in Stage, rewarded with extra points.
Artificial Intelligence (AI)	Illustrate and label different AI approaches Implement and compare AI algorithms	Implement a simple algorithm inspired on biological systems, e.g. an ant algorithm.	Almost all groups developed an ant algorithm. 2-3 groups developed and implemented a more advanced AI algorithm.
Competition	Operate the mobile robot platform in a real 3D scenario maze). Assess the performance of the surveillance algorithm (patrol).	Conclude the algorithm development of the mobile robot platform. Evaluate and carry out final improvements.	All groups were able to develop a full operating mobile robot platform. 10 of 15 groups enter the maze final competition and just 3 teams concluded a successful surveillance algorithm.

3. Robot Craftsmanship

The course developed to be a practical hands-on experience for students of various backgrounds; and to engage students on robotics, met some specific criteria: the use of hardware and software supported by large communities, allowing students the benefit of finding help and examples online, both during and after the course.

All the devices used were relatively affordable, so that students could easily purchase their own components to tinker with, after the course. Although simplistic, the mobile robotic platform assembled, needed to comprise all relevant components inherent to mobile robotics (Figure 1).

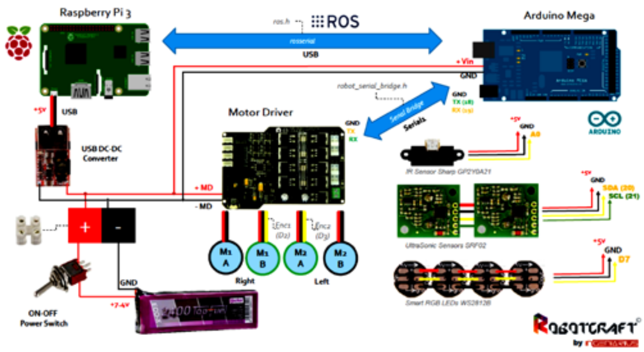

Fig. 1. Main hardware parts of the robotic system.

After the assembly of the platforms, students were introduced to C language and to some common algorithms in mobile autonomous robotic topics, such as mobile robotic kinematics, motion control, localization, path planning, among others. They started merging the developed algorithmic into systems capable of basic autonomous functionality and evaluate it considering the robot performance and then, improving the developed code.

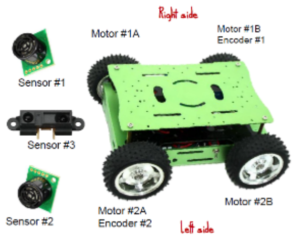

Fig. 2 The mobile robot platform.

As they develop skills working with ROS (Robot Operating System), writing robot software in a flexible framework, they acknowledge that several kinds of robot bases have common points: wheels, motors, odometry, among others. The inter-process communication is an important feature to the overall process. The robot needs to see obstacles and decide where to go next (reactive walk). For this, it continuously needs to read laser scans to make decisions, where through a simple algorithm; it sends commands to the base. This is a kind of service used on any mobile robot. Simple service, like navigation consists on the determination of a valid trajectory between two points, provided by a map. Knowing the robot position, the localization of the robot in space is possible. Synchronous communication is an important issue when defining goals for the robot to move, for determining the possible paths and for knowing when the robot got there.

In order to avoid harming the robot or oneself, they simulated their approach before attempting it in the real robot platforms. They used Stage (OpenSource software), a standalone robot simulation program, on the ROS platform and were able to simulate multi-robot tasks in a ROS packages (e.g., coverage, patrolling, formation control, exploration, mapping, and it can include robots, sensors, actuators, moveable and immovable objects). The attendants learn to configure properly a workspace, to set up and run the simulation program, and to create a ROS package for the simulations. They were able to test and validate their project.

In the final week of the course, participants worked together on the development and improvement of their mobile robot platforms. They gained experience in how to accomplish tasks, in problem solving and in design decisions. Instructional time was primarily spent guiding attendants through the implementation of algorithms, and working through the difficulties and pitfalls of real hands-on development. Their skills in scheduling timelines, teamwork and compromise were improved. One noteworthy event was by the end of the last week, some teams realized that they would not be able to complete the project in time to enter the competition. In order to meet this goal, opposing teams worked together and even shared algorithms and code. At the end of the week, all teams had developed robots that could autonomously compete.

In the final day, the competition took place, and comprised two different objectives: first, the maze solving and second, the patrolling attributes (Fig. 3).

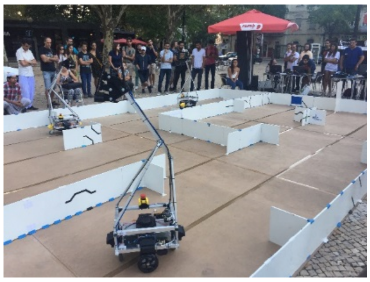

Fig. 3. Competition day: maze solving (left) and patrolling scenario (right).

Figure 3 shows the maze scenario, where the robot needs to find its way through the maze and the patrol mission, where robots needed to patrol cooperatively a given region, minimizing the idleness of all points of interests. The maze scenario assessment was through the distance elapsed, time and number of collisions and for the patrol scenario was through the average idleness.

4. Surveys

To obtain a formalized feedback of the course, participants took two surveys. The first was answered by 96% of enrolled attendants. The main purpose of this survey was to identify the overall knowledge, of each participant, in different related topics. The second, taken in the last seminar by 77% of enrolled participants, aimed to get feedback from the attendants, about their expectations and to provide a useful overall evaluation of the course.

4.1. Participants

During the first seminar, 81 participants answered the initial survey, corresponding to 96% of enrolled attendants and came from twenty different countries. Being an intensive summer course in English language and disseminated in several information channels, Portugal (the host country) is second with just 7% of student participation behind Turkey, representing 51% of enrolled students.

The attendants became aware of the existence of this summer course through several channels of information. The more important ones were through friends and colleagues, social media and Erasmus channels, representing 70% of the enquiries.

From the 81 attendants that answered the initial survey, 92.5% were university students in their home countries, 79% had ages between 20 to 24 years old and 75% of them were male. BSc, MSc and PhD students, corresponded to 80%, 10% and 2.5% of participants, respectively. Figure 4 shows the distribution of participants according to the area of specialization. The others 7.5% already concluded their studies and were not involved in a university course.

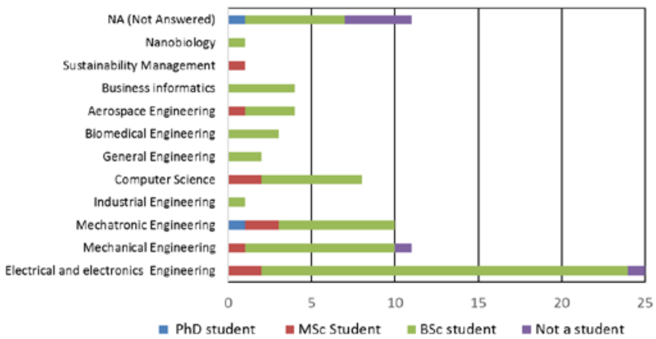

Fig 4. Number of participants according to their area of specialization.

As is it shown on figure 4, 80% of the participants have a background on, or are attending, a university course on engineering. Electrical and electronics engineering is the area with most participants, 31%, against 26% of participants with a mechanical or mechatronics engineering background (14% and 12% respectively); 10% are attending a Computer science course, 5% and 4% of them, are students on Aerospace and Biomedical engineering, respectively.

When asked, what were the main reasons (up to 3) for enrolling in this course; participants gave different and diverse reasons. Some wanted to have an educative summer, others to learn more on ROS, C# and/or Artificial Intelligence; others the main purpose was to make an internship, or visit Portugal (9%), or to improve their English. Most of them, around 42% shown to have personal interest in acquire experience in robotics. Around 47% of the attendants said they had already built a robot before.

4.1.1 Women participation

From the last decades the number of women in engineering courses has been increasing [10]. This edition, has been no exception, there was an increase of the percentage of women involved. There were 84 attendants, 25% of the enquiries were female, corresponding to an increase of 20% of female participation from last year edition. These female attendants came mainly from Turkey, followed by Hungary and Morocco with 40%, 20% and 15% of participation, respectively. 80% of them are BSc students, with ages between 20 and 24 years old. Their areas of specialization are mostly on engineering, with 25% on Electrical and Electronics Engineering, 20% on Business Informatics and 15% on Computer Science.

4.2. Participants knowledge

The initial survey had a series of questions, aimed to access the overall knowledge of the participants in some areas, such as Computer-Aided Design, 3D Printing, Mechatronics, Arduino Programming, Kinematics, Control, ROS and Artificial Intelligence. Figures 5 and 6 illustrate the responses to six of the survey questions, based on a five point Likert Scale [11]. Likert Scales have the advantage that they do not expect a simple answer (yes or no, good or bad) from the respondent, but rather allow degrees of opinion, and even no opinion at all. For example, there are Agreement, Frequency, Importance and is assumed that the experience is linear. The left and right extremes, correspond to numbers 1 and 5, respectively. And it is assumed that there is a continuum of possible answers from the left to the right of the scales, that is, from Never to Very Frequently, or from Unimportant to Very Important, and a choice of five pre-coded responses can be given, with the neutral point being occasionally or moderately Important [12]. Figure 5 shows the current understanding on the topics and reveals that most students do not understand a large part of these topics. In fact, only 4 participants worked with ROS before starting the course.

Fig. 5. Initial current understanding on RobotCraft topics.

Also the background in some subjects like electronic, computer, assembly language, show that the participants have an overall poor knowledge and lack of hands-on experience.

4.3. Participants reactions

Figure 6 illustrates a comparison made with the initial and final surveys taken by the participants, the topics, which they had, a non-relevant initial understating are ROS with 67%, Artificial Intelligence with 49%, followed by Kinematics, Mechatronics, Control and 3D printing with a percentage of around 40%. The topics where the seminars were more important in the context of the course were the lectures within Arduino, Kinematics, ROS, Control and Artificial Intelligence, with 55%, 57%, 66%, 62% and 68%. These were also the topics where the evaluation of the seminar lectures were more relevant, with 43%, 38%, 40%, 45% and 49%, considers that the evaluation was positive. When comparing the initial and current understanding on each topic, when comparing the initial and current understanding are ROS topic with a 29% drop, from 67% to 38%, Mechatronics with a 17% drop from 42% to 25%, followed by Kinematics and 3D printing with a 15% and 14% drop. In fact, ROS, Kinematics and Arduino topics had a very subtle increase of 10%, 2% and 2% of participants with a relevant current knowledge on the topic. When asked about the difficulty of these topics, the ones that had more percentage of non-relevant knowledge and higher relevancy of the seminars lectures to their understanding, ROS, Control and Artificial Intelligence appear with 51%, 46% and 48% of percentage of participants alleging they were difficult topics to learn. In fact, about ROS the participants felt this was a very important topic of the robotics course, but it is very difficult to learn in just two weeks. Based on formal and informal feedback, the course was successful in providing the participants with a meaningful introductory, yet comprehensive robotics experience. In addition, their feedback is important to improve the overall quality of this course.

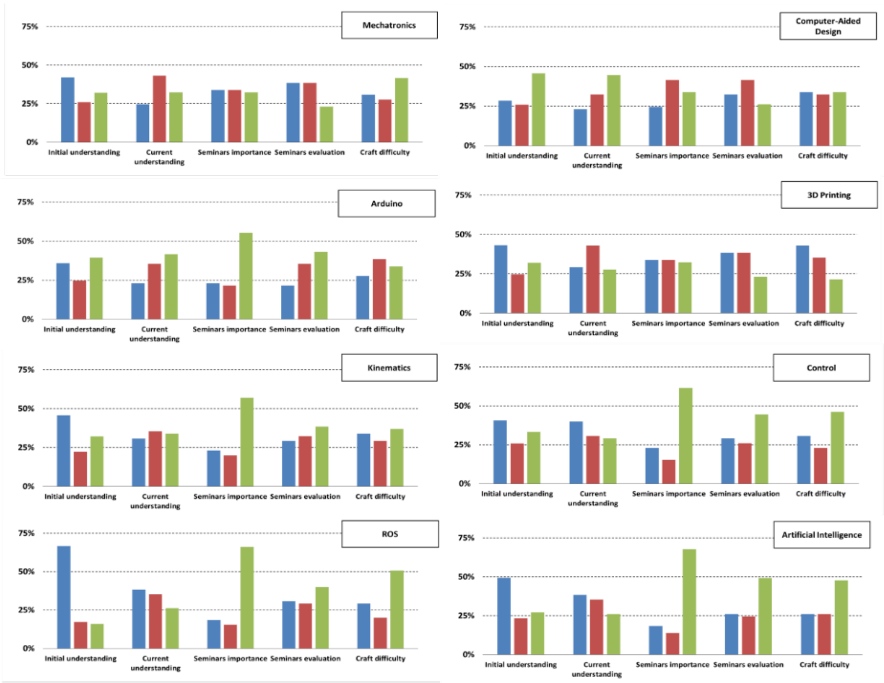

Fig 6. Participants opinion on the topics address

5. Conclusions

A two months robotics course, aimed for international students from varying engineering backgrounds, with the advantage of coupling various skill levels, was successful. The methodology used, had the ability to give to participants an appropriate introduction to a complete robotics design experience. The participants saw their academic knowledge on some engineering subjects improved. The methodology used, developed not just their technical skills but social also, through teamwork. Even a moderate knowledge increase on some approach subjects is a finding that robotics, if well approached, can be a multi-disciplinary learning platform.

Acknowledgments

This work is financed by the ERDF – European Regional Development Fund through the Operational Programme for Competitiveness and Internationalisation - COMPETE 2020 Programme within project «POCI-01-0145-FEDER-006961», and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) as part of project UID/EEA/50014/2013.

References

[1] E. Kolberg and N. Orlev, "*Robotics learning as a tool for integrating science technology curriculum in K-12 schools*," presented at the Frontiers in Education Conference, 2001.

[2] F. B. V. Benitti, "*Exploring the educational potential of robotics in schools: A systematic review*" Computers & Education, vol. 58, no. 3, pp. 978-988, 2012.

[3] A. Melchior, F. Cohen, T. Cutter, T. Leavitt and N. Manchester, "*More than robots: An evaluation of the first robotics competition participant and institutional impacts*," Heller School for Social Policy and Management, Brandeis University, 2005.

[4] S. Grover, "*Robotics and Engineering for Middle and High School Students to Develop Computational Thinking*," in Annual Meeting of the American Educational Research Association, 2011.

[5] W. W. Lau, G. Ngai, S. C. Chan and J. C. Cheung, "*Learning programming through fashion and design: a pilot summer course in wearable computing for middle school students*," SIGCSE Bull., vol. 41, no. 1, pp. 504-508, March 2009.

[6] A. Welch and D. Huffman, "*The Effect of Robotics Competitions on High School Students' Attitudes Toward Science*," School Science Mathematics, vol. 111, no. 8, pp. 416–424, Dec. 2011.

[7] G. Nugent, B. Barker, N. Grandgenett, and G. Welch, *"Robotics camps, clubs, and competitions: Results from a US robotics project*," Robotics and Autonomous Systems, vol. 75, no. Part B, pp. 686–691, Jan. 2016.

[8] Igor M. Verner, Shlomo Waks and Eli Kolberg, "*Educational Robotics: An Insight into Systems Engineering*", European Journal of Engineering Education, 24:2, 201-212, DOI: 10.1080/03043799908923555, 1999

[9] Moshe Barak, *"From 'doing' to 'doing with learning': reflection on an effort to promote self-regulated learning in technological projects in high school"*, European Journal of Engineering Education, Volume 37, Issue 1, DOI: 10.1080/03043797.2012.658759, 2012.

[10] Duyen Q. Nguyen, "*The Status of Women in Engineering Education*", Int. J. Eng. Ed. Vol. 16, No. 4, pp. 286-291, 2000.

[11] Likert, R., "*A Technique for the Measurement of Attitudes*". Archives of Psychology, 140, 1–55, 1932.

[12] Paulhus, D. L., "*Two-component models of socially desirable responding*, Journal of personality and social psychology, 46(3), 598, 1984.