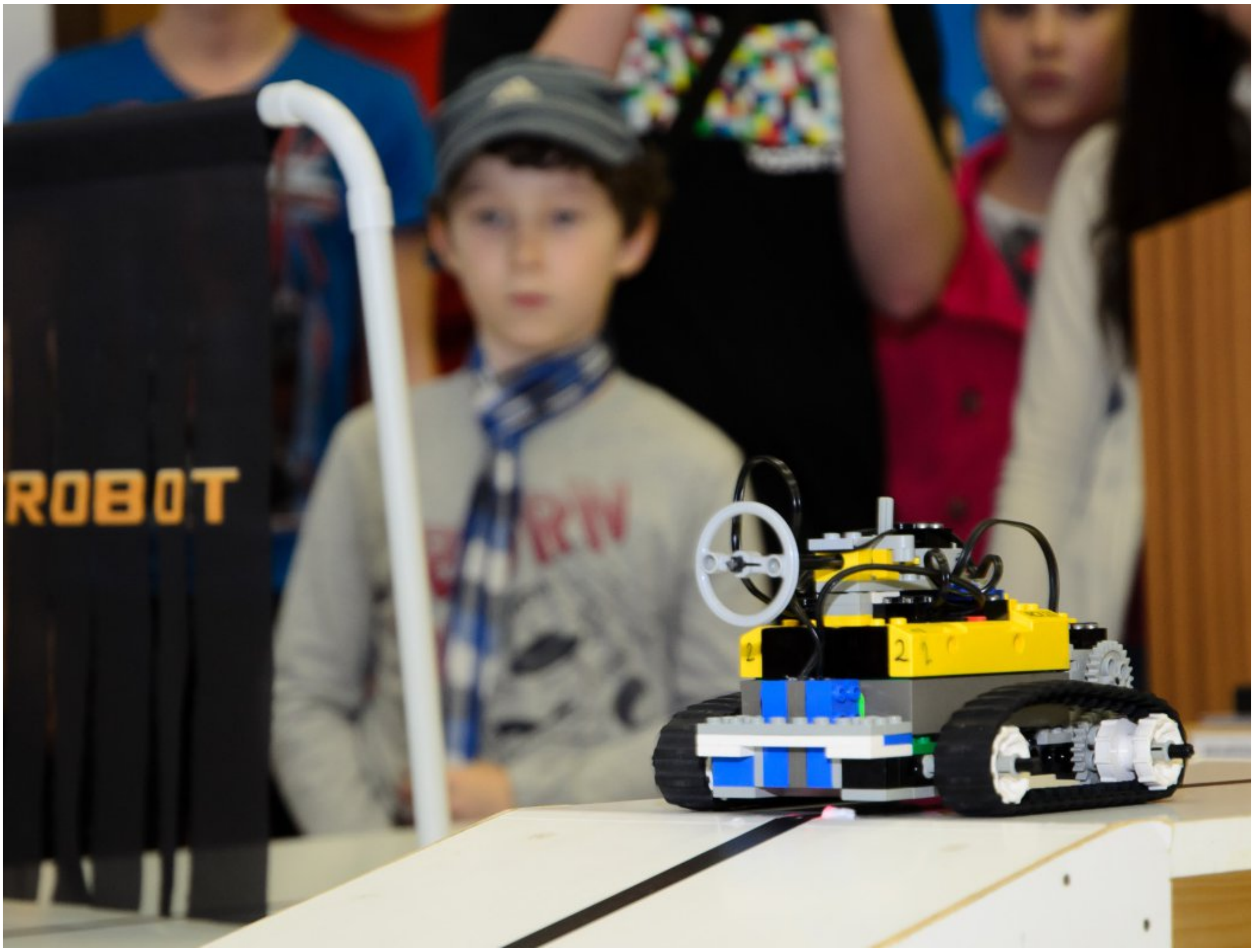

RiE 2014

5th International Conference on

Robotics in Education

July 18, 2014

Padova, Italy

NOTE: this is an archive reprint of an original proceedings which were included in the Proceedings of the 13th International Conference on Intelligent Autonomous Systems
ISBN 978-88-95872-06-3

Editors: Dimitris Alimisis, Grzegorz Granosik and Michele Moro

Proceedings of the 4th International Workshop
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&
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ISBN 978-88-95872-06-3

Origin:
https://www.terecop.eu/TRTWR-RIE2014/proceedings.html

Programme:
https://www.terecop.eu/TRTWR2014/program.htm

Credits:
Cover photo: Zuzana Hečková
Typesetting: Richard Balogh
using LaTeX's 'confproc' class

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Introduction

The 4th International Workshop "Teaching Robotics & Teaching with Robotics" (TRTWR) and the International Conference "Robotics in Education" (RiE) joined forces in 2014. The joint TRTWR & RiE 2014 event was held in Padova, Italy, July 18, 2014, hosted by the 13th International Conference on Intelligent Autonomous Systems http://www.ias-13.org/

TRTWR and RiE have a history of previous successful editions which witnesses the continuously growing interest in educational robotics in Europe and world-wide. The TRTWR workshop originated by the TERECoP project (www.terecop.eu) in Venice (2008) and grew up in Darmstadt (2010) and in Riva del Garda (2012). RiE conference counts so far 4 editions: in Bratislava (2010), Vienna (2011), Prague (2012) and Łódź (2013).

Several efforts and tools developed recently to integrate robotics in tertiary and school education, mainly in science and technology subjects, were presented in the workshop and are reported in the workshop proceedings. The papers present results from robotics projects developed in primary and secondary classes, clubs, camps and competitions. Others examine robotics as a learning tool to support educational transformation, computational thinking, evolution of design ideas, creativity and innovation in education.

We really hope that the proceedings of this event, and the discussion held during the event as well, will contribute to the further development and advancement of the dialogue among the research community of educational robotics at European level.

The Chairs

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Conference Programme

Full papers

Short papers – Posters

Robotics in physics education: fostering graphing abilities in kinematics

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Abstract. This paper reports a robotics-based learning experiement that took place in a school physics class (20 students aged 15). The students worked in groups to construct a robotic vehicle using Lego Mindstorms NXT kit, and then they programmed it to move in linear way first at constant speed, then at constant acceleration and deceleration. Position-time data from each experiement was logged and graphs were produced by the students using Lego Education data logging tool. The students had already been taught kinematics in a traditional lecture-based way before the experiement and their graphing abilities in kinematics were tested before and after the experiement using a special paper and pencil test. Post-test scores were found significantly higher than pre-test ones providing evidence of a positive learning impact.

Keywords: educational robotics, learning, physics, graphs

1 Introduction

The visualization of the relation between two physical quantities through a graph is a commonly used tool in physics education. Students in physics courses have to become able to draw and interpret graphs in terms of the underlying physics quantities and the relations between them. The graphing ability is considered essential for understanding physics concepts and phenomena, and one of the main skills that school physics courses are aimed to develop [1] connected by other researchers with the development of logical thinking structures [2]. In this sense, the benefits of using graphs in a physics course go beyond the specific topic covered. On the other hand, lack of graphing skills is considered a handicap and a limiting factor for learning physics [1].

However, research in physics education has identified serious difficulties that students encounter in drawing and interpreting graphs; especially in the field of kinematics students find often hard to making connections between graphs, motion concepts and the real world [1]. Moreover, other studies have shown that students often come off traditional physics courses with many kinematics misconceptions [1], [3], [4].

To cope with these problems research in physics education has suggested several technological tools (video, multimedia, modeling software and more) to support students' understanding in kinematics and the development of graphing skills through

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

dynamic visualizations [5], [6]. The Microcomputer-Based Lab (MBL) was introduced in 90's offering detection of moving objects and position-time graphs plotted on screen in real time [7]. The MBL approach was advantageous in the sense students could observe the motion event concurrently with its graphical visualization which is considered as helpful for connecting abstract motion concepts with concrete kinesthetic experiences [8]. On the other hand in the MBL approach the graph is offered as ready-made by the device not allowing learners to engineer and control the graphing process. In addition to this, learners have not much control on the motion event and the learning approach is mostly dominated by the guided discovery learning model.

Computer simulations and modeling software have also been successfully introduced in school physics teaching including kinematics [9], [10]. For example the "Graphs and Tracks" ready-to-run model based on an earlier program by David Trowbridge [11] can show position, velocity, acceleration, and energy graphs and can be used for motion-to-graphs exercises [12]. However, computer-based models and simulations have some clear limitations; they work on a virtual environment and can offer only two-dimension scenario where the moving object behaves as a "virtual perfect robot"; its behaviour is a poor iconic representation of real behaviours lacking the side effects (e.g. friction) existing in motions happening in the real world.

Educational robotic technologies have appeared in the last decade as a novel approach promising to offer and extend the benefits introduced by MBL and simulations without their limitations or deficiencies. The use of robotic technologies in education opens a new and unexplored real world environment in which subjects such as physics can be taught in a natural way [13]. Differently from a simulated environment, in educational robotics, thanks to the embodied nature of a robot, students can learn experimenting in the natural 3D real world in an explorable and measurable setting [14].

Robotics is also advantageous compared to MBL and simulations in the sense that educational robots can be designed and constructed by learners themselves from scratch. It means that a robotics-based learning environment is more engaging for students, it fosters motivation and situational interest, offers opportunities for deeper exploration and facilitates understanding of the underlying scientific concepts [15], [16]. Especially in kinematics, students can program their robots to move as they wish and produce the proper position-time graphs. As a result, the robotics-based learning can depart from guided discovery models and turn into an open, transparent activity fully controlled by learners and thus to approach the constructivism/constructionism paradigm [17].

In this framework, a learning experiement in a school class was designed to examine the impact of a constructivist robotics activity on students' graphing skills in connection with the underlying kinematics concepts related to motions at constant speed, accelerated and decelerated ones. The theme-based curriculum approach, one of the main approaches to Educational Robotics reported in the literature [18], was chosen where curriculum areas are integrated around a special topic for learning and studied mostly through inquiry and communication. The paper reports the implementation and the evaluation of the experiement; it is organized in 4 sections: section 2 describes the robotic activity, section 3 presents the evaluation methodology and results and finally section 4 reports the conclusions of this work.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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ISBN 978-88-95872-06-3
pp. 2-10

2 The robotic activity

Based on the above mentioned theoretical framework, a constructivist approach was designed. Students had to work collaboratively in groups of 5 to construct robotic vehicles from scratch using the Lego Mindstorms NXT kit. Then they had to program their robots, using the Lego Education Programming software, to move forward and backwards in linear motion at constant speed, acceleration or deceleration. None guidance was provided by the teacher, just the necessary technical support, for example how to use the programming blocks or how to make data logging and position-time graphs. Worksheets were handed to students presenting open questions/problems and offering technical support. For example: "devise a program that will make your car to move backwards…", "make your car to move in a linear constantly accelerated motion, write down your ideas…", "can you add some more seconds of decelerated motion? How does the graph change now?"

Through this approach students could explore the real motion phenomenon while at the same time could observe the visualization of the motion in the form of a position-time graph and a table of data. This resulted in real-time multiple representations of the motion event which are considered advantageous for students' learning [19].

One class of 20 students aged 15, who had already been taught kinematics in lecture for 12 teaching hours 3 months ago, was involved in the robotic activity in 4 groups of 5. The activity took place at the 1st Lyceum of Sparta, Greece (public school of upper secondary education) in April 2013 in 4 weekly sessions of 2 hours each.

More specifically, in the 1st session each group constructed from scratch a robotic 4 wheeled vehicle with one motor using the Lego Mindstorms NXT kit. Due to the absence of other requirements or guidance, different robots were constructed by each group (fig. 1 & 2).

Fig. 1. A group of students constructing their robot (left) and posing proud of it (right)

In the 2nd session the students learned to program their robot to move forward and backward in linear motion using the Lego Education programming environment. Changing the schedule of the session, the students decided to use their robots in an improvised car-racing. Their excitement with the game of racing introduced in the learning activities some fun and motivated the students to make improvements and interventions in their vehicles to make them faster and more competitive, turning the educational session into a fun activity (fig. 2).

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

Fig. 2. Car-racing (left) and one of the students' robots (right)

In the 3rd session, physics emerged in the front stage; the students were reminded through their worksheets the basics of motion at constant speed and were asked to program their robot to move forward and then backward at constant speed. They were instructed to assemble a distance sensor on their robot in order to detect the distance from a stable object (the closest wall). They were also helped to activate the data logging tool in order to create the position-time graph on their screen. Finally they were encouraged to experiement with the power of the motor trying out different values and to observe the effect on the speed of their vehicle each time (fig. 3).

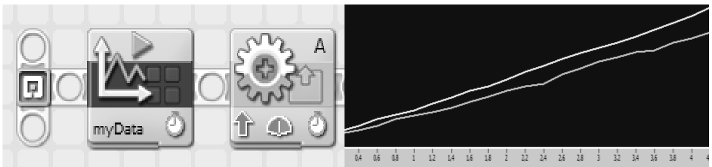


Fig. 3 Students' indicative programming solution and graph for linear motion at constant speed and position-time graph with 2 different speeds.

In the 4th session, the concept of acceleration/deceleration was reminded shortly in worksheets. The students were instructed to use the Loop block to repeat sequences of code and the Math block to perform simple arithmetic operations (addition, subtraction, multiplication, and division). Then they were asked to program their robot to perform a linear motion at constant acceleration, to create again position-time graphs and to study them carefully (fig. 4). After this, they were asked to do the same task but now at constant deceleration (fig. 5) and finally they were challenged to produce a complex motion first accelerated then decelerated (fig. 6).

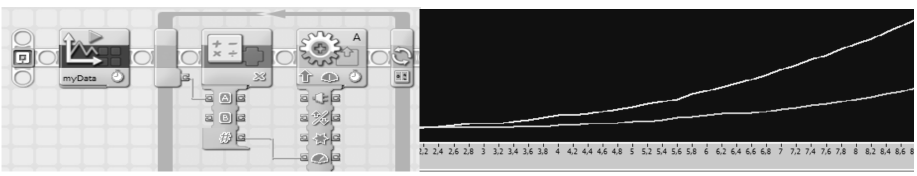


Fig.**4** Students' indicative programming solution and graph for accelerated motion with 2 different values of acceleration

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

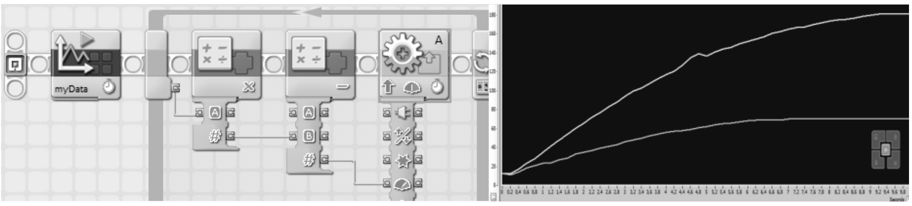


Fig.5 Students' indicative programming solution and graph for decelerated motion with 2 different values of deceleration

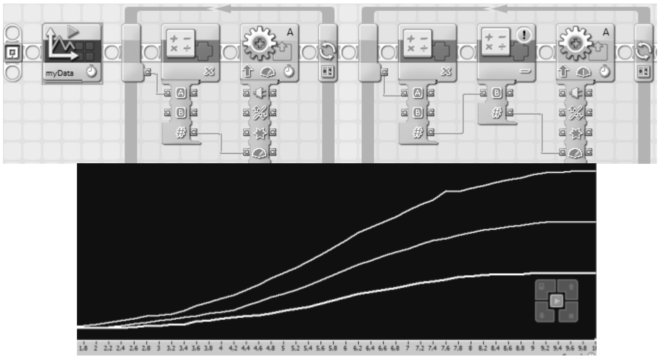


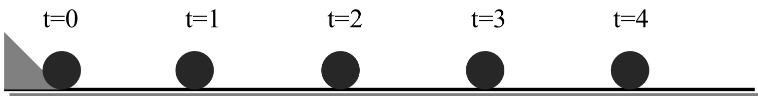
Fig. 6 Students' indicative programming solution and graph for accelerated motion followed by decelerated motion with 3 different values of acceleration/deceleration

3 Evaluation

In physics education research there has been a concern that the methodology and instrumentation used to assess graphing abilities and the impact of relevant laboratories on students' graphing abilities using multiple-choice instruments appears to have significant validity problems. The evidence from the research has identified numerous disparities between the results of multiple-choice and free-response instruments [20]. In line with this critique, we decided to use free-response paper and pencil tasks for students both before and in the end of the above 4 sessions. The test included 5 problems, same for the pre- and post-test. The problems are representative of the relevant literature and have been used in physics education research in the past [1].

The 5 problems are presented shortly below:

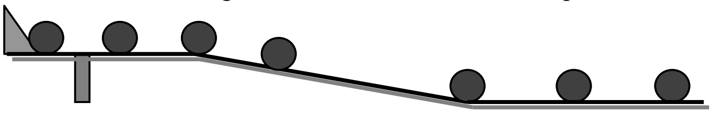
Problem 1: the ball is moving at constant speed; draw the position-time graph.



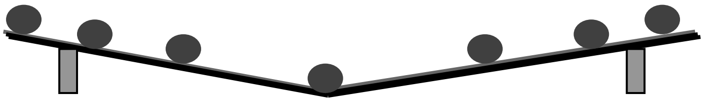
Problem 2: imagine you walk at constant speed straight to the opposite wall and come back, draw your position-time graph.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

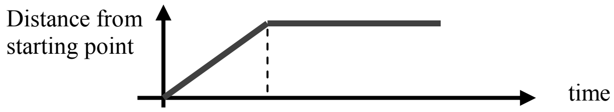
Problem 3: the ball is moving as the sketch shows; draw the position-time graph.



Problem 4: the ball is moving as the sketch shows; draw the position-time graph.



Problem 5: Explain the motion represented in the below position-time graph.



16 from the 20 students took both tests. Their answers in the pre- and post-test were recorded in a spreadsheet. Value 1 was assigned for each successful answer, 0 for unsuccessful, so the minimum score per student was 0 and the maximum was 5. Pre- and post-test score in each question/problem was defined as the count number of successful answers (fig. 7).

A statistical analysis was conducted employing a Paired Samples Test to check the significance of the observed differences between the pre- and post-test scores for each problem (table 1) and for the mean total scores (table 2). Data shows (table 1) that although students had been taught kinematics (in lecture) 3 months ago, the pre-test score was high only in the 1st problem (making graph for a simple motion at constant speed) and in less extent in the 5th problem (interpreting graph of motion at constant speed followed by stopping).

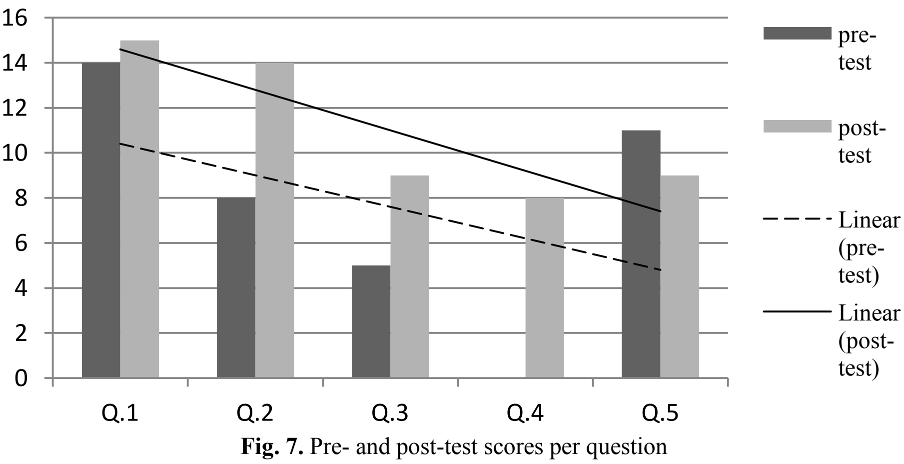


Fig. 7. Pre- and post-test scores per question

The scores in the other 3 problems were rather low; only half of the students could transform in graph the verbal description of the forward and backward motion at constant speed (problem 2); even worse were the results in problem 3 where only

ISBN 978-88-95872-06-3
pp. 2-10

31% of students succeeded in "translating" the sketch of a complex motion (at constant speed, then accelerated and again at constant speed) in position-time graph (problem 3); none drew the right graph for the complex motion (first accelerated, then decelerated) in problem 4.

Table 1. Paired samples test: students' scores per problem in pre- and post-test (N=16)

Problem	Pre-test scores	Post test scores	t-test	df	Significance (2-tailed)
1	14 (88%)	15 (94%)	0.565	15	0,580
2	08 (50%)	14 (88%)	3.000	15	0,009
3	05 (31%)	09 (56%)	2,236	15	0,041
4	00 (00%)	08 (50%)	3,873	15	0,002
5	11 (69%)	09 (56%)	-1,000	15	0,333

After the robotic activity the scores became significantly higher in the problems 2, 3 and 4 (table 1). The improvement was more impressive in problem 4 which had been initially shown the more difficult for the students, may be due to the complexity of the combined accelerated and decelerated motion. It seems that the robotic activity has helped at least half of the students to make the right graph for this complex motion event. No significant difference was found in the 2 constant speed-related problems 1 & 5. In total, the students' mean post-test score in all the 5 problems was significantly higher than the pre-test one (table 2) indicating a positive learning impact of the activity.

Table 2. Paired Samples Test: students' mean total scores in pre- and post-test (N = 16).

Mean pre-test score	Mean post test score	t-test	df	Significance (2-tailed)
2.38	3.44	4,259	15	0.001

4 Conclusions

The robotics-based learning activity reported in this paper offers a small-scale study and for that reason we should be cautious to draw any general conclusions from the findings. However, evidence from this robotic activity provided positive indications that it helped the students to improve significantly their graphing abilities related to the phenomenon of motion which in turn is expected to foster better learning of the related physics concepts. Interestingly, this happened in the 3 problems referred to complex motions (forwards and backwards at constant speed, accelerated and then constant speed, accelerated and then decelerated) where students had underachieved before the activity. On the contrary, no significant effect was found in the other 2 problems referred to simple motion events and with the higher pre-test scores.

Furthermore, the reported activity seemed to have triggered the students' interest and turned, to a certain extent, learning into a game thanks to the invention of the competitive "car-racing". Regarding the attitudinal aspects of the experiement and of the school environment during the robotic activity, it is interesting to quote from the teacher's report: "the kids in the beginning felt embarrassed staring the robotic kits. Soon their hesitation to be involved changed to enthusiasm. They started examining the content of the package. After having designed a vehicle by paper and pencil, they started the creation of their robotic car. I didn't provide any template. I let the kids to create something according to their imagination and experiementations… it's noteworthy the fact that in some cases kids did not want to stop working and leave the class during the breaks and certainly the phenomenon of the very active participation of students who had not shown any interest in the subject before when they had been taught in the traditional lecture-based way".

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Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

Robotics Camps, Clubs, and Competitions: Results from a U.S. Robotics Project

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Abstract. Funded by the U.S. National Science Foundation, the University of Nebraska-Lincoln has spent the last eight years developing and implementing a comprehensive educational robotics program for youth ages 9-14. The program is delivered in informal (out-of-school) learning environments through robotics camps, clubs, and competitions and has provided robotics experiences to over 5,000 youth and 400 educators. The goal of the project is to positively impact the youths' science, technology, engineering, and mathematics (STEM) knowledge and attitudes – and to foster an interest in STEM careers. This paper summarizes the project's evaluation and research results, focusing on the youth outcomes that have consistently emerged across the years. We also present survey results on youths' perceptions of the STEM skills they learned in relation to camp, school, their personal life, and society.

Keywords: educational robotics, research, STEM knowledge, STEM interest

1 Introduction

Educational robotics represents a powerful, engaging tool for youth learning because they can touch and directly manipulate the robots, resulting in hands-on, minds-on, self-directed learning. Our project is based on a theoretical framework derived from experiential learning, which is similar to problem-based learning in that students learn concepts and principles through authentic experiences and problems, typically in small groups, and with teachers as facilitators [1]. We also situate robotics within an integrated STEM framework, where youth must utilize science (inquiry), technology, engineering and mathematics skills to successfully complete the robotics activities.

Empirical support for educational robotics comes from research showing that robotics can increase learning in specific STEM concept areas [2], [3], [4]. Robotics also encourages student problem solving [5], [6] and promotes cooperative learning [7], [8]. Beyond the potential to influence youth learning, educational robotics is a unique technology platform for increasing student interest in STEM. Internationally, many countries are investing in STEM educational programs to compete in the global marketplace and to increase the number of youth pursuing STEM careers [9]. Studies show that robotics can generate a high degree of student interest and engagement in math and science careers [10], [11].

This paper examines how our robotics program -- delivered through informal learning environments as summer camps, academic year clubs, and robotics competitions -- supports middle school youth STEM learning and motivation. Results are provided for three overarching areas of inquiry:

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 11-18

1. What is the impact of the robotics camps, clubs and competitions on middle school youth STEM knowledge, attitudes, and workplace skills?
2. What is the impact of the robotics experiences on youth career interests?
3. How do youth perceive the value of the individual STEM knowledge and skills gained during the robotics summer camps? How do the learning experiences compare to those they experience in school?

2 Description of the Robotics Camps, Clubs, and Competitions

At the heart of our robotics project is the curriculum, which consists of approximately 40 hours of instruction involving the building and programming of robots using the LEGO Mindstorms NXT robotics platform. The format of the activities involves a short introductory presentation by an informal educator followed by hands-on activities supported by structured worksheets. Participants typically work in same-sex pairs to complete the majority of robotics tasks, and small groups of three or four students are formed for more advanced challenges. Individual lessons typically take one to two hours to complete; however more complex experiences can last as long as four hours. Sample lessons cover such skills as writing a simple program to display text on the brick, programming the robot motors for movement and various turns, using loops in a program, navigation to avoid obstacles using touch and ultrasonic sensors, and programming the sound sensor and the light sensor to track a line. (A complete description of the curriculum can be found in [12]; samples of the curriculum are on line at http://www.gt21.org).

The camps and clubs utilize the same basic curriculum but educators are given the latitude to modify and adapt the instruction to meet the needs of their participants. The camps are delivered in the summer and typically last 40 hours (one week). The clubs, which usually meet during the academic year, vary considerably depending on the organizational sponsor (i.e. 4-H, after school). Some clubs meet the entire academic year, others only a couple of weeks. The longer time frame allows more in-depth exploration of individual topics, but individual sessions can be as long as a week apart, which causes more fragmented learning. Instructors often have to review and refocus youth before proceeding with the instruction. The club format is also more susceptible to having youth drop in and out or miss individual sessions.

The robotics competitions supported through the project are through the FIRST LEGO League, one of the largest educational robotics competitions with 16,000 teams competing internationally. The project began sponsoring competitions in 2010, and the events have grown each year. The event is organized around a real-life science-based issue, with middle school participants assembling robots based on the LEGO Mindstorms kit to perform a set of defined tasks to address this issue. They also prepare an issue-based research project. Data from coaches has shown that team preparation typically lasts around 40 hours. The FIRST LEGO League does not have an official curriculum or coach training, but instead provides a handbook for coaches and links to external resources. To help support coaches in preparing youth for the competition, we made the project curriculum available. However, only about 20% of coaches reported using the project resources.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 11-18

3 Methodology

3.1 Participants

Across the eight years of the project, we collected six years of data from 1825 campers, three years of data from 458 competition participants, and two years from 126 club participants. Camp participants represented a U. S. sample from 23 states, with approximately 70% male, 30% female. Competition participants, on the other hand, were concentrated in the Midwest; gender split was again 70% male, 30% female. The club data primarily comes from Nebraska, but data was also collected from youth from seven states. In general, 67% were males; 33% female. Unlike the camps and competitions, the project has less control over club origination, organization, and research participation, and the numbers of club participants are considerably smaller than those for the other two formats.

3.2 Instrumentation

The instrumentation used in the camps and clubs each year was identical, with questions assessing STEM knowledge, attitudes, and workplace skills. STEM content knowledge was measured through a multiple-choice assessment covering mathematics (including fractions and ratios), computer programming (such as looping and conditional statements), engineering concepts and processes (such as gears and sensors), and engineering design. This instrument was modified over the years to be more application oriented and to rely less on factual recall. In addition, early versions of the instrument did not include questions on engineering design and science (inquiry). The instrument's Cronbach alpha reliability was consistently around .82.

The attitudinal instrument [13] contains 33 items that utilize a Likert format ranging from (1) strongly disagree to (5) strongly agree. There are multiple scales, including youth perceived value of mathematics, science, and robotics, as well as their self-efficacy in performing robotics tasks. It also contains workplace skills questions focusing on youth use of teamwork (e.g. "I like being part of a team that is trying to solve a problem") and problem solving skills (e.g. "I make a plan before I start to solve a problem"). Unlike the cognitive instrument described above, this instrument was used consistently throughout the project, and showed high reliability as evidenced by a Cronbach alpha of .97. The final series of questions asked youth how interested they were in certain STEM-related careers. This section again used a Likert format ranging from 1 = very uninterested to 5 = very interested.

The competition instrumentation was similar to the one used in the camps and clubs, but was shortened because of the time constraints within a competition environment. Even with the fewer number of questions, however, the reliability was high, showing alphas of .80 for the knowledge test and .92 for the attitudinal survey.

Because our project was designed as an integrative STEM experience, we were interested in knowing how youth perceived the individual science, technology, engineering and mathematics content. Did youth view the camp primarily as a technology-oriented experience? Did they recognize that science and mathematics content was embedded within the curriculum? Did they believe what they learned in the summer camp would transfer into the school environment? To answer these questions, we developed nine generic Likert-type questions (5-point scale) that could apply to each of the four STEM disciplines. For example, one question involved youth use of the separate skills to successfully complete the robotics activities, i.e. "I had to use _________ skills to successfully complete the robotics skills in this camp." The question appeared four times on the survey, with a different STEM area appearing in the blank. Other questions probed youth perceptions of a) the individual science, technology, engineering, and mathematics skills they learned during their robotics experiences, b) how this learning differed from what they experience in school, and c) how it helped them understand the impact of STEM on their personal life and the world.

3.3 Data Analysis, Collection and Procedures

The basic research design used throughout the project was a repeated measures, pre-post design, with dependent "t" tests examining differences between means at the two time points. The results addressing research question 3 were analyzed through a series of one-way, repeated measures ANOVAs to ascertain specific differences between each STEM discipline in terms of youth perception of their impact at various levels – in the robotics camp, school, their personal life, and society.

Separate analyses of the research data were conducted for each year of the camps, clubs, and competitions and many of these annual results have been published elsewhere. This paper provides a synthesis of the research results, identifying data trends, and which reflect consistent and stable effects of the robotics experiences.

4 Results

Table 1 shows Cohen's d effect sizes for the various youth outcomes by format by year. Discussion of the results is organized around the three guiding questions.

1. What is the impact of the camps, clubs and competitions on middle school youth STEM knowledge, attitudes, and workplace skills?

While the camp results are the most stable, results from all three formats reveal comparatively high effect sizes for the knowledge outcomes. (Cohen's rules of thumb for interpreting effect sizes: a "small" effect size is .20, a "medium" effect size is .50, and a "large" effect size is .80). Closer analyses of the individual scale scores show that the results were driven primarily by increases in knowledge of engineering and programming. Camps also resulted in the most consistent attitudinal results, with highest effect sizes for robotics self-efficacy. Self-efficacy also showed consistent increases in clubs. However, results for the youth perceived value and importance of STEM subject areas (task value) did *not* show consistent increases. The competitions and clubs had low effect sizes and the camps did not begin to show impacts until the last two years of data collection. An ongoing problem was the fact that the pre-test scores have been relatively high (over 4.0 on a five-point scale), making it difficult to realize increases. The possibility for increase is particularly problematic for the robotics scale, where youth tended to have even higher pre scores than other areas.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 11-18

Table 1. Effects sizes for robotics camp, club, and competition research

	Camp					Club		Competition		
Outcome	'09	'10	'11	'12	'13	11-12	12-13	'10	'11	'12
Cognitive: Overall	.60	.72	.51	—*	—	.58	.69	.28	.06	—
Programming	.40	.70	.45	.43	—	.50	.96	.40	.09	—
Engineering	.44	.60	.62	.49	.43	.39	.59	.14	.09	—
Math	.49	.12	.05	.28	—	.01	.06	—	—	—
Eng. Design	—	—	—	.16	.17	.34	.16	—	—	—
Science	—	—	—	—	.11	—	.25	—	—	—
Task Value										
Science	.15	.10	.20	.14	—	.01	-.09	.20	-.02	.13
Math	.02	.03	.14	.30	—	-.08	-.08	.17	.06	.17
Robotics	-.11	-.06	.16	.38	—	-.05	-.05	-.02	-.11	.12
Robotics Self-efficacy	.57	.33	.37	.40	—	.04	.36	.22	-.02	.18
Workplace										
Teamwork	-.47	.03	.13	.05	—	-.02	-.02	.00	.11	.38
Problem Approach	.12	.31	.25	.19	—	-.04	-.04	.30	.17	.43
Career										
Scientist	.05	.04	.14	.08	.16	.05	-.20	-.06	-.02	.08
Engineer	.11	.13	.20	.01	.09	.08	-.25	-.08	.16	.21
Mathematician	-.08	.18	.13	.08	.17	.10	-.16	.06	.15	.11
Technologist	.09	.01	.11	-.01	.13	-.07	-.41	-.02	-.19	.07

*Data not available

The problem approach scale from the workplace skills instrument also showed increases for all three formats. In contrast, teamwork, which was emphasized in all formats and was particularly important in the robotics competitions, had low effect sizes, including several that were negative (representing pre-post decreases).

2. *What is the impact of the robotics experiences on youth career interests?*

The camp data is again more positive, particularly for engineering. In addition, there were increases in youth interest in engineering careers in two of the three years of competition data, but not in science, technology, or mathematics. The clubs did not show any increases in youth interest in pursuing STEM careers.

3. *How do student perceive the value of the individual STEM knowledge and skills gained during the robotics summer camps? How do the learning experiences compare to those they experience in school?*

Results are presented in graph form below. The means above the scale midpoint (3) in Figure 1 show that youth perceived that the STEM skills they learned during the camp helped them to be successful in completing the robotics activities and in understanding how STEM impacts society and their personal life. (Average SD = 1.09.) They also reported that they used technology and engineering skills more than science and mathematics, and they gained significantly more science, engineering, and technology knowledge than math to help them in school and in their personal life.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 11-18

However, even though the math skills were considered less useful, youth still rated the math knowledge gained as being helpful (3.56 to 4.00 on a 5-point scale).

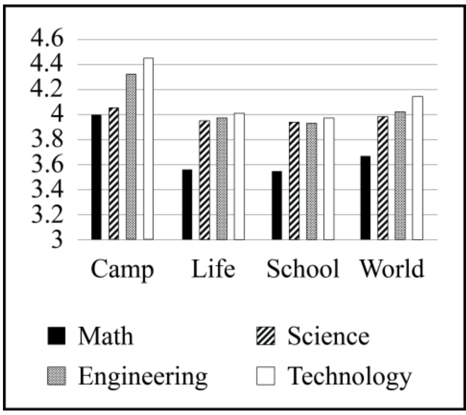

Fig. 1. Impacts of STEM skills learned in robotics camps

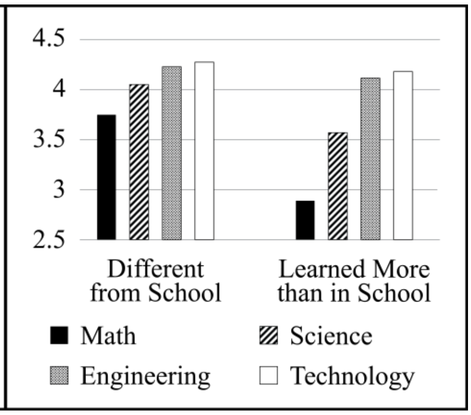

Fig. 2. STEM learning from camps vs. school

Results shown in Fig. 2 show that youth generally felt that all the STEM skills they learned were different from school (3.75 to 4.28 on a 5-point scale; average SD = 1.08) and particularly the technology and engineering skills. Fig. 2 also shows dramatic differences between the four disciplines in terms of whether youth perceived that they learned more in the camp than in school. Engineering and technology were again rated significantly higher, with math having the lowest rating (average SD = 1.20). Looking at the data descriptively, there is one result which did not exceed the scale mid-point. Youth did not believe that they learned more math in camp than in school (M = 2.92 on 5-point scale).

One question directly asked youth to assess their level of learning of each of the four STEM areas (1=none, 2=a little, 3=some, and 4=a lot). Again, youth believed that they learned significantly more science (M=3.39), technology (M=3.52), and engineering (M=3.45) than math (M=2.72).

In comparing the out-of-school learning environment to the in-school environment, youth also reported that the camp learning was more interesting (M = 4.2 on 5-point scale) and involved more hands-on activities (M = 4.36).

5 Discussion

Results show that robotics summer camps, academic year clubs, and competitions promote STEM learning, particularly in terms of knowledge of engineering, engineering design, and programming. The higher scores for engineering and programming may reflect the lack of an engineering course in middle school and the unique technology skills required to program a LEGO robot. With no previous exposure to this specific content, it is not surprising that youth showed significant gains in knowledge in these two areas. Mathematics knowledge, on the other hand, did not show increases from participation in robotics clubs and competitions and limited increases in the camps. The student perception data also triangulates these results; youth reported learning about engineering and technology but they did not believe they learned a lot of mathematics from camp participation.

Consistent results were found for youth robotics self-efficacy, suggesting that participation in robotics camps, clubs, and competitions increases student self-confidence in performing robotics tasks. The self-efficacy results, which focused on student robotics *performance*, complement those from the knowledge assessment, which assessed basic knowledge. The self-efficacy increases reflect youth growing in self-efficacy as they gain experience in writing programs to effectively control their robot's actions.

A major goal of the robotics project was to increase student perceptions of the value and importance of science, technology, engineering and mathematics, with the hope that such attitudinal increases would translate into further STEM course taking and career interest. Our data has shown that most students enter the program with relatively high expressed interest, leaving little room for increases. We did, however, begin to see some camp impacts during the last two years of data collection. The positive results in the later years of the project may be due to the fact that the camp format and curriculum were constantly being refined as we gained experience, and these results may reflect project formative improvement.

The careers data showed most success in increasing interest in engineering careers. We expect that the engineering increases are due the fact that youth are typically not exposed to any engineering curriculum in middle school and are unfamiliar with engineering both as a field of study and as a career. Thus, their experience with robotics design and the engineering process, coupled with explicit discussion of the responsibilities of an engineer as part of the curriculum, may have fostered both an increase in the knowledge of engineering, as well as in career interest. Interest in engineering careers also increased in two of the three years of competition data, but not in science, technology, or mathematics. Since there was no specific competition curriculum and no coach training, coaches focused on the requirements of the competition itself, with limited emphasis on educating youth about STEM careers. The lack of any significant results for the clubs may also be due to the variation in club format, with leaders having the option of picking and choosing the lessons. Thus, it is entirely possible that leaders omitted the lessons dealing with STEM careers in order to focus more on the hands-on robotics activities.

Regarding the workplace skills, consistent results were found for problem solving, which we believe is a result of the extensive troubleshooting necessary to control a robot. Informal observations showed that youth moved from using ineffective problem solving approaches, including trial and error, to a more plan oriented approach. Results across all three formats support the use of robotics as an excellent vehicle to promote more systematic problem solving in middle school youth

In contrast, the lack of consistent increases in the teamwork scale may be due to the complex influences of peer relationships in middle school years and the variation in facilitator expertise in encouraging teamwork. More complete results of the camp teamwork results, including gender analyses, can be found in [12].

Finally, we know that the learning environment can shape the participant's experience and impacts, and our research showed that robotics summer camps, with

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 11-18

their structured one-week format, resulted in the most potent impacts. However, the club format, despite its inconsistent length and youth participation, also showed positive increases in learning And despite the fact that increasing STEM learning is not an articulated goal of robotics competitions, our research showed positive learning impacts, as well as general attitude changes. Overall, the research results highlighted that despite the differences in goals, format, and curriculum, camps, competitions and clubs can all contribute to youth STEM learning and more positive STEM attitudes. Our research echoes other findings [14] showing that multiple formats can result in successful robotics programs, with positive impacts on youth.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 11-18

Enabling Rapid Prototyping in K-12 Engineering Education with BotSpeak, a Universal Robotics Programming Language

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Abstract. In this paper we introduce a technical approach to rapid prototype engineering ideas in the classroom. Even though a variety of educational robotic platforms exist, it is often not trivial to get started quickly. Usually, students have to get familiar first with programming concepts such as variables, data types, iterations etc. For some activities, however, the focus doesn't lie on teaching programming rather to explore and quickly prototype engineering ideas, so dealing with native programming environments is inefficient. With BotSpeak we aim at providing a universal robotics programming language for cross-platform compatibility. We explain the technical details of BotSpeak and how it enables rapid prototyping in engineering education.

Keywords: Educational Robotics, Engineering Education, Raspberry Pi, Arduino, LEGO Mindstorms, robot programming language, rapid prototyping, cross-platform compatibility.

1 Introduction

Small, low-cost personal robots have found their way into K-12 classrooms in the past two decades and are still gaining popularity [1]. They are seen as an innovative learning tool for engineering education due to their hands-on approach, which facilitates the application of pedagogical principles such as constructionism, problem-based learning as well as collaborative learning [1]–[4]. Robotics seems to unify all required skills for STEM education such as problem solving, logic reasoning, computer science and engineering as well as team work [5]. There is a variety of in-school educational robotics initiatives (e.g. Roberta [6]) as well as a large number of out-of-school activities, such as summer camps, robot competitions (e.g. RoboCupJunior[1], FIRST LEGO League[2], World Robot Olympiad[3] etc.) for students of all ages.

1 http://www.robocup.org/robocup-junior/
2 http://www.firstlegoleague.org/
3 http://www.wroboto.org

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 19-26

1.1 Educational robotics platforms

Fig.1 shows a selection of robots used in education. The list is far from complete, but it gives a good representation of platforms students and teachers can choose from. The most popular toolkit in K-12 education is LEGO Mindstorms (Fig. 1a). This might be explained by its flexibility, user-friendliness, and robustness as well as the familiarity of LEGO bricks among students and teachers. A simpler version, the LEGO Education WeDo (Fig.1b), is used at elementary school level and for the popular Dr. E's WeDo Challenges[4]. Another colorful robot used in elementary schools is ThymioII (Fig.1c). These platforms are examples of educational robotic kits that are shipped as complete systems, either as a fixed robot (ThymioII) or as a toolkit that consists of all the components needed to build a robot (e.g. motors, sensors, batteries, structural material, controller etc.) It is very difficult to incorporate non-proprietary materials and electronics to these platforms. Embedded systems platforms offer an alternative when more flexibility in shape and properties of a robot are required. Fig.2 shows examples of some popular products that range from simple microcontroller boards such as Arduino Uno (Fig.2a) and Arduino Lilypad (Fig.2c) to small, fully-featured computers running a Linux distribution, e.g. Intel Galileo (Fig.2b) and Raspberry Pi (Fig.2d). These more flexible and open embedded systems platforms give the user the possibility to build custom robots (e.g. Fig.1d–f), since high-quality, commercially available sensors and actuators can be attached. It requires, however, much expertise and effort to build robots from scratch using these products.

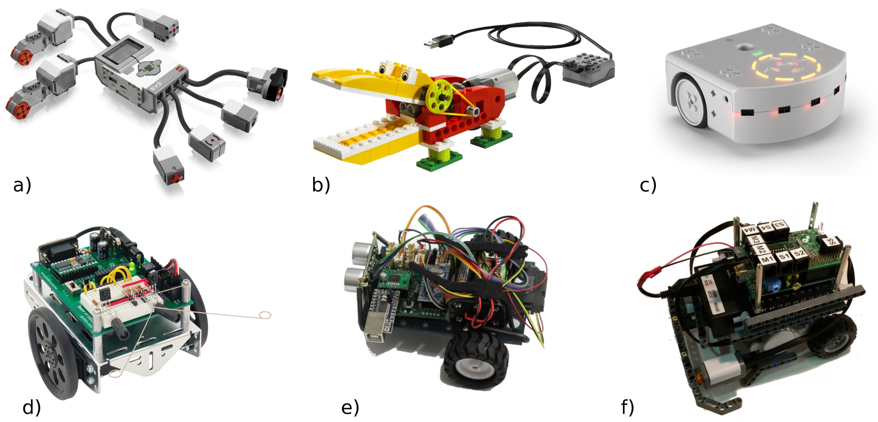

Fig. 1. A selection of educational robotic platforms. a) LEGO Mindstorms EV3, b) LEGO Education WeDo, c) ThymioII, d) Boe-bot, e) an Arduino Mini robot, f) a Raspberry Pi & BrickPi robot.

4 https://wedo.dreschallenges.com/

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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pp. 19-26

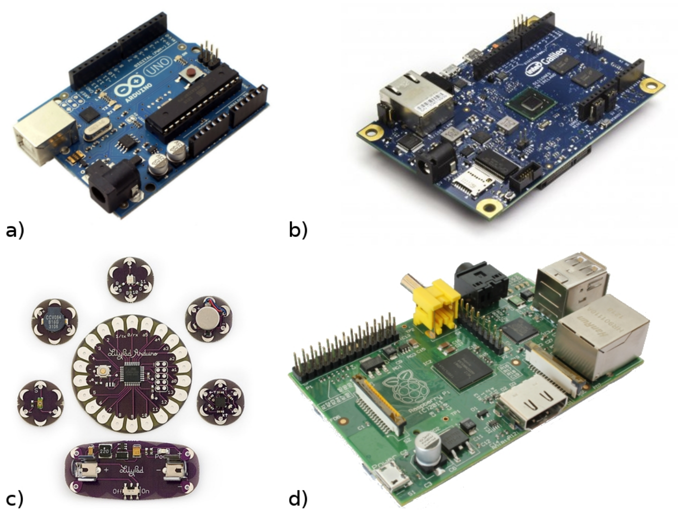

Fig. 2. A selection of embedded systems platforms a) Arduino Uno, b) Intel Galileo c) Arduino Lilypad d) Raspberry Pi.

1.2 Programming educational robotic platforms

The platforms discussed in the previous section as well as the other products available on the market vary not only in respect to their hardware properties; from a software point of view, the variety is even greater. Each product has its own way how it is programmed. The LEGO Mindstorms kit is shipped with a proprietary, visual programming language (NXT-G, EV3). In addition, it can be programmed through LabVIEW (visual data-flow language) as well as classic textual languages such as Java and C/C++. LEGO Education WeDo has its own visual programming language, so does ThymioII (Aseba). Even though C/C++ is a common programming language for microcontrollers, Arduino has its custom library, Raspberry Pi is programmed through the Linux shell, Scratch, or Python, the Intel Galileo can be programmed both through the Arduino IDE and the Linux shell. Generally, it is not trivial to getting started quickly with these platforms. The proprietary IDE's (integrated development environments) often don't run on all operating systems, connecting to the Linux shell of a RaspberryPI or Intel Galileo through SSH or Telnet requires know-how. The variety of programming languages and IDE's can have advantages, however, in a classroom context this inhomogeneity is difficult. Teachers and students cannot easily switch from platform to platform, program code cannot be re-used and shared on other platforms. Teachers tend to stick with one platform once they got used to working with it. It's is simply too much effort to get familiar with yet another IDE and programming language every time a new platform is introduced to the market.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 19-26

ROBOTC[5], for instance, tries to address this problem and provides a C-like programming language that compiles to a number of platforms, such as LEGO Mindstorms, Arduino, VEX etc. The problem to share programming code among different platforms affects not only education but also research and industry (e.g. ROS[6], Robot Raconteur[7]).

1.3 Maker Spaces in schools

Fig.1 and Fig.2 show a very small selection of all the educational robotic platforms that are commercially available at reasonable price today. And the trend has not stopped, new platforms emerge constantly. The growing do-it-yourself, or *Maker* community accelerates the development of these kind of products. The Maker philosophy turns away from pure consumption towards self-fabrication of custom, beautiful (high-tech) products. The Maker community, therefore, uses predominantly open-hardware products as in Fig.2, traditional workshop tools (e.g. for wood/metal working, sewing, soldering) as well as digital fabrication machines (e.g. 3D printers, laser cutters, CNC machines etc.) The Maker trend is growing and the number of Maker Spaces (community spaces with digital fabrication machines, traditional workshops, fabrication classes, etc.) is rapidly growing all over the world. To date, maker spaces have been used mainly by tinker enthusiasts, but now innovative educators have discovered them as possible learning spaces for STEAM (science, technology, engineering, arts, math) education. Traditionally, schools have established infrastructure for a number of disciplines: there is a gym for sports, a music room for music, a laboratory for chemistry etc. However, there is often no space for (digital) fabrication, engineering, and innovation [7]–[9].

2 Engineering activities require rapid prototyping of ideas

To improve engineering education we need suitable tools that support the right activities. Schools use frequently LEGO Mindstorms for engineering activities, Blockly[8] and Scratch[9] for programming, App Inventor[10] for Android App development etc. The aim of these educational programming applications is to lower the barrier to learn textual programming such as Java or C/C++. The students are getting familiar with concepts such as iterations, conditional statements, data types, variables etc. Everyone that wants to get started with building robots or any interactive system that controls sensors and actuators (e.g. in Maker Space activities) has to start from a basic programming introduction. There are many cases, however,

5 http://www.robotc.net/
6 http://www.ros.org/
7 http://robotraconteur.com/
8 http://code.google.com/p/blockly/
9 http://scratch.mit.edu/
10 http://appinventor.mit.edu

ISBN 978-88-95872-06-3
pp. 19-26

where the focus doesn't lie solely on teaching programming. Our classroom activities often require rapid prototyping of engineering ideas. Students should be able to think of an engineering solution for a given problem and construct a prototype quickly in order to get immediate feedback about their idea. We often emphasize an approach where different materials and a variety of technologies are used either at the same time or interchanged. For instance, one group of students is working with an Arduino board but then they want to display some data on a website. In that case it would be easier to use a Raspberry Pi instead, because all these features are already available on that board. Only, to switch from Arduino to Raspberry Pi (i.e. hook it up, setup the new programming environment, learn a new programming language etc.) would take up at least the rest of the remaining class time. Also from a teacher's perspective it is too much effort to get familiar with all platforms and have everything up and running for a class activity. In this example, it would have been better if the students could have switched the platform without any effort in order to focus on their initial idea to display data on a website.

Another example where it is useful not to have to deal with the platforms' proprietary programming environments is for interaction design research. We are currently developing an Android App called *Jumbo*[11] with the aim to explore new possibilities tablet devices have to offer for programming. It is intentionally developed as a mobile App, which forces us to rethink visual programming. We are exploring interaction possibilities with gestures, multi modal feedback such as sounds and vibrations, the use of inbuilt sensors as an interaction source and are exploiting the responsiveness and intuitiveness of mobile devices. The goal is to program a number of different platforms with this App and in addition, provide share-ability of the programming code. For the App development, we would like to focus on the user experience and not on technical details how to generate code and how to deploy it to the target platform.

These two examples show why we need to have a technical solution for cross-platform compatibility of (visual) programming code. With *BotSpeak*, a universal programming language for robotic platforms, we try to address this problem.

3 BotSpeak – a universal programming language

The BotSpeak project originated from our need to find a solution to easily deploy (visual) programming code to a number of different platforms. The commonly used educational robotics platforms (Fig.1&2) have each a proprietary way how to program, compile and upload code. It is difficult to compile and upload code natively for each individual target platform especially from a mobile device. Our solution with BotSpeak was not to compile code natively, rather to send it to the target platform as

11 http://www.jumboflow.org/

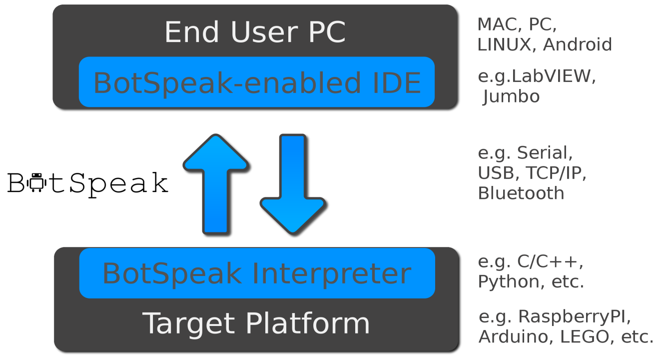

Fig. 3. A BotSpeak-enabled IDE is generating BotSpeak commands that are being sent over a communication interface (e.g. serial, USB, TCP/IP, Bluetooth). A proprietary interpreter that is running on the target platform converts BotSpeak commands to native code. BotSpeak is therefore a scripted language and is not being compiled natively on the target platform.

text commands. A proprietary interpreter (provided by BotSpeak project) runs on the target platform, receives BotSpeak commands and converts them to native code (Fig.3). BotSpeak is therefore a scripted language and is not compiled natively on the target platform. There are two ways the interpreter deals with BotSpeak commands. In direct mode the received commands are executed immediately. For instance, a `SET DIO[13],1` BotSpeak command will set the digital output on channel 13 high (e.g. turn on LED). `GET AI[2]` will read and return an analog value from channel 2. These commands can also be saved on the target platform's memory and executed later. The following BotSpeak script will blink an LED on channel 13 forever with an interval of 1.2 seconds (for a LabVIEW example, see Fig.5).

```
SCRIPT
SET DIO[13],1
WAIT 1.2
SET DIO[13],0
WAIT 1.2
GOTO 0
ENDSCRIPT RUN
```

Our aim is not to support all possible features of each target platform. Standard BotSpeak commands support the main functions a common robotic platform offers: digital input/output, read from ADC, generate PWM, timers, etc. For target specific functions a `SYSTEM` call with arguments can be sent. This requires, however, that the system call is implemented on the target platform. The BotSpeak project is still at a prototyping stage, and its language is still evolving. To present we have LabVIEW and Jumbo (the Android App) enabled to generate BotSpeak commands. On the target platform side we have interpreters for Raspberry Pi, Arduino Uno/Mini/Lilypad, BeagleBone black[12], and ThymioII. We are currently working on supporting LEGO Mindstorms EV3 as well (Fig.4). On the BotSpeak project website[13] the newest language definitions and platform interpreters are available. There are further video examples that demonstrate BotSpeak (e.g. using the LabVIEW visual library to detect a red object through a webcam and to control both a BeagleBone and an Arduino robot with the same LabVIEW code).

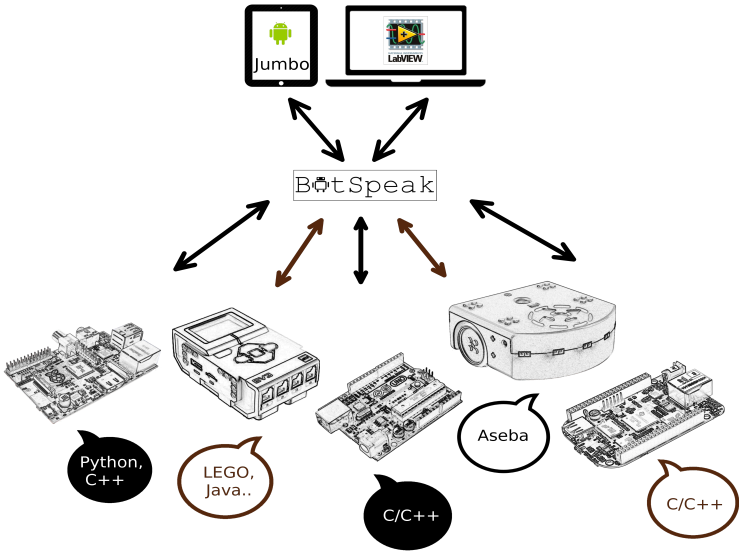

Fig. 4. Each target platform speaks its own language. With BotSpeak we aim at developing a universal language for all platforms. So far we have LabVIEW and Jumbo (an Android App) BotSpeak-enabled. That means that the same code can be run on every target platform.

4 Conclusion

The solution to define a common language for basic functions robotic platforms offer and to have it interpreted on the target platform enables us to rapidly prototype ideas. The same code can be executed on each supported platform without having to deal with native programming interfaces. The user only needs to run the interpreter on the target platform and establish a communication (e.g. TCP/IP, Bluetooth) and the system is ready to be programmed. This approach, however, has also drawbacks. The code is not compiled and deployed natively on the target platform. This would always

12 http://beagleboard.org/Products/BeagleBone+Black
13 http://botspeak.org/

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 19-26

be the most efficient way to run software. To store the script on small processors like the ones on Arduino platforms is especially difficult, due to their limited memory storage. Every target platform has different properties, supporting all possible features with one language is difficult. Nevertheless, for rapid prototyping in the classroom the support of basic features is sufficient. Furthermore, a cross-compiler for every platform is not required, only a BotSpeak interpreter. This enables the support of new platforms without much effort.

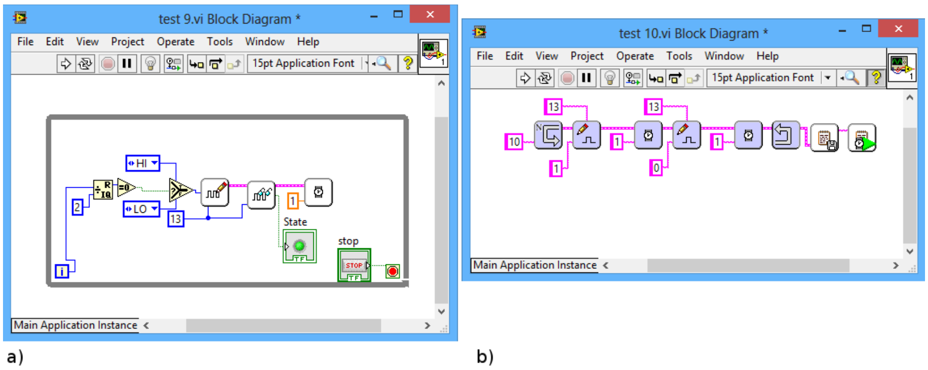

Fig. 5. The blinking LED example programmed in LabVIEW. a) BotSpeak direkt mode. b) BotSpeak scripting mode.

Acknowledgments. We would like to thank Rafi Yagudin, Jed Palmer, Dani Ithier, David Taylor, Emily Stern, and Blake Tashjian for contributing to BotSpeak.

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Robotics as a Learning Tool for Educational Transformation

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Abstract. Educational robotics is a transformational tool for learning, computational thinking, coding, and engineering, all increasingly being viewed as critical ingredients of STEM learning in K-12 education. Although robotics in education for school age children has been in existence since the late 1900s and is becoming more popular among young students, it is not well integrated as a technological learning tool in regular school settings. The paper aims to convey the importance of integrating educational robotics as a technological learning tool into regular curriculum for K-12 students and explain how it helps students prepare for the future.

Keywords—Educational Robotics; STEM education; Computational Thinking; Engineering Thinking; Coding

1. Introduction

The world is changing at a rapid pace. Technological advancements have accelerated, enhanced by the interconnectedness brought on by the power of the Internet and social media and resulting 'flattening' of the world [1]. New technological tools are introduced in our life more rapidly than ever before. New iProducts are introduced into the market almost every six months. Creative project crowdfunding platforms, such as Kickstarter (http://www.kickstarter.com) and Indiegogo (https://www.indiegogo.com/), are contributing to the accelerated birth of innovative technological tools by providing essential funding.

News headlines featuring various robotic innovations are a strong indication of how much popular attention robotics technology has garnerd in recent years. When watching the Jetsons television program in the 1960s and 1980s, very few people believed that a humanoid robot, like Rosie, could become a reality in their lifetime. On June 5, 2014, Softbank Mobile, a Japanese company, in collaboration with Aldebaran Robotics, a French company, unveiled *Pepper*, the world's first personal humanoid robot able to assist humans by reading and responding to human emotions[1]. Pepper is scheduled to be on sale for less than US$2,000 in February 2015. Prior to the introduction of Pepper, Amazon introduced its drone delivery system and Google announced its acquisition of eight robotics companies in 2013, including Boston Dynamics, a Boston-based robotics company that produces robotics creations supported by the Department of Defense, and Schaft Inc., a Japanese robot venture start-up company, and the DARPA Robotics Challenge trial was held in December 2013, followed by its final in December 2014. Aldebaran Robotics' NAO, an autonomous and programmable humanoid robot, has been used in various educational settings including RoboCup Soccer league for the development of algorithms for humanoid soccer and for the research of children with Autism.

[1]http://www.softbank.jp/en/corp/group/sbm/news/press/2014/20140605_01/

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 27-34

1.1 Recent Movements in Education

Technology is ubiquitous and integrated into every aspect of our lives. Our students are digital natives who have grown up using smartphones or iProducts. Home computers have been in existence since before they were born. A second grade student shared that he thought 'B.C.' means "before computer"! Although their lives are filled with technology, our students rarely stop to think about how their devices actually work. They rarely realize that technological tools could be fixed when they stopped working. Instead, they simply ask for new one, as if those technologies are disposables. We have failed to teach students to question or think about technology, which has the danger of creating passive users of those tools.

Popular interest in robotics has increased at an astonishing rate in the last several years [2]. Robotics technology has been implemented in a variety of fields including medicine, elderly care, rehabilitation, education, home appliances, search and rescue, car industry and more. The world and its economies are changing at such a speed that it is impossible to predict what it will look like even at the end of next week [3]. Although the world is rapidly changing, public education has maintained almost the same system since its introduction to the world [3]. Though educational reform efforts have been made around the world, the trouble lies in the fact that the majority of schools are trying to prepare students for the future by continuing what was done in the past [3].

There have been several educational movements in recent years that encourage educational innovation, such as the introduction of K-12 coding (coding education for primary and secondary students). During the Computer Science Education Week in December 2013, an initiative to bring coding into classrooms around the world called the Hour of Code was launched. During the week of December 9th to 15th, Code.org reported 15 million students from 170 countries participated in an hour of coding. One in five U.S. students participated and more girls participated in computer science in US schools than in all of the past 70 years [4]. The Hour of Code has created a large movement encouraging integration of coding in primary and secondary education. In the United Kingdom, a new curriculum framework published in 2013 emphasizes coding and engineering design [5]. It reported,

> We aspire to an outcome where every primary school pupil has the opportunity to explore the creative side of Computing through activities such as writing computer programs (using a pupil-friendly programming environment such as Scratch). At secondary school every pupil should have the opportunity to work with microcontrollers and simple robotics, build web-based systems, and similar activities. We recognise that not all pupils will wish to seize these opportunities, but they should be able to do so if they do wish to. [6, p.4]

Integrating computational thinking in primary and secondary education

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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pp. 27-34

curriculum is another movement that encourages K-12 coding. Computational thinking is a problem-solving method that uses techniques typically practiced by computer scientists. Computational thinking is "increasingly being viewed as an important ingredient of STEM learning in primary and secondary education. STEM is clearly center stage for policymakers, curriculum designers as well as researchers" [8, p.1]. Since modern economies are profoundly influenced by technology-related industries, acquiring computational thinking is crucial for the success of the next generation of students. Engineering education is an important focus in education because of the recent emphasis on STEM education. "Engineering in K-12 Education: Understanding the Status and Improving the Prospects" (published in 2009) emphasizes the importance of integrating engineering education into primary and secondary education curriculum [9]. The report suggests that engineering education enhances students' learning in STEM subjects, as well as their awareness and willingness to pursue careers in the field of engineering. Integrating engineering into curriculum will increase the technological literacy of students. The maker movement has helped encourage innovative change and creativity in schools. 'Making' integrates elements of K-12 coding, computational thinking, engineering and STEM education. Maker Faire, an annual event for *makers*, launched in 2006 by Make Magazine, has spread around the world, inspiring school age makers to participate. The White House recently announced plans to host their own Maker Faire[2] in the near future. Maker Education Initiative (http://www.makered.org/) is a non-profit organization formed "to create more opportunities for young people to develop confidence, creativity, and spark an interest in science, technology, engineering, math, the arts, and learning as a whole through making" [7 , para 1].

Robotics in education is one of the best technological and educational tools to integrate all of the movements previously described. Using robotics introduces students to emerging and innovative technological creations, as well as encouraging their participation in the act of making, which, in turn, nurtures them to become active creators rather than consumers of technological products in the future.

2. Robotics in Education for Transdisciplinary Curriculum

Introduced to the field of education as the next big thing, STEM education is commonly understood as an educational approach that integrates Science, Technology, Engineering and Mathematics, which was [24]. STEM education aims to expand the number of students pursuing advanced degrees and careers in STEM fields, increase the size of the STEM-capable workforce, and promote STEM

[2] http://www.whitehouse.gov/blog/2014/02/03/announcing-first-white-house-maker-faire

literacy for all students [25]. Increasing the size of the STEM workforce requires a transdisciplinary approach to integrating STEM knowledge and skills. As students integrate STEM academic concepts (not just one of four subjects in isolation) and real-world lessons, they will then learn to apply STEM knowledge in a context that links school, community, work, and the global enterprise [Tsupros, N., Kohler, R., & Hallinen, J. cited in 24]. Educational robotics is an effective learning tool for project-based learning where STEM, coding, computer thinking and engineering skills are all integrated in one project. Robotics provides opportunities for students to explore how technology works in real life, *all with one tool* through the act of making.

Learning with educational robotics provides students with opportunities for them to stop, question, and think deeply about technology. When designing, constructing, programming and documenting autonomous robots, students not only learn how technology works, but they also apply the skills and content knowledge learned in school in a meaningful and exciting way. Educational robotics is rich with opportunities to integrate not only STEM but also many other disciplines, including literacy, social studies, dance, music and art, while giving students the opportunity to find new ways to work together to foster collaboration skills, express themselves using the technological tool, problem-solve, and think critically and innovatively. Educational robotics is a learning tool that enhances student experience through *hands-on mind-on* learning. Most importantly, educational robotics provides a fun and exciting learning environment because of its hands-on nature and the integration of technology. The engaging learning environment motivates students to learn whatever skills and knowledge needed for them to accomplish their goals in order to complete the projects of their interest.

The following section provides three examples of the transdisciplinary integration of STEM, coding, computational thinking and engineering skill learning as students work to learn how technology works through robotics projects.

2.1 WaterBotics (http://waterbotics.org/)

WaterBotics is a NSF funded underwater robotic curriculum for middle and high school students developed by the Stevens Center for Innovation in Engineering & Science Education at Stevens Institute of Technology. The WaterBotics program provides hands-on experiences for participating students to learn engineering design and STEM concepts, while using information technology tools to increase awareness and interest in engineering and IT careers. The WaterBotics curriculum asks small groups of students to work collaboratively to design, construct, test, and redesign their underwater robots. The program uses LEGO Mindstorms NXT kits and other components for the construction of the underwater robots. Students use Mindstorms software to program a remote controller using NXT to control the robots to maneuver in the water. The WaterBotics curriculum covers various standards including the National Science

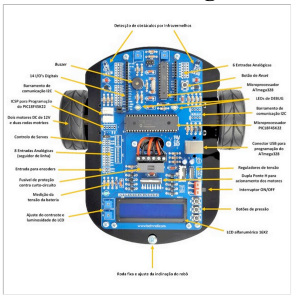
Education standards, International Technology and Engineering Association (ITEEA) Technological Literacy Standards, and the International Society for Technology in Education (ISTE) National Educational Technology Standards (for more information: http://waterbotics.org/curriculum/standards/). The curriculum also emphasizes the engineering design process (1. design task; 2. Brainstorm; 3. Design; 4. build; 5. test; 6. redesign; and 7. share), an important element of engineering thinking process. From the author's experience when participating in the teacher training workshop provided by the project, the WaterBotics program has the potential to enhance students' learning of computational thinking skills defined by ISTE and CSTA [26], including confidence in dealing with complexity, persistence when working with difficult problems, ability to deal with open ended problems, and ability to communicate and work with others to achieve a common goal or solution. Students also learn up-to-date underwater robotics technology by watching various videos and visiting research facilities.

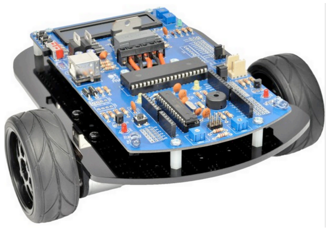
The WaterBotics program reported that the program had positive impacts on student learning of science concepts and programming knowledge, based on the statewide program with more than 2,600 participating middle and high school students in New Jersey during the period of 2006 to 2009 [27, 28].

2.2 RoboParty (http://www.roboparty.org/en/)

RoboParty is a robotic camp organized at Universidade do Minho in Guimarães Portugal, by Professor A. Fernando Ribeiro, his students and staff from the institution's Industrial Electronics department. During the three-day camp held on campus, school age children learn electronics, mechanical engineering and programming, while participating in various cultural and sports activities. The students register in teams of three with one teacher or mentor working side by side with the students. Each team receives one Bot'n Roll One A, an Arduino based robotics kit per team. The kit comes with one Arduino based controller board with all the necessary connection ports printed on the board (Fig. 1). They solder all of the components, sensors and motors provided in the box to complete the circuit. Through the hands-on experience of building with trial and error, since one soldering mistake will cause the robot to have trouble turning or moving, the students learn electronics and mechanical design. Once the robot is built (Fig. 2), the students learn C-based programming using Arduino IDE. There are three different challenges that the students may attempt to solve: Pursuing competition (a line following race), Obstacle competition (maze with walls), and Dance competition (free robotics dance to music). While developing algorithms and code for each challenge, students learn to program. On the last day, the teams compete in each challenge and showcase their robotic creations and algorithms. According to the preliminary study conducted in 2011, participating students gave very positive feedback and showed an increased interest in engineering [29]. In addition, students indicated that they had positive learning experiences while working as a team, communicating their process and product, managing disagreements and engaging in productive decision-making.

Fig. 1. & 2. Bot'n Roll Robot





2.2 RoboCupJunior (robocupjunior.org)

RoboCupJunior (RCJ) is an educational robotics initiative that promotes STEM learning, coding, computational thinking and engineering skills with hands-on, project-based and goal-oriented learning through an educational robotics competition. RCJ is open to all children up to 19 years of age. RCJ has three challenges or leagues designed to attract and motivate students to pursue robotics – soccer, rescue and dance. Since the challenges of each league remain relatively unchanged from year to year, student learning is scaffolded. Students continuously develop and sophisticate their solutions as they grow and expand their skills and knowledge over time. RCJ is committed to the *education* of young robotics scientists rather than a pure focus on competition. All three Junior leagues emphasize both the cooperative and collaborative nature of engineering design, programming and building in a team setting [12]. Each year there are more than 30 countries participating in RCJ initiatives. The annual RoboCupJunior World Championship attracts more than 250 teams from participating countries. In a study conducted with the US teams participating in the RoboCupJunior World Championship 2013, participating students reported very positive feedback on their learning of STEM, computational thinking and engineering skills as well as learning of soft skills including communication, collaboration, presentation skills, learning to be patient, and not giving up [30].

3. Conclusion

The three examples provided are just a few of many successful robotics programs and projects that utilize the transdisciplinary integration of STEM, coding, computational thinking and engineering skill learning. Robotics in education effectively engages students in the learning of STEM concepts, coding, computational thinking and engineering skills, all necessary knowledge and skills for students to become successful members of the workforce in the future. Educational robotics is an all-in-one technological learning tool that promotes the future success of our students and should be integrated more and more into school curriculum.

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ISBN 978-88-95872-06-3
pp. 27-34

Testing in Robotics Student Teams - A Case Study about Failure and Motivation

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Abstract. Robotics competitions are a very motivating approach for project-based learning. By the requirements of the leagues and the feedback from the competitions, students are developing ideas concerning quality assurance via testing as a self-organized team. The quality requirements they addressed encompass to a huge extent the software quality model of ISO/IEC 25010. These requirements were addressed by an adequate architecture and quality was enhanced by the introduction of software tests. The main motivation for all these measurements is based on the idea that the student team is responsible for their project in a holistic sense.

Keywords: Student projects, robotics competitions, self-organization, quality assurance, testing, agile methods, project-based learning, software quality models

1 Introduction

Computer science students are lacking to a considerable extent the motivation for testing even if it is part of the curriculum. In programming courses in our experience they do not accept to take the effort of writing tests, because they believe that their software is correct. For normal programming courses that is often addressed by agile methodologies like test-driven development [1], sometimes combined with automated testing of results [2]. Test-driven development requires that tests are written before a feature is implemented to prevent defects already during the implementation [3]. In robotics testing is even more complicated because of the complexity of the systems that consist of several components. Additionally, because of the sensors and actuators of robots that interact with the physical world, tests need also to be performed in the real world, testing in simulations is not sufficient.

The central question which is investigated in this paper is how students get the motivation for thorough testing. We investigated this question in self-organised student teams that develop systems for the RoboCup robotics competition [4]. The whole team consists of about 10 to 15 students which take part in two leagues of the RoboCup. We focus here on the work for the RoboCup

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

@work league. The students work voluntarily as a supplement to their curriculum. They stay typically between 2 and 4 years in these interdisciplinary teams which consists mainly of students of computer science and engineering.

This form of project-based learning [5] is an important element beside traditional teaching approaches. Robotics competitions offer an interesting environment for student projects where students are motivated to solve complex problems nearly on their own [6]. The lecturers role in this environment is to act as experts or advisers. The competency of these self-organised teams concerning project management was enhanced by coaching them based on agile methodologies [7]. A light-weight variant of Scrum [8] was proposed to the team where the students decided which elements fit in their team situation. This methodology was a good start for the student team to get more control over their project. Important issues that the student teams perceived were the complexity of quality assurance in robotics and the alteration of hardware. In this paper we investigate how self-organised teams tackle these questions motivated by competitions as source of motivation.

This paper is structured as follows. In Section 2 we provide a short overview of the RoboCup @work competition which is in the focus of our investigation. Afterwards, in Section 3 methodologies for software and system tests for robotics are stated. Section 4 describes the system architecture and Section 5 investigates the influences of quality requirements. In Section 6 we evaluate the approaches used by the student teams for testing based on experiences in competitions. Finally, we summarize the results and outline ideas for future work.

2 RoboCup @work Competition

The RoboCup robotic competition and symposium was initiated as a benchmark to elicit and measure advances in robotics research [4]. The RoboCup @work league is the most recent extension of the RoboCup. The tasks of the respective RoboCup @work competition are related to industrial applications, specifically having a robot to navigate and manipulate work pieces in a workshop environment. The main competitions therefore are navigation, manipulation, transportation, precision placement and interaction of two or more robots [9]. The workshop setup for the competitions, typically named 'arena', consists of navigation points and service areas. Figure 1 gives an impression of the competition setup.

For competitions robots have to navigate along given navigation points autonomously and perform manipulation and transportation tasks at, respectively between service areas. Many different aspects of production situations are considered. For example, dynamic changes are considered by introduction of a conveyor belt. Robots have to master the challenges fully autonomously. However, real-world set-ups are subject to sensor noise and wheel slip and thus cause many different situations within repeated runs of the same tasks. This has many implications on the development and test of software for such systems.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

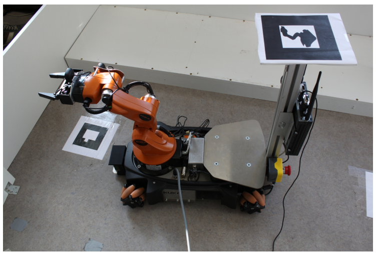

Fig. 1. Kuka Youbot robot for Robocup @Work

3 Software Testing for Quality Assurance in Robotics

For software testing of robotics we consider here techniques of the area of software testing [10] that are evaluated and adapted to the specific needs of systems that interact via sensors and actuators with the environment. The basic step to ensure quality is *static analysis* of code by automated checking tools. There syntax and coding styles can be checked to enhance the readability of the code and hints concerning potential defects, e.g. data flow anomalies, dead code, are given. The next step in software testing is typically the use of *white-box testing* to test the internal structure of software components. Because of the strong interaction with the physical world this is only applicable in few situations. Afterwards *black-box testing* is employed to test the functionality of the system based on the defined requirements.

A common approach to test such complex systems like the software structure of robots is using *simulation* for black-box testing [11]. In this environment the robot can show all its intended behaviour and failures can be observed. In robotics often *grey-box testing* is used which incorporates aspects of white-box and black-box testing. It tests part of the functionality of the system with the internal structure of the components in mind and allows to test the integration of components. It is often applied to situations where mere white-box testing is not reasonable, because the complexity of the system lies in the interaction of components and testing of isolated components is time-consuming. Based on the general idea of grey-box testing there exists approaches for random generation of test suites by Barret et al. [12].

Black-box and grey-box testing can be used as a basis for regression testing [13]. These ideas allow further on to use concepts as test-driven development where tests are defined at the same time or even before the development of the software [14]. This is typically combined with the technique of *continuous integration* of agile software development [3], where the software is built and static analysis and tests are performed several times a day, e.g. each time a developer checks in the software in the revision control system. Concerning quality assurance of software in robotics in general Koo Chung et al. [15] propose an approach for quality assurance in robotics based on ISO 9126 (now replaced by ISO/IEC 25010 [17]).

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

4 System Architecture Based on ROS

The Robot Operating System (ROS) framework [16] was chosen as the overall software structure for the RoboCup @work robot. The ROS framework is based on a blackboard architecture. This blackboard is maintained by the central program of every ROS system, the *ROS-Core*. Every sensor is publishing its data to topics on the ROS-Core where other programs, which are called nodes in the following, can subscribe to these topics and receive the data they need.

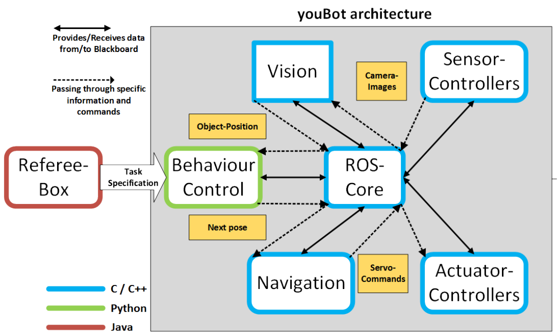

Fig. 2. Software architecture of the robot

The whole ROS system is network based so distributing nodes to different machines is an easy task as long as the network connection between the nodes and the ROS master remains stable and sufficiently fast.

5 Quality Requirements Influencing the Architecture

Based on the ideas of Koo Chung et al. [15] to use ISO 9126 as the basis for a quality model in robotics, we employ the "software product quality model" of the subsequent standard ISO/IEC 25010 [17] and investigate which of the quality characteristics the team addressed in the software architecture. It is an interesting observation that there are examples for measurements for most of the characteristics. The student team developed this architecture on their own initiative motivated by the rules of the competition [9] and problems they perceived in competitions.

– *Functional suitability:* To address the problem that during travel the sensor mounts are often bent during transport, the student team print sensor mounts with a 3D printer for accuracy. Hence afterwards they can assure that the sensor positions are accurate.
– *Reliability:* To enhance reliability especially concerning the subcharacteristic fault tolerance and recoverability failure situations are monitored and recovery behaviour is introduced.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

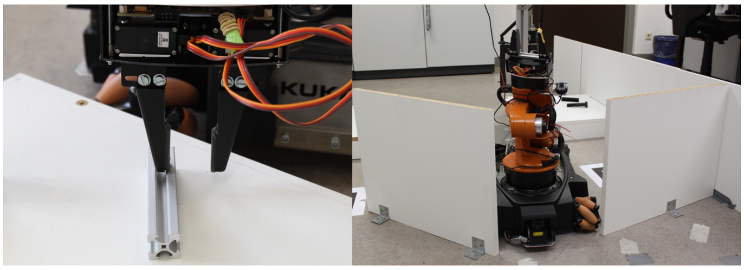

Fig. 3. Actually occurred misbehaviours (f. left, missing the object while grasping it and r. crashing into arena)

- *Performance Efficiency:* Since the computational power of the robot is limited and due to the time limit for each challenge, resource utilization and timing are important design goals for the nodes.
- *Operability:* (not addressed)
- *Security:* (not addressed)
- *Compatibility:* The basic aim of the blackboard architecture used is modularity.
- *Maintainability:* The robot allows to exchange parts like sensors which are subject to change very often and the software assumes that some kind of sensor is to be found under a designated port.
- *Transferability:* The use of configuration files for e.g. the description of service areas, delays for camera stabilization, supports the easy parametrization of the behaviour for different arenas. The ROS software stack used by all teams ensures that different teams can exchange software. There is an idea to mount LEDs around the camera to render the vision less dependant of the current light situation.

Concerning the criteria of the system quality in “use model” of ISO/IEC 25010 the system addresses the attribute of *safety*. According to the rules for the competition, the robot needs to have an emergency stop, also the robot is not allowed to leave the arena.

6 Increasing Quality by Testing

Year 0 - Competition: The student team received the robot and started the development of the software based on the ROS core three weeks before they planned to participate in their first tournament in the late spring of 2012. The main goal during this time was to produce a working behaviour and a code base that allows the robot to solve the tasks navigation and manipulation. During this time no quality assurance took place in the development process. Most of the code was written by one developer in Python.

Year 1 - Evaluating Testing Methodologies: When the team returned from the competition it turned out that nobody was familiar with the code any more. Additionally, the code was difficult to adapt, because hard-coded values where spread all over the code. The team addressed this by starting from scratch,

Methodology	**Remarks, Tools**	**Result**
Static Analysis	cpplint, (valgrind)	useful
Continuous Integration	Jenkins (bugtracker, revision control system)	useful
White-Box Testing	used for the Vision	partly useful
Grey-Box Testing	Simulation	partly useful
Test-Driven Development	AR-marker, tracking	useful

Table 1. Testing methodologies of student team

introducing configuration files into the architecture instead of hard-coded values as described in Section 5. Also, they introduced static analysis to ensure coding styles and get feedback about code with potential defects. All the nodes written in C or C++ are tested by a continuous integration server using cpplint for static analysis. There also valgrind, a tool to detect potential memory leaks, was introduced. For documentation of work the team introduced beside the continuous integration system also a bug tracker and a revision control system for the software.

Another critical aspect concerning quality assurance is the use of Python for many central nodes. With Python being an interpreted language, without the checks of the tool chain of compiler languages, failures will only become obvious by means of an exception, if the respective code is executed. This problem has been partially addressed by means of parsing the configuration files with an external program after every change.

Most of the students have a strong background in software engineering. When agile methodologies were introduced, they started to evaluate software testing techniques in the field of robotics. Hence they perceived that white-box testing is only applicable in few situations, since the interaction of components is in the focus. An example of white-box testing used by the student team is the vision, where pre-recorded pictures with annotations can be used for isolated tests. Additionally, a simulation was used as a way to test the behaviour of the whole system as a form of grey-box resp. black box testing.

Year 2 - New Ideas: It was witnessed that even the lightest changes of the environment led to different path chosen by the navigation and changed the way of grasping objects in the physical world. With simulation it was not possible to reproduce this behaviour. So an approach was chosen that uses the real robot for repeatable testing (see Laval et al. [14]). The student team developed a system based on AR-markers and off the shelf cameras to track the robot in the arena.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

Fig. 4. AR-marker tracking setup

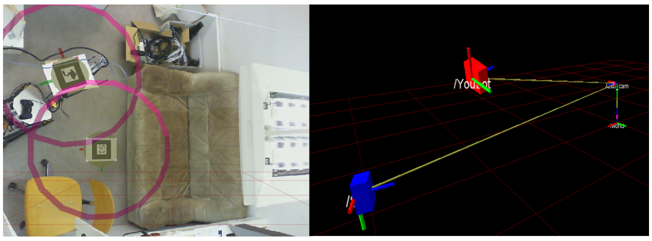

Fig. 5. Screenshot of tracking visualisation

The fact that markers are used in the @Work league led to the approach of using AR-markers attached to the robot to track it and identify the service areas the robot has to drive to. With AR-marker it is possible to reconstruct the relative rotation and translation of a marker to the camera by one camera at a time. To build up the test environment special AR-markers were prepared for the robot and its destinations. Then a setup of cameras were installed to be able to observe the whole arena (Figure 4). With the help of this setup test-driven development could be introduced.

7 Conclusion and Future Work

In the student team the motivation for thorough quality assurance and testing grew over several steps fostered by failure in competitions, starting competency in the field and a growing insight in the structure of defects and failures. This growing competency concerning software and system quality even influenced the way the students refined the architecture and evaluated technologies. Hence their perceptions and decisions are influenced by their experiences in quality assurance. Additionally, they even engineered a very innovative low-cost approach for black-box testing in a robotics environment. Based on these results, we will investigate the possibilities of transfer to programming courses.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 35-42

How to Support Students' Computational Thinking Skills in Educational Robotics Activities

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Abstract. The term Computational thinking has received intense attention over the past several years as a fundamental skill, which promotes new ways of thinking to the students across all disciplines of science. The present study describes the implementation and evaluation of developing computational thinking skills in Educational Robotics activities for secondary Technical schools, which focus on the basic skills of CT: abstraction, generalization, algorithm, modularity, decomposition and problem solving. We summarize the results from pre- and post-questionnaires and a series of think-aloud interviews. The results suggest that the students became familiar with the concepts of CT, and integrated them to a satisfactory extent in the process of problem solving in ER activities.

Keywords: Computational Thinking, problem solving, Educational Robotics.

1 Introduction

This work presents and discusses a specific didactic approach to support the development of students' computational thinking skills in activities of educational robotics. Computational thinking is a fundamental skill for everyone and as Wing believes it should be added along with reading, writing, and arithmetic to every child's analytical ability [23]. There has been a growing recognition of the importance of CT for controlling and managing cognitive activities, as well as understanding and solving problems in a wide range of contexts, not only in the field of computer science, but in all disciplines [24].

Robotics can be used as a tool that offers opportunities for students to engage and develop computational thinking skills [14], [19]. Educational robotics is being introduced in many schools as an innovative learning environment, enhancing and building higher order thinking skills and abilities, and helping students solve complex problems [7]. In addition, a guided instructional approach with robots, facilitates teamwork, develops conceptual understanding, enhances critical thinking, and promotes higher-order learning in the domains of mathematics and science [8].

This paper describes the implementation of Educational Robotics activities in a secondary Technical school, and focuses on the development of computational thinking and problem solving skills. Students work in small groups, guided by

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 43-50

worksheets to solve authentic complex problems through our proposed model for developing CT skills that focus on the following CT concepts: abstraction, generalization, algorithm, modularity, decomposition.

2 Background

Computational thinking (CT) is defined by Wing (2006) as a way of solving problems, designing systems, and understanding human behavior that draws on concepts fundamental to computer science. She argues [23] that CT is a type of analytical thinking that shares many similarities with mathematical, engineering and scientific thinking. CT roots go back, to Papert's work on Logo programming language and the idea of the computer being the children's machine that would allow them to develop procedural thinking through programming [18].

According to Wing [24] the keys of CT are abstraction, decomposition, separation of concerns and modularity. Other researchers support that the keys of CT are computation, communication, coordination, recollection, automation, evaluation, design, algorithm building, conditional logic, debugging, simulation, working effectively in teams and analyzing problems [2], [21]. Lu and Fletcher argue that, teaching CT should focus on establishing languages that can be used to annotate and describe concepts of CT and provide notation around which mental models of processes can be built [17].

Robotics is usually seen as an interdisciplinary activity drawing mostly on Science, Maths, Informatics and Technology and offering major new benefits to education in general at all levels [1], [20]. Drawing on the theoretical perspective of Piaget's constructivism, Papert's constructionism and Vygotsky's collaborative learning, ER activities help students transform from passive to active learners, developing many mental skills as researchers and creating new knowledge. Many studies indicate that ER activities have a positive effect on the development of critical thinking, problem solving and metacognitive skills [3], and also on the learning of a programming language [1]. In addition, a great advantage of using robots is that abstract concepts can be turned into real-world problems and solutions [25].

Studies have focused on the environment of robots, as an appropriate tool for the development of CT. In 2011, a research from National Science Foundation, examined how abstraction, automation and analysis in problem-solving take shape for middle and high school youth. In a robotics project, student programmers needed to think about how the robotic agent would interact within its world and the results indicated that the students were able to use abstraction, automation, and analysis to create original products. Still the field requires systematic assessment procedures. Prior research demonstrates that children as young as four–six years old can build and program simple robotics projects as well as learn powerful ideas of engineering, technology, and computer programming while also building their computational thinking skills [5], [6].

Although, CT is a concept that has received considerable attention over the past several years, the literature on implementing CT in a K-12 setting is still relatively sparse [25]. Little is known about the development of CT in K-12, although recent

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 43-50

articles begin to describe what it looks like [4]. Furthermore there is little agreement about strategies for assessing the development of CT in young people [2].

We can see that there is a lack of empirical evidence in defining the explicit boundaries of CT [11]. In our study in order to investigate the contribution of ER to the development of CT skills in Elementary and Secondary school's students, we designed and implemented the following CT model of Computational Thinking skills.

Considering the above, we focus on the following research questions:

(a) How can the CT and problem solving skills supported efficiently in educational robotics activities? , and

(b) Which are the appropriate strategies for assessing the development of CT?

3 Method

3.1 Participants

For the purpose of this study we used the Lego Mindstorms NXT 2.0 educational tool. The ER activities took place in a secondary High Technical School in Thessaloniki. We recruited 35 school students (28 boys and 7 girls). The students worked in groups consisting of 3 members. The study was conducted in 11 sessions that lasted two hours each.

3.2 A model for CT skills

In order to operationalize our approach for CT support we need to model this set of skills. A proposed model for CT skills is as follows:

Table 1. A model for CT skills

CT skills	Definitions of CT skills	Guidance for development CT skills
Abstraction	Abstraction is the process of creating something simple from something complicated by leaving out the irrelevant details, by finding the relevant patterns, and by separating ideas from tangible details [22].	1. Separate the important from the redundant information. 2. Analyze and specify common behaviors or programming structures between different scripts. 3. Identification of abstractions between different programming environments.
Generalization	Generalization is transferring a problem-solving process to a wide variety of problems.	1. Expanding an existing solution in a given problem in order to cover more possibilities / cases. 2. Use variables in solution

Algorithm	Algorithm is a practice of writing step-by-step, specific and unambiguous, instructions for carrying out a process.	1. Explicit wording of the steps of the algorithm. 2. Possibility of different algorithms for the same problem. 3. Effort to find the most effective algorithm.
Modularity	Modularity is the development of autonomous processes, which encapsulate a set of often used commands that perform a specific function and might used in the same or different problems.	Develop autonomous sections of code to be used for the same or different problems.
Decomposition	Decomposition is the process of breaking problems down into smaller parts that may be more easily solved	Breaking apart problems into smaller / single ones that are easier to be solved.

3.3 Learning Design – Implementation

In each session, the students are separated into groups of 3 with each member assuming a role such as analyst, algorithms' designer, programmer or debugger that are alternated in each activity. Students are guided through worksheets in the investigation of authentic complex problems and focus on CT language in order to develop basic skills of computational thinking:

During the sessions, the teacher has the role of the facilitator and the instructor who directs children through appropriate questions and explains and analyzes the skills of CT.

The implemented ER activities were divided into two phases: the "trainings" and the "challenge". The "training" phases consisted of 10 sessions and the "challenge" phase 1 session. At the beginning, we did an introduction on Robots and Lego Edu programming environments NXT-G and handed out an individual pre-questionnaire in order to create the students profile about their experience with computing and robotics tools. In the first 4 sessions we handed out worksheets to students for familiarizing with ER and basic programming concepts. At the core of each worksheet is the understanding and assimilation of the basic CT skills that constitute our computational model. Then we gave the first quiz in order to investigate if students understood the CT skills. In the next 6 sessions the activities had integrated more CT skills in complex authentic problems with graduated difficulty. In the robotic activities the students programmed the robots in authentic scenarios such as an alarm, a car that follows the rules of traffic, a security guard, a recycler, etc. A second quiz and a final questionnaire followed to record the student's views. Finally, a challenge took place and all the groups were required to implement an activity in which the winning group would be the one with the best performance.

3.4 Data collection

In the present study we used qualitative and quantitative methods. The evaluation tools were:

(a) systematical monitoring of the students' work by taking notes on a structured form.

(b) individual pretest questionnaire given before the sessions for creating the student's profile about computing and experience with robotics tools.

(c) individual posttest questionnaire, given after the completion of the interventions, which documented the students' views and evaluation of their overall experience with educational robotics activities. Both questionnaires used a 5-grade Likert scale (1= 'Not at All Interested', 2 = 'Not Very Interested', 3 = 'Neutral', 4 = 'Somewhat Interested', 5= 'Very Interested').

(d) Quizzes (Quiz1 and Quiz2) given in the 4th and 10th session, in which students were asked to solve problems and cite the CT concepts that they use in the problems (e.g. identify the concept of abstraction between two or more given problems and propose a generalization), and finally

(e) interviews with the students were they described the process that they followed to solve a problem. The assessment of quizzes and interviews was evaluated with graded criteria (rubric) on a 4-point Likert scale (1= 'unsatisfactory', 2 = 'quite satisfactory', 3 = 'satisfactory', 4 = 'excellent').

The evaluations tools focus on five dimensions: (1) the development of computational thinking skills and (2) problem solving skills, (3) the basic programming concepts, (4) the collaboration in the groups, and (5) the educational robotics tools.

3.4 Results

The statistical analysis t-test for paired-samples on Quiz1 and Quiz2, showed that between Quiz1 and Quiz2 they was statistically significant difference a) in the averages of CT concepts, as presented in table 2 and b) in the Problem Solving skills, in table 3.

Table 2. Results of Quizzes for CT concepts

CT skills	Quiz1	Quiz2	Statistics t-test
Abstraction	M=2.37, SD=0.826	M=2,629 SD=0,843	t(34)=-2.491, p=0.018
Generalization	M=2.21, SD=0.949	M=2.59 SD=1.003	t(34)=-2.176, p=0.037
Algorithmic	M=2.43, SD=0.822	M=2.85 SD=0.805	t(34)=-4.606, p=0.000
Modularity	M=2.06, SD=1.056	M=2.77 SD=1.330	t(34)=-3.841, p=0.001
Decomposition	M=2.35, SD=0.928	M=2.97 SD=0.954	t(34)=-3.899, p=0.000
Overall CT	M=2.29, SD=0.667	M=2.76 SD=0.792	t(34)=-5.202, p=0.000

Table 3. Results of Quizzes for problem solving

Skills	Quiz1	Quiz2	Statistics t-test
Problem Solving	M=2.55, SD=0.84	M=2.88, SD=0.89	t(34)=-2.961, p=0.006

Table 4. Results of student's Interview

Skills	N	Mean	Std. Deviation
CT	35	2.58	0.788
Problem Solving	35	2.87	0.944

According to the results of the students' Interview about the solution of a problem (Table 4), results of Quizzes for CT concepts (Table 2), and the systematical monitoring of the students' work, we noticed the following:

(1) Regarding the development of CT skills, we noticed that they have managed to assimilate them in quite a good degree (2.58). Specifically, (a) most of the students (2.38) experienced difficulties in the identification and the description of the concept of abstraction but despite this they were able to identify easily the common programming parts between different scenarios. (b) The students, in the beginning, found it difficult to understand the concept of generalization and to suggest a more general solution. However, at the end of the training, with our encouragement, we observed interesting generalizations in the activities (2.76) and more specifically in the alarm scenario the students had the idea of adding more sensors to activate the alarm in many different cases (e.g. fire). (c) Relating to the algorithm's design, most of the students (2.69) found it difficult to describe the algorithm with clarity and accuracy. They preferred to describe a process in general rather than analyze it step by step. (d) The students, after our encouragement, incorporated the creation of code's modules in their activities (2.26). (e) The students directly acquainted with the process of decomposition and they divided the problems into smaller ones, easily (2.83). Specifically it was documented during the interview that they have applied it to other courses.

(2) In the first sessions, students faced difficulties with the complex problems, however after a few trainings they became familiar with the process of solving them (2.87). It is worth mentioning some answers about the development in problem solving: "Now I think differently and solve problems more easily" and "I changed my way of thinking in problem solving".

The post-questionnaires and the systematical monitoring of the students' work on three dimensions: (a) the basic programming constructs, (b) the collaboration in the groups, and (c) the educational robotics tools, can be summarized as follows:

(a) The students became familiar with basic programming constructs such as repetition and selection and even said they would continue with programming. In particular 21 students of the computer science department stated that they understood better some of the basic programming concepts such as the concept of choice (If ... then... else) and the concept of repetition (For ... Next, Do While ... Loop).

(b) Additionally, regarding the collaboration, the students liked working in groups and assuming roles. The most popular role, for the students, was the programmer's.

(c) Finally, the students found the activities of ER very interesting and said that they would like to continue engaging with ER afterwards. Specifically they replied: "I'd like to keep working on robotics because it is the job of the future".

3.5 Conclusion

In the present research, we studied the effect of ER activities on the development of CT skills and problem solving. The results showed that the students, during the first trainings, faced difficulties understanding the CT concepts, however as the trainings progressed they started familiarizing and adopt this concepts satisfactorily. From the results of the quizzes and the final problem during the interview, which we evaluated with graded criteria (rubric), we found that the students developed CT skills quite successfully. Specifically, concerning the understanding and assimilation of the CT concepts, the ones that the students became more familiar with and in a shorter time were the Algorithm, Modularity and Decomposition. Abstraction and Generalization, on the other hand, they posed the greatest difficulty. Many students told us that they remember and they use these CT concepts in other courses as well.

From the interviews and the post-questionnaires we observed that the students considered very interesting the activities and important the guidance for problem solving in the worksheets as well as the collaboration within the teams. However, more sessions and more engagement with complicated, authentic problems are required for the students to be able to assimilate and pore over the CT skills.

Our future goal is to improve the proposed model for supporting the development of CT skills, focusing on: (a) enrich the worksheets with targeted activities it guide and support the students (b) increase the number of sessions, and (c) make a wider research about the assessment.

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ISBN 978-88-95872-06-3
pp. 43-50

Visegrad Robotics Workshop - different ideas to teach and popularize robotics

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Abstract. In this paper we summarize our experiences with the series of educational robotic workshops organized for a group of students from four schools in four countries. Brief description of the activities, their results and evaluation are presented.

Keywords: robotics education, robotic contest, robotic workshop.

1 Introduction

The robotics now became one of the best tools for training of students of engineering. Why the robotics is so popular in the educational environment? Some reasons are: multidisciplinary, practical results, new application, intelligent algorithms, etc. However, methods of using robotics in education are often very different. So the laboratories in Slovakia, Poland, Belarus, and Czech Republic have their various achievements. There are specific features in teaching, seminars and laboratory work.

In addition, each laboratory conducts its own competitions, aimed at developing certain skills in students. Each laboratory has its own interesting ideas and problems, and even mission, so the exchange of experience between them is very important and inspiring. It stimulates the development of approaches in the general direction, while maintaining its own unique character. To implement this idea, the authors have joined forces in a standard grant at the International Visegrad Fund [1].

1.1 Goals of Visegrad Robotics Workshops

Visegrad Robotics Workshop [2] was composed of four events organized in four partner cities: Bratislava, Prague, Łódź and Brest. Each event was three-fold and contained:

1. workshop giving hands-on experience for participants,
2. lectures or conference being educational part and
3. robotic competitions providing entertainment.

2 Descriptions of workshops

2.1 Workshop in Bratislava

The 13th annual robotic contest Istrobot [3] organized by Slovak University of Technology in Bratislava (STU) and Robotika.SK [4] was the first event of Visegrad Robotics Workshop. This dynamic competitions lasted whole day and was located in the premises of the Faculty of Electrical Engineering and Information Technology. Visitors could see over 60 robots in four official categories and on display in the corridors of the faculty. Some 500 spectators came to see various robots competing on the scene and presented all around at STU.

Fig. 1. Left: workshop in Bratislava with Acrob robots. Right: MiniSumo contest at the Czech Robotic Day contest in Prague.

The next day the Bratislava Robotic Workshop began. Participants from three guest countries (4 students from Belarus, 4 from Czech Republic, and 6 from Poland) could listen to interesting lectures and had hands-on workshops in the laboratories of the Institute of Control and Industrial Informatics. Topics of presentations are listed in the evaluation table (see Tab 1.). Besides the lectures, students had the laboratory tour and hands-on workshop with Acrob robots [5]. The detailed explanation on the objectives and experiments was provided. Part of the workshop was also an excursion to the ME-Inspection Company that concluded the first Workshop. Evaluations of the activities based on questionnaires from the participants are summarized in Tab 1.

2.2 Workshop in Prague

The next visit within the Visegrad Robotics Workshop began with the jubilee 10th robotics competition Czech Robotic Day [7]. It was co-organized by Robonika association and Charles University in Prague and brought over 120 robots from 6 countries. Over 500 spectators visited this event and observed 7 categories of competitions, including two new in Prague. Since the start in 2004, Charles

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 51-59

Table 1. Evaluation of the first workshop in Bratislava. Marking is based on school grading system: 1 - best / 5 - worst. Results are based on 13 valid responses.

No.	Activity	Average	Min	Max
1	Istrobot robotic contest	1,31	1	2,5
2	Andrej Lúčny: Learning Objects Representation	1,46	1	3
3	Pavel Petrovič: AI Topics	1,92	1	3
4	Peter Hubinský: History of robotics	2,12	1	5
5	Acrob workshop and training	1,15	1	2
6	Laboratories excursion	1,62	1	3
7	ME-Inspection excursion	1,69	1	3

University supports the event recognizing the values of joint theoretical and practical education. Therefore, Robotic Day is composed not only of competitions, but indivisibly also of a workshop for teams and public. It is dedicated to the exchange of experiences related to the construction of robots starting in the competition. Intentionally, this workshop is organized always one day after the competition when the participants are still well aware of everything concerning their robots and at the same time they are already past the competition stress. The basic layout of the workshop is set as a series of presentations by individual teams participating in the contest with sufficient time margins for discussions.

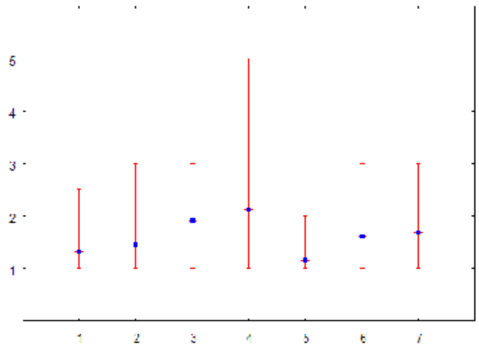

Fig. 2. Graphical evaluation of the 7 activities from the workshop according the Tab. 1

At the workshop, teams discuss deep technical details and willingly answer many questions both from other participants, visiting students as well as general public attending the workshop. It has proven over the years that the impact of this workshop is manyfold; participants share knowledge about all topics concerned (hardware, software, theory, algorithms, team management etc.) and set new contacts both on professional as well as social level. The presence of Visegrad Robotics Workshop participants was well accepted especially for the opportunity to discuss different curricula styles in their home institutions and possible future cooperation between them.

On the following days, the program consisted of lectures and hands-on exercises: Tomáš Bureš approached issues of real-time scheduling, Tomáš Plch gave lecture on Artificial Intelligence and Decision Making, Alexander Wilkie introduced us to realistic computer graphics in the lecture: Predictive Rendering – The Other Type of Realistic Computer Graphics, Marta Vomlelová spoke on Markov Decision

Fig. 4. Lectures at Charles University, Prague

Processes. Every day the morning was devoted to the lectures and the afternoons were reserved for practical hands-on robotic lab experience. These were implemented using mobile robots "MOB-2" designed by David Obdržálek for his curricula on software engineering and allowed for efficient testing of control algorithms. Although the participants did not have any experience with this particular platform, they were quickly able to exploit it and perform basic tasks in localization and control.

2.3 Workshop in Lodz

Robotix Week [8] in Lodz started on 17.11.2013 with workshop about human-robot interfaces based on Android devices or other computers communicating via Bluetooth. The latest gadgets like smartphones, tablets or laptops are perfect for intuitive driving of the mobile robot, and if the robot is additionally equipped with a camera we can see on the screen images from the remote places where we had sent our scout to. The detailed description of this workshop and the whole philosophy behind it can be found in [9]. The next day brought a new experience - working with sets of LabVIEW Robotics Starter Kit [10] utilizing hardware and software from National Instruments - project partner of the Robotix Week. Students got familiar with LabVIEW graphical programming environment; worked with RealTime and FPGA based systems being brains of the mobile robots.

On Thursday and Friday (19-20.09.2013) was the 4th International Conference on Robotics in Education RIE 2013 [11]. The conference hall of the Faculty of Electrical, Electronic, Computer and Control Engineering hosted over 50 participants from 17 countries. We had an opportunity to listen to 5 plenary speeches delivered by two outstanding professors Andrea Bonarini from Politecnico di Milano and Edward Jezierski from Lodz University of Technology as well as three representatives of partner companies: National Instruments, Kuka Roboter Poland and RoboNET. Twenty two regular papers were presented in the sessions and we could see robot exhibition with LabVIEW Robotics, Kuka Agilus and the NAO.

On Saturday the sun came out and the inhabitants of Lodz (a few hundred people, mostly with kids) were able, for the first time in Poland, to see the struggles of autonomous mobile robots in the Poniatowski Park.

The Robotour [12] contest was brought to Lodz from the Czech Republic by Martin Dlouhy from the association Robonika. Eight robots of various sizes and interesting constructions were designed to independently drive the distance of over

Fig. 5. Left: Prof. Andrea Bonarini's plenary talk on RIE 2013. Right: Roborace competition in Brest in action.

500 meters from the starting point to the target location determined by GPS coordinates.

2.4 Workshop in Brest

The last meeting of the project took place in Brest on 4. - 9.11. and included the International Conference Robotics and Artificial Intelligence, Problems and Perspective (RAIPAP) [13], workshops and robot competitions Roborace [14], all organized by Brest State Technical University.

Next two days included practical part of event. First workshop on robots programming with the use of machine learning tools (reinforced learning) were realized on mobile robots Pop-Bot and using RL-Glue environment. Second workshop was devoted to the preparation of robots to compete in a special run during competition Roborace (see workshops voting in table 2).

The meeting agenda was pretty tight, but the organizers, apart from the scientific aspect, took care of the cultural experience: we visited the Brest Fortress, bisons in the Bialowieza Forest, dairy factory, and we commemorated the anniversary of the October Revolution (7.11.) with the patriotic movie Stalingrad (watched in Russian!).

Obviously excursions won first place in estimating of activities (See table 2.2), but most interest event was Roborace - new competition for participants from Europe.

Table 2. Voting of best activities.

	Activities	**Number of votes (Total 13 votes)**
	Lectures	
1	Reinforcement learning in Robotics (PhD-student Anton Kabysh)	6
2	How can we make robot navigation more intelligent? (Prof. Akira Imada)	5
3	From neural networks to intelligent systems: researches and application (Prof. Vladimir Golovko)	2
	Workshops	
1	POP-BOT Roborace Competition	10
2	POP-BOT Reinforcement Learning	3

ISBN 978-88-95872-06-3
pp. 51-59

Table 3. Activities in Brest workshop. Results of evaluation shown non-scientific part of workshop advantages, Marking is based on school grading system: 1 - best / 5 – worst.

No.	Activities	Average	Min	Max
1	Conference RAIPAP'13	2.33	1	4
2	Excursions	1.5	1	5
3	Roborace Competition	1.91	1	5

They unite dynamism and staginess of a formula 1 with robotics knowledges. It isquite natural that conference which was held for the first time, received the smallest evaluation. In Belarus the robotics is still too young to organize serious conference.

3 Results

3.1 Results of Workshops

The main result expected from the project was a series of workshops that could help to launch new internationally connected activities. During four events, as planned, we have shared our knowledge and experience in teaching robotics and other high-tech related subjects (control theory, computer graphics, Android programming, artificial intelligence) and therefore we have strengthened the scientific potential in participating organizations. Our face-to-face meetings proved to be much more effective than any kind of distant conversation and learning. Being in one place for a few days faculty and students became aware of the local problems and learned new methods of teaching. We have continuously exchanged ideas, discussed new opportunities and further plans. We have already prepared extended version of Visegrad Robotics Workshop involving more organizations from Eastern Partnership countries (Belarus and Ukraine).

Our initiative included also organization of the large robotic competitions and conferences that could promote science and technology on the regional and international level. Presence of Visegrad partners raised some interest among visitors.

Thanks to the IVF support Czech group was able to observe the Ketchup House tournament (until 2013 it was known only in Bratislava), and bring all equipment necessary to organize the same competitions during next event in Prague.

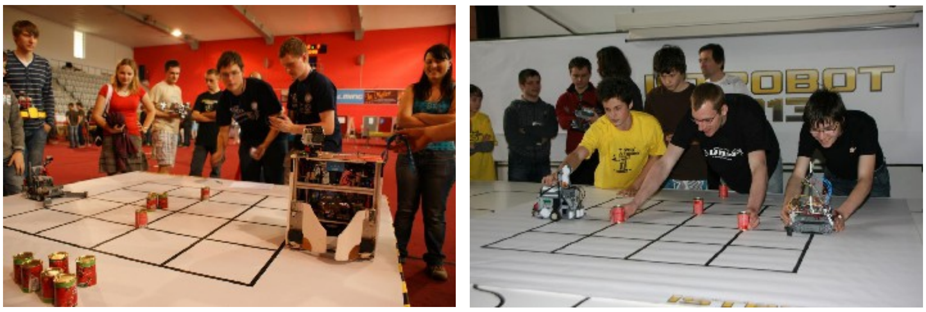

Fig. 6. Ketchup House at Istrobot (left) and at Czech Robotic Day (right).

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 51-59

The Robotour contest (until 2013 organized in Czech Republic, Slovakia and Austria) was brought to Poland as a part of Robotix Week (see Fig. 7 left). Similarly, International Conference on Robotics in Education started its travel beyond the original region: previous editions in Bratislava, Vienna and Prague were extended by holding it in Lodz and a decision to organize it in Italy 2014 and tentatively in Switzerland 2015.

Fig. 7. Left: Robotour competition. Right: POP-BOT preparation for competition.

This project was the main motivation to organize International Conference on Robotics and Artificial Intelligence, Problems and perspective (RAIPAP) in Brest where we had the opportunity to listen to guests from Belarus, Ukraine and Russia. The project participants also gave two lectures: Richard Balogh, Evaluation of the optoNCDT ILR sensor and Igor Zubrycki, Grip recognition and control of 3-finger gripper with sensor glove.

New knowledge came also with Roborace (see Fig. 5 right) – contest unknown in Visegrad countries, while extremely popular in Ukraine, Belarus and Russia. It is based on the race of autonomous mobile robots competing on the track at the same time resembling a miniature Formula 1. This is a very spectacular event with a dynamic course - a few robots is on the track at the same time causing collisions and sudden twists, which possibly will be adopted in other countries next year.

Brest Workshop had immediate results – participation in Roborace run – all students worked on the same robots and, therefore, control programs were the main issue showing seamless cooperation in mixed teams. As we expected, events in different countries encouraged students for mobility and gave positive results on social and personal level.

Project Visegrad Robotics Workshop was focused on exchange of experience and best practices in science and education. We have prepared the special DVD containing some lectures presented during workshops and conferences, educational material from workshops as well as video relation from competitions. It will be used by all participants for education and promotion. Most of this material is also available on-line [2].

Workshop participants had a chance to compete in different countries: e.g, students from Poland and Belarus won in Czech Robotic Day in category Art, Robots & Entertainment: Igor Zubrycki – 1st place with robot MousePal-2, and Dmitriy Sklipus – 3rd place with autonomous car. Two robots named MousePal and

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 51-59

OmnIVOice (built by Workshop participants) won FreeStyle contest (I and II place, respectively) at Istrobot. During last workshop in Brest we could observe truly international cooperation – team mates from Slovakia, Poland and Czech Republic worked together, as shown on photo in Fig. 7 right.

Project was prepared and realized by two public educational institutions and two non-profit and non-government organizations. All four partners of the project had equal responsibilities: organize one of the events located in their countries and help other participants with travel and accommodation. Additionally, Lodz University of Technology was responsible for coordination of the venture. Partners from Visegrad countries prepared three leading workshops while partner from Belarus could gain more experience, and has organized last event. In total almost 40 different persons from partner organizations attended workshops expanding their knowledge and experience, several hundred people (from Visegrad and other countries) took part in conferences and competitions within the project.

Fig. 10. International cooperation during last workshop in Brest – team mates from Belarus, Slovakia, Poland and Czech Republic.

4 Discussion and Conclusion

All four workshops brought new experiences and besides the immediate positive impact on the participants also some new challenges and questions. All participants, teachers and students appreciated the work in international teams, practical workshops and contests. For the future there is a question how to include such method of education into the standard curricula at the host universities. It would be beneficial if such workshops are not occasional but standard part of the regular engineering education. Financial support is crucial; without it, probably no one would take part in this venture. Especially travel and accommodation costs are too high to be covered by students themselves.

For the first time, partners just explored possibilities and resources of each university and organization. In case of repeated activity one can imagine more

ISBN 978-88-95872-06-3
pp. 51-59

interconnected workshops and continuous work on the single study/research project through the overall project period.

Acknowledgments. This project was supported by International Visegrad Fund grant No. 21220294. Authors are also grateful for all the support of the hosting universities, students and the faculty involved in organization of described events. This work is supported by the Czech Science Foundation under the project No. P103/10/1287. Publication of this paper was supported by the scientific grant VEGA 1/0177/11.

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Interactive Robotics Workshop

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Abstract. The paper presents an idea and short history of Interactive Robotics Workshop that we have been teaching since September 2013 at the Lodz University of Technology and that was conducted at Ostfalia University of Applied Sciences. For now we had three editions of the workshop: two of them as one day events in Lodz, Poland, while the third one was a three day intensive course in Wolfenbuettel, Germany. The objective of the workshop was familiarizing students with an idea of human-centered-robotics through designing, prototyping and testing small mobile robots based on Arduino controller with user interfaces employing Android devices.

Keywords: HRI,Human Centered Robotics, Interactive Robotics

1 Motivation

There are two main reasons why we have created workshop about Interactive Robotics: (1) the field of service robotics is growing rapidly - new knowledge and experience will be valuable for students on each level, both future operators as well as designers of such robots, (2) as a way to introduce students to a range of different technical and design subjects.

Recently, we can observe clear trend of moving robotic technology from constrained, industrial environment to the human environments. This is because robots have a potential of enormously improving lives of people (particularly in case of disabled people), making several tasks easier and safer as well as commercially feasible or even fun to do. Accomplishing this task requires highly interactive robots, so just as revolution of computer in each home was possible by graphical user interfaces, new robotic applications must be preceded by well designed interfaces. This however, requires highly trained robot designers, who think holistically about working with human centered robotics.

Designing service robots is a difficult task, not only because of the range of technical aspects but also because it requires some understanding of psychology, sociology and design. We can observe a few approaches in this matter: some self-motivated students from technical schools can acquire these skills on their own, or focus on technical skills while collaborating with experts of the other sciences, some universities offer interdisciplinary courses for mixed groups of students

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 60-67

(e.g., robotics and design) [1]. Nevertheless, students of control engineering and robotics need at least basic knowledge of before mentioned subjects to realize what they do not know, to learn vocabulary necessary to understand difficult design problems, and finally to motivate them to further studies.

Our workshop provides introduction to the design of interactive robots where students can see the design process in action, from the concept and research phase to prototyping and testing on small robots. During this very hands-on workshop students gain knowledge and experience on many modern technical tools for interaction design and robot prototyping. They use Arduino based micromouse robots, Processing IDE to program PC and smartphone applications connected with sensors and actuators kit. For some students this is the most interesting part as they can see and test their designs moving.

2 Main methodology

As we are introducing students to a wide range of different subjects,we had to find balance between theoretical knowledge and practical aspects that would also be interesting for students. We have based our workshop on paradigms of Human Centered and Design Based robotics, described below:

2.1 Human Centered

While robots can be used in many different scenarios, the whole workshop is based on human users and their activities. That is, robots are designed and thought of as human partners or human's tools. This is very important as robots designers understand behavior and abilities of their products very well, but end-users may not. But if the robots end-user is in the center of the design process from the beginning, there is a good chance that the ability to communicate and responsiveness, the intuitiveness of interfaces, ergonomy and comfort of use will be the main part of the design rather than add-on.

This way of thinking about robots - as a tool or partner of humans, gives also well constrained context for novice student designers. They have easier time imagining how the robot would, for example, interact with their family or move around their house, instead of imagining a robot on Mars or under the water. Human context provides also an easy way to evaluate robot designs - students can test their robots with their friends and family. This results in robots, that are more realistically designed.

2.2 Design Based

As highlighted in the previous section our students put end-user in the center of their robot design projects. By focusing on user's needs, abilities and knowledge they can ensure that final robot will be in fact useful, checking it through methods and paradigms established in design community. These methods have been particularly well studied by human-computer interaction designers and although

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5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 60-67

switching from computers to robots requires thinking in whole new dimensions, basic methods of need-finding, rapid prototyping, visual design and interface evaluation remain the same. In our workshops, we focused on some particular methods, that we found most useful in human-centered robot design, listed below:

- storyboarding. To understand the human-robot interaction task, students have to understand the whole context in which the interaction is happening, and a simple way to sketch such a scenario is to make a storyboard - a comic-like set of drawings describing what the user is doing and how the robot is involved [2][3]. Drawing such scenarios can help to see the whole picture and correctly plan interaction methods that are practical in a scenario described. Storyboards can also be used in communication with team members or consultation with experts, like on example seen in Fig. 1
- using robot mockups and role playing. Developing a mobile and well behaving robot at the very beginning of the process is a difficult task, however, students can easily use cardboard boxes or not-programmed (yet) robots to animate the proposed construction (Fig. 1). By just having physical object to move and pretend, students can understand what exactly they want to accomplish, what difficulties there could be and even start testing their robot mockups with people. On later stage, similarly they can use Wizard of Oz technique when robot is remotely controlled or animated but behaving as if it was autonomous [4].
- prototype cycle. We introduce students to the idea of prototype cycle, where on different design steps they produce prototypes - object that have some functionality of final robot, of increasing fidelity. In making successful interfaces it is important to iterate, that is to make and learn from repeating. We encouraged students to make their prototypes fast, using code snippets, paper models and whatever material they had around them. At the beginning their prototypes can be very simple moving robots (or objects), drawings of interfaces. Each of these prototypes can be used to check whether their design intention is correct. With a very simple model it is much easier to focus on important features instead of technical details.
- evaluation procedures. Robot designers typically spend long time with their constructions and get used to their quirks. To objectively evaluate their designs, students in our workshop had to use evaluation methods used by interaction designers such as Jacob Nielsenn's ten design heuristics [5], design studies with users or design comparisons. This makes final designs better as well as guides on design procedure.

3 Tools

While the whole section above described the workshop's philosophy here we present some tools we found particularly useful in teaching the interactive robotics. These tools must fulfill a number of requirements: have easy learning curve, be

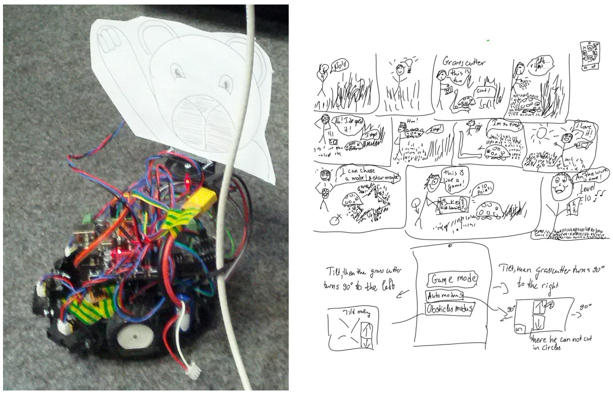

Fig. 1. a) Example of robot mockup. b) Simple storyboard of grass cutting robot game created by students of Interactive Robotics workshop

fast and robust, be usable but in the same time not limiting for those students who would like to explore these subjects deeper. In our workshop we used Arduino devices, the Processing language and modern Android based smartphones and tablets. This set of tools provided best balance between ease of use and flexibility, so that students could start fast but also have ability to use their knowledge in further projects.Taking students out of computers, giving them paper, crayons and making them playing roles also proved to be invaluable.

3.1 Arduino Micromouse robots with a set of tools

Arduino is a great tool for prototyping electronics. To ease introduction to electronics and give students the ability to work on higher level of abstractions they were given ready to use code snippets, API for robot control (PID speed controller, interrupt based encoder, etc).

Base robot for the workshop was a micromouse like robot with encoders on wheels, Arduino clone romeo board with H-bridges and a Bluetooth module, as shown in Fig. 2.

Each of student group was provided with such a robot and also a set of additional sensors and actuators like light sensors, tilt sensors, servo motors, diodes, flexion sensors, encapsulated as a building brick to avoid unintentional damage and ease the operation.

3.2 Processing

Processing is a programming language and IDE focusing on interactive applications. Created in the way that non-professional programmers, such as artists, could make their own programs. It gives easy access to non typical methods of interaction - sound, gestures, sensors. As interaction with robots usually happens while the user is away from the computer, therefore, easy access to a wide range of interaction methods is essential.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 60-67

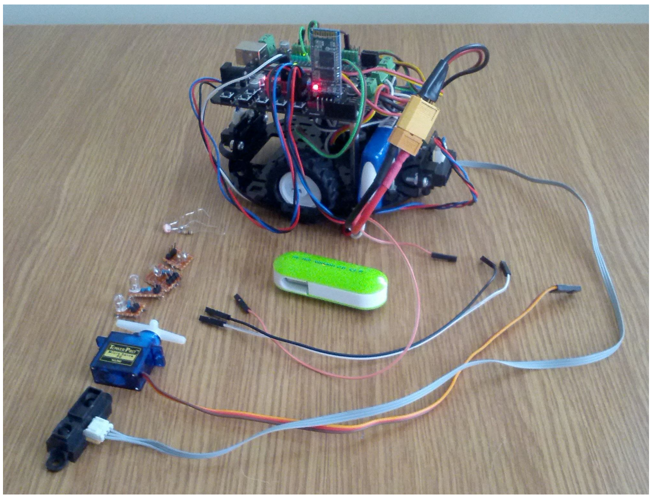

Fig. 2. Arduino micromouse robot with bluetooth, diodes, servo, tilt and range sensors.

We have prepared a set of example programs explaining the Processing functionality in context of robotics. Some demo procedures included: visual presentation of the state of the robot, moving the robot by the PC mouse with Bluetooth communication, or the sound generation.

Processing has also a dedicated mode for Android system as well as a set of libraries providing access to most of Android devices' features [6][7]. Most prominent of them - Ketai library was used in most of examples provided for students as it gives a very easy - (usually only couple lines of code) access to most of smartphones features: sensors (gyroscope, accelerometer), touch screen, gestural interface, camera, vibration, etc. (Example of students' applications can be seen in Fig. 3). Ability to make applications that could be given to end users for tests, without having them come to computer, made students focus on the interaction and not on the development process itself, as they could see how applications are used in natural environment.

Processing is JAVA based (although much simpler), all libraries for this very popular language are available. Ease of use of Processing allows rapid prototyping of Android applications and JAVA origin makes this applications easily expandable. Therefore, programs developed during the workshop are not wasted at any point, can be shared, and can be a basis for a fully developed, mature programs.

3.3 Analog prototyping

One of the main design methods is the use of abstraction - although the result of design is a physical artefact - interactive robot - the whole design process is based on its representations: plans, prototypes or word descriptions.

ISBN 978-88-95872-06-3
pp. 60-67

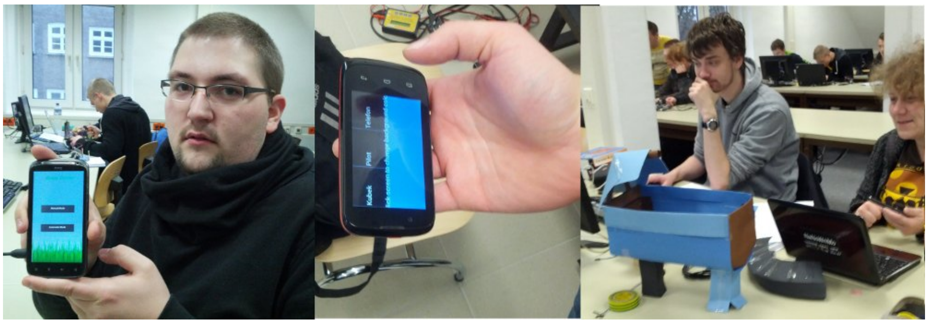

Fig. 3. Students prototypes a),b) Android applications for robot control, c) Robo-Nanny

In such demanding projects like interactive robots, working only on the technical aspects can be very misleading and narrowing the picture (one see a tree without seeing a forest). Therefore, design tools must help to understand the main problem, divide and share the work, prioritize it, and evaluate. Analog prototyping - talking, using paper, role-playing - provides very high level of abstraction, robot's functionality is imagined and as so, can be very easily modified.

Paper prototypes are also very good for receiving and delivering critique. Firstly, because little work was needed to create them, the designer is less likely to defend them without strong cause. Secondly, the person asked for an opinion knows that not fully developed product and she or he can be stronger in judgement. Paper prototypes can also be cheaply and quickly modified so the iteration process can be really rapid [3].

Role-playing and describing the robot-under-design forces team-mates to step aside the computer (the keyboard) and allows natural interaction between them. In contrast groups working only on the technical subjects students may just tap the keyboard without talking to each other and this could lead to very uneven projects.

4 Workshop history and results

Interactive robotics workshop was conducted three times in evolving form. The first edition was prepared for the Robotix Week in Lodz on 17th September 2013 as a part of Visegrad Robotics Workshop project [8]. We had very diverse group of participants starting from the high school students, through IT and robotics undergraduate, graduate and PhD students, up to faculty members from four countries: Belarus, Czech Republic, Slovakia and Poland.

Second edition of the workshop was conducted with a group of young students from the Robotics Research Association. Some of them had previous experience in robotic contests (e.g., line follower, sumo robots) but they had no experience with design methods and the interactivity.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 60-67

The third time was the longest and the most intense, conducted as a set of lectures and workshops at Ostfalia University of Applied Sciences, Computer Science Faculty as a part of International Week between 25 and 27 November 2013. As a longer (24 hours long) course there was a longer time designated for a theory of interactivity and best practices.

Introductory workshop was divided into two parts, one focused on design skills necessary to build interactive robots: observation and user needfinding, paper prototyping, storyboarding and storytelling and design evaluation as well as the second part teaching technical skills such as: robot control, usage of different sensors, Android programming.

Basics were introduced by the series of exercises, where lecturer was explaining example code followed by demonstrations made by students who presented and tested their robotic ideas.

Main part of the workshop was focused on some particular human activity that could be robotized or improved by the use of robots. It had to be quite simple idea that could be done and tested in place, therefore, students limited themselves to students' or home life. Their task was to design and test the first iteration of the idea. Students could modify examples to create interfaces that used Bluetooth, accelerometers, touch interfaces and other tools available. Their challenge was to design an interface that would be straightforward enough for members of other teams to use without long explanation. Example of such project is described in case study below.

4.1 Case study: developing friendly grass cutter robot

The Grass Cutter robot idea and prototype was developed by three students from Ostfalia University: Tina Heiliy, Lars Kelm and Oliver Bouffcher.

Students first started with brainstorming different ideas, focusing on a scenario of any service robot that could be used around home. Four of the best ideas were then converted into paper drafts, detailing stories involving using a robot: fetching robot for disabled person, pet feeding robot, grass cutter and hair washing robot. Basing on their rough drawings, students discussed each proposal, focusing on the question: how much a robot could improve each activity. They decided then to develop further the grass cutter robot idea.

Students made a list of features that users wanted to have from a device, such as safety of use, ease of use, making activity more attractive and so. Further they came with an idea of gamified robot grass cutter that would cut grass as a form of a game for the user, their storyboard is presented in Fig. 1.

Students used several paper prototypes for smartphone interfaces and the wizard-of-oz technique for the whole robot activity to evaluate their ideas. When satisfied with design they proceeded to make physical prototypes using Arduino robots and Processing language.

Students decided to use a resistive light sensor for prototype automated mode, tilt sensor to detect someone picking up and turning robot (robot should switch off). Prototype Android interface would show simple buttons for mode

ISBN 978-88-95872-06-3
pp. 60-67

choice (Game mode, Auto mode, Obstacle mode) and allow to control robot by tilting smartphone as a prototype game.

Students then divided their activity, working simultaneously on robot and Android prototypes. Workshop finished with them presenting paper and physical prototypes and discussing with peers - using Nielsen ten Heuristics as a basis [5]. They did not succeed in producing all they wanted in their prototypes but created and presented a coherent, creative vision of robot that could be easily developed further.

5 Conclusion and future steps

We have presented methodology and the history of Interactive Robotics Workshop that focus on the practical design skills of human centered robots.

Workshops' formula can be used as an introduction to robotics, as human application is easy understood and motivating and as an introduction to human robotics interaction for advanced students of robotics. Currently workshop is given to a group of high school students as a part of project of designing simple robots for autistics children therapy.

In the future we plan to make a spanned version of the workshop that would be more project based and also prepare a manual for the techniques used for a reference.

Acknowledgment

Research was partially supported by the National Centre for Research and Development under grant No. PBS1/A3/8/2012.

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When a Bee meets a Sunflower

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Abstract. The paper describes a project which involves two first primary classes and was dedicated to a reproduced natural scenario, with two protagonists, a bee (represented by a Bee-bot robot) and sunflowers. Learning motivations and approach, objectives, expected results, details of how the activity was designed and conducted are presented. Some evaluations of the experience and its outcomes complete the presentation and give substance to the proposed approach. The activity originated by a training course dedicated to constructionist educational robotics.

Keywords: Educational robotics, Primary education, Bee-bot, Constructionism, Learning by discovery.

1 Introduction

Technology is currently perceived as a pervasive aspect of everyday life: this can lead parents to expect that the school system introduce ICT very soon. But the introduction of technology at any school level is not a value 'per se' and must not act as a temporary myth or an illusory panacea for any teaching/learning problem [1]. What makes ICT at school valuable is the possibility to use technological advanced tools for promoting joyful interests in STEM and in other disciplines [2][3], to organize a collaborative and project-based learning [4], to make open-minded evaluation of real life experiences [5] reproduction and simulation of the physical reality giving a deeper understanding of our surrounding world together with a clearer awareness of our intimate perceptions (see Tinkerability in [6]).

With respect to other technologies, robotics is proved particularly powerful as a learning tool due to its attractiveness, its multidisciplinary, its easiness to be integrated in broader multimedia and multi-channel learning projects [7]. Recent researches [8] [9] [10] provide proofs of the positive effects of good practices and cues for conducting calibrated, effective and relatively low-cost laboratory experiences at any level using robots. Most research work has been done at secondary and university level, but literature has started to propose good examples and

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 68-75

researches also at kindergarten and primary school [11] [12] [13]. Even pupils with severe problems can benefit from educational robotics [14] [15].

When introducing robotics in a primary class, special attention must be dedicated to motivate the role of the various actors in the project: teacher(s), robot, pupils, and other recognizable elements of the scenario. The robot can be a sort of protagonist but should not be considered as the only centre of attention during the development of the project. Other elements play relevant importance: the story which acts as the glue for all the developed elements; the realization of accessory artifacts, like other characters of the scene or objects of the story; the importance of discussions within groups and among groups about the aspects related to the story and to the task of the robot. In all this scenario the robot embodies a specific aim: it acts as an operative delegate of a pupil or a group of pupils. After an articulated design the actions for the robot are programmed to achieve established goals which are significant and particularly rewarding in the pupils' perspective [16] [17]. Though the teacher preferably leaves an 'open minded' development of solutions, these goals should be suitably identified in order to make the overall experience reach the desired learning objectives.

This paper describes a laboratory activity done during this present school year in two first classes of a primary school. The story was carefully chosen to allow the teacher to deal with various topics spanning subjects like biology, botany, geometry, earth science, and formalization of actions. The robot used was Bee-bot [18] [19] [20] which has already been proved as an effective platform for this level of school. The project was developed as the experimental part of an intensive training course on Educational Robotics, attended by the primary teacher (one of the authors): after some lectures with a group of teachers at the beginning of the year, the training included the work in class for every teacher. The course was organized following the curriculum developed by the TERECoP project [21]. In section 2 we describe the design of the project and its main goals and expected outcomes; section 3 describes all the preparatory decisions and how the experiment was conducted together with some relevant facts; section 4 is dedicated to the evaluation the obtained outcomes, followed by some final remarks and future development.

2 Project design

2.1 Operating context and cognitive challenges

The activity was designed for pupils of two first class of primary school, with respectively 27 and 21 pupils, with a slight majority of males over females. Up until now, we used, about 11 hours per class during the curricular hours for maths, science and technology. The main teacher received only the partial support of a special-needs teacher (appointed to regularly support one kid with special needs in one class).

In designing and carrying out the activity some specific aspects usually shown by a group of this age was taken into account. In fact, in the 6 years olds you see the overcoming of the childish syncretism (global, undifferentiated perception of reality) and the appearance of analytical ability, hierarchical structuring of the phenomenal

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 68-75

field, adoption of a reversible perspective, the ability to perform exhaustive explorations, the development of the constancy of magnitude and its measurability. At this age, reversible operational thinking matures, memory expands becoming not only episodic but also schematic, the capacity of representation strengthens, the pupil begins to coordinate two perceptions following in time and to perform first simple classifications and serialization. Moreover there is the slow and complex transition from pre-causality to causality and the ability of distinguishing between a rational and a fantastic explanation arises.

Starting from all the aspects briefly summarized above, we designed the experience to propose a path of development that would have stimulated the described cognitive transition, not giving the robot a secondary role. We were first looking for an argument acting as a general subject, and a motivating excuse, for the experience, easily identified in a usually known flower like the sunflower and an insect which could have a special relationship with it, the bee. This second choice would have simplified the introduction of the robotic component due to the Bee-bot specificities. Apart from the robot, all the other elements used during the experience should have been low-cost and easily obtainable components, with a good degree of repeatability of all the phases.

2.2 Objectives and expected results

Main objectives which have been taken in to account during the design:

- to start stimulating some discussions which should instill the desire for literature and family research;
- to establish a link between the first ideas and abstractions built during the initial phase and the 'robot game', in a constructive way;
- to make the pupils perceive the constrains imposed by the adopted robot and harmonize them with respect to the robot's goals;
- to define a suitable form for coding sequence of actions of the robot and control the transfer of the sequence onto the Bee-bot;
- to convince the pupils (this is not very hard!) that following the trial-and-error procedure is an absolutely acceptable strategy;
- to lead the pupils to perceive and assume direct responsibility towards the other components of the group, and accept team working;
- to emphasize the multidisciplinary aims of the experience;
- to valorize the discover-by-experience approach, a sort of serendipity that can bring a deeper understanding and learning.

This project involves pupils who face scientific aspects probably for the first time. Thus the main expected result was the ability to discover relevant facts from research, direct observation, simulation and discussion. Such an experience was largely based on team work and we expected that the pupils learn how to collaborate for a shared purpose. In the Papertian perspective we expected also that the awareness of the importance of teamwork for problem-solving purposes were made easier by integrating the robotic component in the experience. The depth in the comprehension of all the scientific details encountered will be evaluated all along the experience through observations, discussions and Q&A sessions with the teacher.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 68-75

3 Conducting the experiment

The preliminary research, organized on an individual basis as homework with the help of families, was aimed at finding information about the flower, its growth, its behavior, its utility for human and animal nutrition, and on the insect and its many interesting aspects. One specific theme suggested for deepening was the relationship between sunflowers and bees, how a bee moves to reach a flower and how it communicates to other bees the position of an 'interesting' flower.

Fig. 1. The realization phase of the prototype

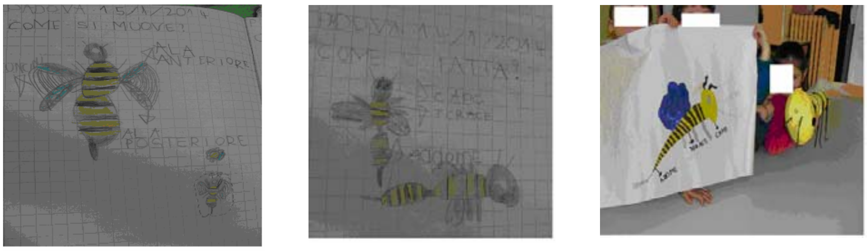

Fig. 2. The design phase of the prototype

The laboratory part of the experience was conducted with groups of 4 kids each. The first step of this part was to choose materials and, more specifically, for building robotic prototypes taking inspiration from the scientific information previously collected. The idea of constructing these prototypes (i.e. physical models of bees which could in principle be subsequently motorized and rendered autonomous) (Fig. 1), it represents the sort of cognitive link we mentioned above. This construction was preceded by a graphical design (see Engineering design process in [22]) (Fig. 2) through which pupils were free to imagine their prototypes with appearance and potentiality fruit of their knowledge and fantasy. The prototypes, being actually simple puppets, express their potential only ideally: therefore the teacher can easily motivate the introduction of the programmable robot which responds to a need of performing dynamic and 'intelligent' behaviors as the natural completion of the role of the bee in the story.

Also the 'robot game' was anticipated by a paper-and-pencil design. We defined the first task of the robot: there is a sunflower, drawn on the sheet that acts as the plane of movement; the bee, starting from a point near one border, must reach the flower along a path made of segments which have a size multiple of the Bee-bot step and parallel to the borders. The groups were asked to code the sequence of movements using a textual language: its keywords are the Italian translation of the Logo-like base

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 68-75

commands (forward, backward, right, left and pause). The evaluation of the repetition factor necessary for long straight movements was made easy using a squared paper and considering one square edge as the Bee-bot step (Fig. 3). After having agreed on the apparent correctness of the program on paper, the translation of the code into commands (i.e. robot button pushes) did not offer great difficulty, though the repetition parameter of the moving commands requires a transformation into a suitable sequence of one-step commands. This first task was followed by a couple of more challenging options: to reach first one flower and then another one in a different position; to come back to the starting point after the flower tour and make a small 'dance' to communicate to the other bees the presence and positions of interesting flowers.

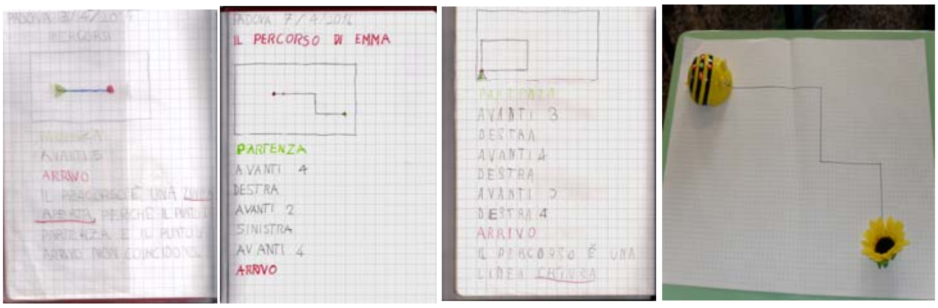

Fig. 3. The programming language and the robot game

To give the project a broader view of the context and to stimulate other competences, the experience was accompanied by an activity related to botanic aspects: some sunflower seeds, initially germinated in a mini-greenhouse, were put into different containers and the groups were asked to classify the different types of seeds, to make observations on the germination and growth using a lens, and to write their comments on their exercise book.

4 Evaluation of the results and conclusions

The experience presented in this paper was initially proposed by the primary teacher as an example of a didactical unit during the training course. Through a successive refinement in the design it became an actual multidisciplinary laboratory activity where learning by doing, project-based learning, open-minded discussions, constructionist approach, inquiry-based learning as opposed to ex-cathedra teaching, were not empty-of-meaning words but precise guidelines for what eventually developed in the classrooms. Observing the steps suggested by the teacher during the experience, you can find a classical refinement cycle through: documentation, design, realization of the prototype, coding, programming the robot, evaluation, where the results of the evaluation can motivate refinements for any of the previous steps. This structure is also related to the phases which were considered the basis of the TERECoP methodology for introducing robotics in the curriculum [23]: engagement, exploration, investigation, creation and evaluation. Moreover, when preparing a

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 68-75

multidisciplinary experience like the one presented here, we should always emphasize the importance to ask even very young pupils to report whatever they have done or found. Reports showed a correct use of language in describing both natural and technical details. We also observed that the accountability shown by the pupils when applied in a scenario of cooperative learning translates into forms of spontaneous group solidarity, not solicited by the teacher.

Regarding the work with the autonomous robot, its importance and degree of satisfaction is easily accepted by the pupils because the robot is perceived as a natural strengthening and improvement of the realization of the 'static' prototype, and therefore relevant for the personal expectation. The robotic component permitted to more naturally introduce some important geometric concepts (like segment, open broken line, close path, and in perspective perimeter and area of a close figure) together with the identification and perception of regularity of figures and also a first idea of angles, with a better awareness of the learnt abstractions through a constructivist approach.

The adoption of a textual command language was successful and without faults or great difficulties in terms of proper understanding. A language with keywords having unambiguous meanings for pupils better allows open discussions and reasoning, thus it makes the transfer of knowledge among groups and between the teacher and groups easier. It was also useful to promote a trial-and-error approach when, for example, having to move two steps aside on the left, the incorrect sequence of 2 left rotation was rapidly corrected after the robot had showed the error with evidence. Also the effectiveness of teamwork was proven by all the materials of good quality produced by the groups and by the richness of the discussions spontaneously emerging or solicited by the teacher.

About the expected results mentioned in paragraph 2.2, all of them were essentially obtained. The assessment of these results, for this first experience, was done through a more careful evaluation of the usual *in itinere* verification tests and through an observational research [24] supported by check lists and a diary. Tests delivered at the end of the year revealed noticeable improvements with respect to some initial evaluations, (namely, 21% of the total in one subject, 49% in two subjects, 30% in three). Kids was observed in action during the laboratory moments and outside those moments during the entire period of experimentation, taking notice of all the interesting reasoning, behaviors and discussions spontaneously produced. This 'observing on the field' ask the teacher for an attitude of listening and attention oriented to capture all those signals relevant for the evaluation. Documentation is provided in the form of photos and collecting digital materials when possible. The gain reached by integrating the autonomous robot in the experience was positively evaluated in terms of problem solving degree, easiness to rapidly reach correct solutions, depth of the learning process with respect to all the scientific elements introduced in the experiment. We are consequently convinced that robotics makes all these achievements, which are of relevant importance in the first year of a primary level of education, more easily and deeply obtainable.

One specific aspect worth to be mentioned is related to the low threshold/no ceiling principle. No distinction was applied among the pupils in the class: all of them, excellent, 'normal' and with some difficulties were involved in all the phases (design, prototyping, programming) actively participating to the work of their team. Even in

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 68-75

the case of a kid with some learning difficulties he could experiment situations of 'good engagement': we observed that the other kids in the group related to him by observing his potentials and not his problematic aspects; in particular the activity with the robot did not create any negative discrimination for this kid. The additional special-need teacher, who was present all the time with the class of this kid, was not forced to concentrate her attention to the group of the problematic kid but could help the main teacher in a rather exceptional broader sense.

Finally we observed that the cohesive moments of discussion and reflection produced a general improved ability to listen and an improved capacity to express their own hypotheses and opinions even for pupils who were not used to relate happily with their classmates, ensuring the general participation of all.

Like in other experiences described in the mentioned literature, the educational robot is actually a powerful cultural artifact and, more specifically, the Bee-bot has proven itself adequate for the purposes of the project and for the level of development of the involved pupils, due to its constructive and programming simplicity, whereas most expectations were fulfilled. This first experience will help to design further robotic-oriented projects involving the same classes in the next year(s) with the possibility to experiment improvements such as a differently dressing of the Bee-bot, integrating the activity with the physical robot with a simulation on a PC, adopting more performing robot kits and programming environments, and a more structured evaluation plan, also taking into account the possibility to get a wider feedback depending on the different age of the kids.

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A new educational tool for Bioloid Kit

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Abstract. The aim of this paper is to show the implementation of a new educational tool within Physical Etoys that enables the use of the Bioloid kit in the classroom. A new firmware was made and some of the objects of the kit were virtually represented with Physical Etoys in order to create a more intuitive approach. In addition, a simplified example of inverse kinematics with a humanoid for high school students is proposed.

Keywords: physical etoys; educational robotics; bioloid; inverse kinematics: trigonometry

1 Introduction

Since the emergence of educational robotics kits, the presence of particular technological materials in the classrooms has been growing. In Argentina, there are three provinces that have already implemented the use of this resource in their classrooms. To achieve the same aim, the rest of the provinces begun with pilot programs. Another proof of the presence of such materials is the surging of both nationals and internationals contests such as the Roboliga, the Argentinian Robotics Olympics and the Robocup Junior, which is an international competition where students from around the world gather to share their experiences in educational robotics. In the Robocup Junior, particularly, there is a category known as Dance [1], that brings together the largest number of participants in which is common the use of humanoids within a developed choreography.

In summary, the use of robots as an educational source inside the classrooms is no longer a novelty. As an innovation, we propose the inclusion of humanoids in the kits used at school. What special qualities does this kind of robots offer us as teaching material? On the one hand, the interest and motivation that they cause on children is much greater than the one caused by any other type of robotic material. On the other hand, the design and programming of a humanoid's behavior implies a careful consideration about the human being itself.

Following our aim of introducing robotics in the educational system, we can use this robot in other disciplines such as natural sciences, where it allows us to study the body of a human being and its various systems. It also offer us a new set of challenges related to calculations, trigonometry and physics as we will see in a further example.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 76-83

At the same time, developing any intelligent behavior of the robot as a response to the captured data by the sensors implies studying aspects of communication, collaborative behavior and so on.

Researchers have begun to investigate, within special education, the use of robots, humanoids in particular, for the treatment of autism. The most important job in this field is the one that has been developed since 1998 by the Aurora Project of the Adaptive Systems Research Group at the University of Hertfordshire. [2] [3]

Various studies allow us to affirm that its therapeutic use in imitative interactive games help the development of social skills in autistic children. In the last few years inexpensive and highly versatile humanoids have emerged in the market which allows its mass usage at school and/or health institutions. Unfortunately, the programming of these devices requires complex languages, which impedes a simple use on behalf of professors or the kids themselves.

This is why we decided to expand our graphic platform of robots programming, Physical Etoys, to be able to control the most popular low-price humanoid in the market: Bioloid robot from the Korean firm named Robotis.

2 Physical Etoys

Physical Etoys is an extension of Etoys, a media-rich authoring environment and visual programming system made by the very same people who created Smalltalk, and it inherits all its educational potential [4]. The purpose of Physical Etoys is to allow kids to program robotic kits in an environment specially designed for them, following Papert's constructionism ideas [5]. Within this environment, physical objects are represented graphically and the students can directly interact with those entities, instantly seeing the consequences in the real world.

Physical Etoys is free, open source, it works in several operating systems, and it is translated to many languages such as Spanish, English, French, and Portuguese and others. Comparing Physical Etoys to other popular programming platforms for kids, such as Scratch, falls beyond the scope of this paper. However, we chose Physical Etoys because of its distinct characteristics: the entire Smalltalk programming environment is available in case the user needs to add more complex behaviours to his projects; and it provides different ways of expressing solutions to its problems through the use of multiple programming models (for instance, you can express your problem using a spreadsheet or a state-finite machine).

Among the robotic kits supported by Physical Etoys we find two big referents widely used by the education community: the Lego Mindstorms NXT and the Arduino board [6]. Since version 2.0, Physical Etoys also supports an argentinian robotic kit called DuinoBot, which is used in several schools from Argentina. Moreover, Physical Etoys includes a module system that allows the user to extend it in order to support many different electronic devices such as Microsoft Kinect, Nintendo Wiimote, Orbotix Sphero, among others.

Physical Etoys exposes a graphical user interface in which the real objects used in each kit (including motors, sensors, controllers, and wires) are represented by virtual objects. The user can create scripts by dragging and assembling tiles. These scripts run virtually at the same time, implicitly exposing the student to concurrent programming in an easy way.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 76-83

3 Graphical User Interface of the tool

The Bioloid module of Physical Etoys has two objects: the motor and the CM-510 controller. They represent graphically some of the real objects that the Bioloid kit has in order to reduce the complexity of the interaction with it.

The properties and behavior of these objects can be programmed with these tiles:

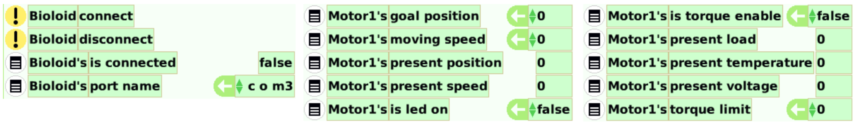

Fig. 1. Important tiles to program the Bioloid controller and Motor objects.

For example we can create a script in which the Bioloid Humanoid waves. We can take advantage of changing the script's ticking rate to one time per second in order to wait for the motor to reach its final position before the next movement:

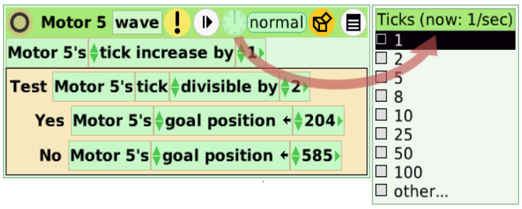

Fig. 3. Scripts to make the robot wave.

The objective of this virtual representation is to let the user focus specifically in the problem to solve instead of dealing with the complexity of the abstract thinking. If the user demands new challenges to program that cannot be done with tiles, he can switch to Smalltalk within the same environment.

4 Description of the Firmware

The original firmware included in the Bioloid kit has a few problems that we needed to solve before being able to use the kit with Physical Etoys. Among these problems, the Bioloid's firmware does not allow to easily access the data from the sensors and it provides little to no control over the possible errors produced in any part of the system (being the CM-510 controller, the servos, the communication between the controller and the servos, or between the controller and the computer).

Moreover, the original firmware includes a request-response communication protocol, which is not very suitable for Physical Etoys typical usage. Since in Physical Etoys all slots are constantly updating its value, this constant update would mean a lot of useless requests sent to the robot's controller.

For these reasons, the original firmware provided by the Bioloid kit was replaced by a new firmware that solves the abovementioned issues. This new firmware is based on the communication protocol used in Physical Etoys to communicate to the Arduino board, which is in turn inspired by Firmata [7].

This protocol message format is very simple and quick to parse, which makes it easy to implement and efficient for most use cases. In this protocol, each message contains a byte denoting its type followed by a series of arguments. Each type of message expects a fixed amount of arguments, so all messages have a fixed size known beforehand. Thus, when receiving a message, reading only its first byte is enough to know how many arguments to expect next. The "type" bytes and the "argument" bytes are marked distinctly using their first bit (being 1 for "arguments", and 0 for "type"). This allows them to be easily identified and helps preventing communication errors. However, it means that the maximum number of messages allowed is 127 and all arguments sent must be split in packets of 7-bits. In practice, this disadvantage is insignificant.

To control the Bioloid servos from the computer only two type of messages are necessary: RQ_SERVO_WRITE_BYTE and RQ_SERVO_WRITE_WORD.

With this two messages any attribute from the servo can be modified, being the most interesting: Goal position, Led, Moving speed, Torque enabled, and Torque limit.

From the other side of the communication, the robot controller sends at regular intervals the data from each servo. This data is limited to only a few of the servo's attributes in order to prevent overloading the communication channel with useless information. The attributes we most care about are: Present load, Present position, Present speed, Present temperature, and Present voltage.

Additionally, in order to avoid receiving data from servos we do not need to monitor another type of message was implemented, called:
RQ_SERVO_ACTIVATE_SAMPLING.

5 Inverse kinematics example

5.1 Description

As an example of this educational tool we have developed an application that takes advantage of the humanoid structure provided by the Bioloid kit and the skeleton information given by Microsoft Kinect.

This example can be used to teach the following concepts: basic trigonometry relations, coordinate systems, and linear functions.

By taking advantage of the information provided by Kinect, the application performs the necessary calculations in order to translate the positions of each skeleton's node to appropriate angles for each Bioloid's motor, so that the robot can mimic the human position in ACAACA near real-time.

We will be using the type A humanoid structure provided by the Bioloid Premium Kit. In this structure the controller is attached to the back of the robot and it does not interfere with its movements. Furthermore, the connection from the controller to the computer is done wirelessly using the zigbee module (provided by the Bioloid kit as well).

The modular design of Physical Etoys allows installing the Kinect and the Bioloid controllers separately. The sources of this modules as well as this entire example can be found in Physical Etoys' website[1].

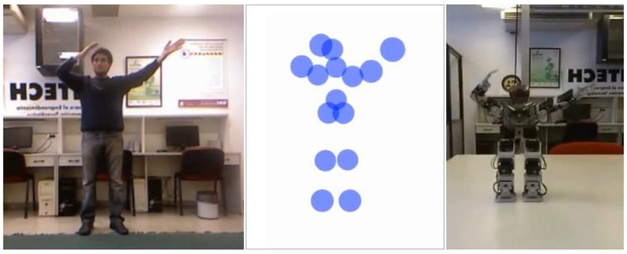

Fig. 3. From left to right: the position of the human, the skeleton produced by Kinect, the final

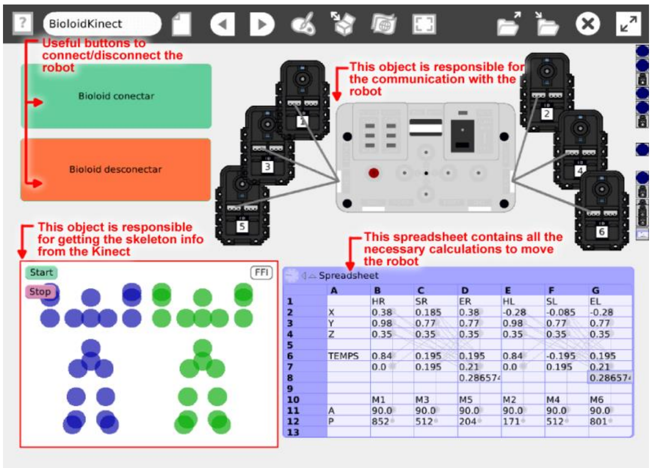

Fig. 4. The application and its parts.

The problem presented by this example can be classified as a dataflow programming problem, which in turn can be naturally expressed with a spreadsheet. Although Physical Etoys' programming model is essentially imperative, it includes a Spreadsheet object developed by Takashi Yamamiya [8], which is especially useful to express programs in a functional style.

5.2 Implementation

The problem of moving a robotic arm to a specified location is known as "Inverse kinematics". In our case, we do not need to provide a high degree of precision; instead

[1] http://tecnodacta.com.ar/gira/projects/physical-etoys/

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 76-83

we only need the movement to look as closely as we can to the movement of the human.

So, for this example, we have chosen a trigonometric solution that relies on the law of cosines because it involves high-school math and its implementation is relatively simple. [9].

For the moment, we have only implemented the movement of both arms. Controlling the legs and the body requires solving an additional set of problems, which falls beyond the scope of this work.

Each arm has 3 degrees of freedom. We will briefly describe the necessary calculations to solve the movement of the right arm, knowing that the left arm can be solved in a similar way. By applying the law of cosines to each triangle formed by the different joints, we can calculate the appropriate angle for each motor (as shown in fig. 9).

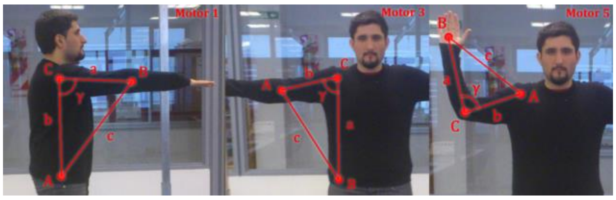

Fig. 5. The angles we need to solve for each motors.

Once we have the angle for each joint we need to calculate the final value (between 0 and 1023) that we will deliver to the servo. This can be solved with a simple linear function for each motor, calculated empirically.

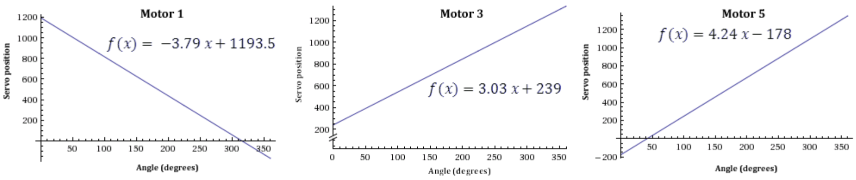

Fig. 6. Linear functions to translate the calculated angle to positions for each servo.

All these formulas were coded inside a Physical Etoys' spreadsheet, as shown in figure 7. The input cells are linked to the "x", "y", "z" slots from the corresponding joints in the Kinect object, so that their value will be updated automatically whenever the Kinect camera sends new information. The output cells contain the formulas described above and are linked to the "goal position" slot from the corresponding Bioloid motors, so that the motor's position would get updated automatically with every tick.

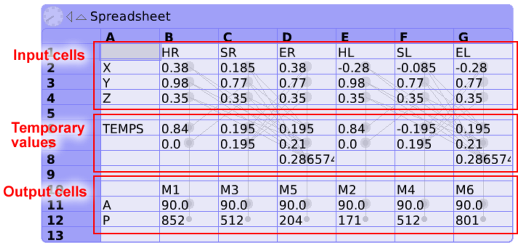

Fig. 7. The spreadsheet used to calculate the angles.

6 Future work

The future priority tasks of this project can be categorized in two different ways: technical and pedagogical.

Regarding the technical tasks, even though we have a functional version of the project, only the motors and the controller were virtually modeled. We have to add the sensors that belong to the kit in our software and we need to implement an appropriate way to report errors that may occur during the use of the robot, especially to increase its durability in the classroom.

In the particular example abovementioned, the robot was moving its arms. The tool supports many motors but only six are used. We have to consider that there are motor positions for the Bioloid humanoid that are physically invalid; therefore, we have to develop a basic sense of proprioception for it because the robot can be damaged while someone is interacting with it. Finally a study will be made of the new possibilities that Kinect 2.0 will bring to see if it could improve the experience with Physical Etoys and Bioloid Kit within the educational environment.

Regarding pedagogical tasks, we will invite teachers to think other practical exercises using this environment not only for students but also for their colleagues and their courses.

7 Conclusion

Although we have laid the foundation for the development of an environment that promulgates a new way of interaction with the Bioloid Kit in the classroom, it should be noted that there is still a significant way to go in terms of future work. It is also important to note that nowadays, robotics offers transversal content in a more accessible way to supplement the subjects of the educational programs. We believe that it is important to inspire children with a useful and attractive activity at an early age to prepare them for a world that tends to be robotic.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 76-83

Examining Influences on the Evolution of Design Ideas in a First-Year Robotics Project

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Abstract. Presented here is a data-supported analysis of design ideas from first-year students completing a group robotics assignment. While classroom learning is typically assessed through content exams and final project presentations, an alternative approach is taken that analyzes four group members throughout the entire design process as they develop their project, from initial brainstorm of ideas to finished robot. Using video data of students working together, this paper examines how the group negotiated various influences and explores the evolution of design ideas on two dimensions: *possible* versus *impossible* and *must have* versus *like to have*. The paper concludes by discussing implications for robotics education and further development of methods used to evaluate student work.

Keywords. First-year engineering, Robotics Education, LEGO NXT, Project-based learning, Interdisciplinary learning.

1 Introduction

The multidisciplinary learning that a robotics curriculum affords has prompted many universities to add one or more robotic courses as part of their offerings for undergraduate engineers. Past and current courses have leveraged robotics to teach professional skills [1], the Robotic Operating System (ROS) [2], interdisciplinary design [3,4], teach students the basics of engineering [5], or a combination of the above [6]. For schools not offering relevant courses, many robotics competitions [7,8,9] provide opportunities enabling students to independently learn relevant skills outside the classroom. While these courses and competitions have challenges engaging students in the technical activities of constructing and deploying robots [5], little work has been done to fully understand the engineering design process and skill learning in which students engage while working on these types of projects. While specific expertise like fluency in programming languages are easier to measure, a team's or individual student's capability to effectively negotiate constraints and limitations and make quality design decisions is not. Yet, these abilities are important for future work as professional engineers, researchers, or roboticists [10,11]. Within this context, this study examines the iteration of design ideas in a group of four students working on a class-based robotics project.

Past studies have examined the way novice to expert engineers design [12,13,14,15,16,17]. These studies have characterized design practices commonly exhibited by beginning designers to professionals at different stages of the design process. Yet, most of these studies examine a single designer creating only a conceptual design in a laboratory setting and provide little insight into how teams of students design within a

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 84-92

class context and how the tasks assigned within the classroom develop deeper design practices in the students themselves. The goal in the data collected and analyzed here is to examine a class project (worked on by a team of four students, both in-class and back at the dormitory) to gain a better understanding of the types of activities in which students engage, influences on design decisions related to the project, and the negotiations and choices with which students contend as they complete their projects. In general, robotics projects are interdisciplinary, design based, and technical, so provide an excellent context full of student initiated design choices, resulting in a rich dataset for analysis. This study is the first of this type of investigation, with the methodologies and analysis to be extended in the future to additional groups of student engineers and other styles of project assignments for further support and to generalize the findings.

2 Theory

When new projects begin, students often engage in brainstorming sessions that produce a wide variety of ideas, development directions, and potential solutions in order to complete their project. From that point on, students then need to negotiate, as a group, the various constraints and limitations that directly influence decisions made during development. These constraints under which the final artifact is created range from professor expectations, grade/formal assessment, available time, acquired content knowledge, skills possessed, available resources, team dynamics, and peer opinions of their work. These influences shape their project trajectory. While we don't have access to their (individual or group) underlying motivations when balancing these influences, each team member values these influences differently and the project as a result is directly affected. Despite not knowing all the details, examining the design trajectory over time of how the student group worked, evidence exists of how the students struggle and how resolution is achieved within different scenarios.

When negotiating a particular design idea, we have identified two dimensions on which it falls. First, the *must have* versus *like to have* dimension. *Must have* ideas capture the core requirements of the project, either dictated by the assignment or personalized aspects required by the individual/group based on passion. *Like to have* ideas are more decorative in nature and, while not required by the project, add to project quality and overall impression. Ideas that begin on one place on the spectrum may move from *like to have* towards *must have* as other *must haves* are completed or more sills are learned. While rubric specifications may determine many of the initial *must haves*, students may feel certain ideas are necessary to impress clients, peers, or the professor. The second dimension ranges from *possible* versus *impossible*. While expert engineering teams may have a better sense of their own internal skills, content knowledge, and abilities (and thus have less "spread" on the axis), early engineers still exploring the topic struggle with ideas ranging from what is *possible* (components students are able to implement with the knowledge/skills already possessed) to those that are *impossible* (from the fantasy, e.g. time travel, to the technically difficult, e.g. advanced/complex systems). Ideas positioned here, in between the two ends of the spectrum, indicate how much learning is required in order to accomplish implementation. This ranges from an idea closer to *possible* only needing a little new knowledge compared to those nearer to the other end (*impossible*) requiring larger, and perhaps unattainable, gains in understanding. The external and internal influences dictate, for a particular group, where individual ideas fall on these two spectrums and as a result directly shape the decisions made en route as well as final solution the students eventually create. This paper examines the details of how one group negotiates these influences in the creation of class-based robotics project.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 84-92

3 Course Description

Tufts University has shifted, over the last few years, to a system where first-year engineering students in their first semester have a selection of courses from which to choose as their initial Introduction to Engineering exploration. Across a variety of topics, representing content from the various departments within the School of Engineering, these courses provide an opportunity for students to explore a particular content area prior to declaring their major (at the conclusion of their first year). One of these courses, *Simple Robotics*, highlights a wide range of engineering material (mechanical to structural to electronics to programming/computer science) through robotics.

The *Simple Robotics* course, similar to many of the other courses, offers opportunities for engaging in additional practices (beyond just core content) of professional engineers through the structure of weekly assignments. Emphasizing innovation and creativity on behalf of the students, the presented challenges require the students to struggle with a wide range of relevant constraints as they negotiate working within small groups to design, build, program, test, and showcase their creations. These constraints vary such as a set time limits , materials, acquired knowledge, etc. Within this context, presentation skills are emphasized as well, acknowledging the importance of being able to communicate and share their engineering creations beyond just the process of creation; while often in-class demonstrations to their peers, sometimes larger displays are orchestrated and opened to the public, further encouraging final products that are reliable, robust, repeatable, and ultimately engaging to the audience.

One assignment, from the 2013 fall semester, had students working on robotic additions to a “Haunted House” exhibit produced in collaboration with an on-campus dormitory celebrating Halloween. Students in the *Simple Robotics* class were aware, beyond just creating an interactive robotic artifact to satisfy class requirements, that the best performers would be featured in the showcase that would be open to the entire campus to experience for several hours throughout the evening. As such, beyond the in-class specifications of creating a functioning product that sensed the environment, processed inputs, and reacted through actuator outputs, student groups had to consider both the environment in which their creations would be presented as well as the eventual “clients” who would be interacting with these robotic Halloween creations: other students from throughout the university visiting the haunted house.

This project, occurring in late October, fell approximately 2/3rds of the way through the semester. Project number seven in sequence (six smaller weekly assignments preceded it), this was the first in which students had more than a single week to complete the assignment; as such, partially completed prototypes were required for a mid-project in-class presentation to demonstrate progress as well as receive classmate, teaching assistant, and instructor feedback. While initial assignments during the semester were completed in pairs, starting with project 5 the small groups were combined together; thus, in the “Haunted House” project explored here, these four students were now working together for the third project in a row. This is significant because at this point in the semester the team dynamics and interpersonal relationships had been previously explored, in terms of personality, expertise, etc.

At the beginning of the project, which required students to create a robot using the LEGO MINDSTORMS robotic toolset and program using the LabVIEW graphical programming environment, students were additionally provided a selection of scary props for incorporation into their creations, such as plastic knives, fake skulls and bones, pretend spiders, and other Halloween-themed decorations. Additional materials, collected by the team, were allowed to be incorporated into their creations. While some in-class time was provided for working and presenting, the majority of the work students did was at home; overall, the students worked on the project over a period of 10 days.

4 Data Collection

Within the class, students groups (in which all members had consented, at the beginning of the semester, to participate in the research investigation) were given a video camera in order to record any work related to the project that occurred in-class or at home. For the research subjects examined here (four students: two males and two females), the "Haunted House" assignment resulted in about six hours of video recorded by the group. The video was transcribed and analyzed according to the various ideas negotiated by the group and significant design decisions made throughout the project.

From the supplies provided in class, the students in this group chose a fake bone and plastic knife in order to create a "Scary Sword" (Figure 1) actuated by the motors and triggered by a sensor. During the initial brainstorm portion of the project, ideas ranged from incorporating sound effects, sparks, a skeleton hand, fog, fake blood, etc. In the final design, there were three components to their project that will be examined in more detail here: the *Swinging Sword*, audible *Scary Sounds*, and visual *Flying Sparks*.

Figure 1. Picture of Scary Sword project

Analysis of the video, broken into five-minute increments throughout the six hours of recorded project work, reveals moments where details of each project component was discussed, negotiated, or developed. Figure 2 depicts a visualization of the data analysis, showing iterations on ideas related to each component over time.

Time (in minutes)

	Ideas	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165
Swinging Sword	Sword	x		x		x		x	x																		x	x							
	Bone	x		x		x	x	x	x	x		x	x	x									x	x	x	x	x	x	x		x	x	x	x	x
	Hand			x		x																					x		x	x			x		
	Motors					x	x	x		x			x														x	x	x					x	
	Motion Sensor	x				x		x																											
	Base		x	x		x	x	x																											
	Secure via Tape		x	x																															
	Counter Weights	x	x	x																															
	Gear Motors																																		
	Sensor Stand					x																													
Scary Sounds	Sound	x	x	x					x	x	x	x	x		x		x					x					x					x			x
	Program																		x	x	x	x					x				x	x		x	x
Flying Sparks	Steel Wool/Battery	x		x		x																						x	x						
	Flashing LED																																		
	Location in Showcase	x	x																																
Decorations	Skulls			x					x			x																							
	Motor shakes skull								x																										
	Blood/Skin			x					x																										
	Fog	x																																	
	Wrap Bone			x																															

	Ideas	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305	310	315	320	325	330	335	340	345	350	355	360	365
Swinging Sword	Sword			x	x	x				x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x						x	x	x	x	x
	Bone	x	x		x	x				x	x		x	x	x	x	x			x	x	x	x	x		x	x	x	x	x	x			x	x		x	x	x	x	x
	Hand			x	x	x				x	x	x	x		x	x	x	x	x	x						x	x	x	x	x	x	x					x	x	x	x	x
	Motors				x					x					x			x												x			x						x		
	Motion Sensor				x			x		x																	x														
	Base										x		x																												
	Secure via Tape							x																					x											x	
	Counter Weights																														x										
	Gear Motors																												x	x								x	x		
	Sensor Stand												x	x																											
Scary Sounds	Sound		x		x	x	x	x	x	x	x							x		x		x			x	x			x	x								x	x		
	Program					x	x	x		x	x			x	x			x									x											x			
Flying Sparks	Steel Wool/Battery				x													x				x				x		x	x	x	x										
	Flashing LED																														x	x			x	x		x	x	x	
	Location in Showcase																										x								x						
Decorations	Skulls																																								
	Motor shakes skull																																								
	Blood/Skin																																								
	Fog																																								
	Wrap Bone																																								

Figure 2. Sequence of design idea development over time for "Scary Sword" project

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 84-92

An example of the analysis process is illustrated in the following transcript segment, taken from minutes 180 to 185 of the video data where a member of the group summarizes the status of the project mid-way through development. The words in bold indicate project ideas being specifically identified during this time period. (Due to the overview provided by this student, multiple concepts are discussed simultaneously; for most transcript segments, the group focused on only a few ideas in tandem.)

> [182:41.17] *Student 1:* It's going, okay, so this [the **bone**], the **hand**'s attached to this and the **sword**'s like being held by the hand. And it's **motion triggered** so when you walk by it swings the sword at your feet and then we're gonna put a piece of **steel wool** on the ground and a **battery** on the sword so it sparks. And then they're doing **sound effects** and it's this girl going "I don't wanna dieeee."

5 Analysis

5.1 Statistical Analysis

Concept	% of work time
Bone	10.40
Motors	18.79
Sword	1.68
Hand	8.05
Sound	17.45
Sparks	13.42
Set-up/Location	2.68
Base	5.03
Program	11.41
Overall Prototype	11.07

Figure 3: Percentage of Time spent on concept development

Using Figure 2 and additional tabulated data, the table in Figure 3 details the percentage of time students spent on each component. As there were multiple students in the group, many times a number of these ideas were made simultaneously. Each of these segments of time worked were added together to create the total time worked. The above percentages are the percentage of the total segments that were dedicated to that piece of the component. The greatest amount of time spent discussing and making were dedicated to attaching the motors to the bone and putting the sound file on the NXT. While the attachment of the motor to the bone was a *must have* as determined by the project description (moving actuators), the sound effect feature was chosen as a *must have* desired by the students, while not explicitly required by the project. More details of this case are discussed below.

5.2 Case Studies

Through the examination of the students' ideas, a pattern of idea development emerged, as it appeared the negotiation of ideas by the group would consistently follow a set of possible design directions. The Idea Flow Diagram, shown in Figure 4, captures the set of potential progressions observed. After initial idea brainstorms, time was spent iteratively working on the development of the particular ideas associated with a component of the project. This either resulted in a successful implementation (idea achieved) or the students realizing it wasn't possible (failure). In either case, that idea might be enhanced through continued refinement of the details and the process started again. Otherwise, the achievement was considered sufficient and the idea was completed, or the idea was abandoned due to the failure to implement.

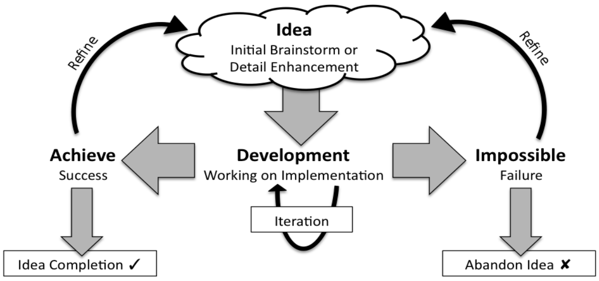

Figure 4. Idea Flow Diagram

The following demonstrates three examples observed within the data of the group negotiating constraints as they progressed through this process when developing ideas associated with their project. The three ideas explored are implementing sound effects, sparks, and fog.

For the implementation of sound effects (see Figure 5), the group spent a significant amount of time (multiple iterations) implementing the code in LabVIEW (and on the NXT programmable LEGO brick). Once this was achieved, the idea was refined for the inclusion of multiple sound effects, which were then easily implemented and completed. While the sound effects were a *like to have* as determined by the group and not core to the robotics project, they strove to implement this feature due to knowledge that it was *possible*. (Although, despite it being known to be possible, for this particular group a significant amount of time, encompassed in the multiple iterations, was spent on this feature due to a lack of specific content knowledge on how to initially implement.)

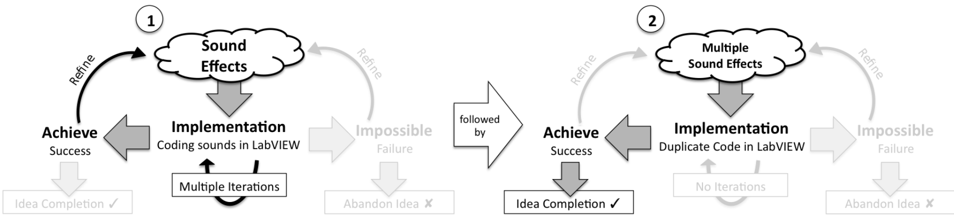

Figure 5. Idea Flow Diagram for implementation of sound effects

For the implementation of sparks (see Figure 6), the group's initial idea was to use a battery attached to the sword that would come in contact with steel wool and produce sparks. Through iteration on the physical design, they developed a prototype, but the sparks created would have started a fire (deemed unsafe). While this didn't rule out the idea completely, the initial idea was refined where "sparks" were simulated through a flashing light. Thus, a touch sensor and light were implemented (fairly easily/quickly) as an alternative. This feature, while not a component directly related to the given robotics assignment (and thus, not related to their class grade), was determined by the group as a *must have* within their implementation, due to other motivations around peer-perception and perceived "coolness" of the project implementation. As such, when the battery/steel wool version was deemed *impossible*, the updated idea (flashing light triggered by touch sensor), while not considered ideal by the group, was known to be *possible* and thus the direction this design decision proceeded.

ISBN 978-88-95872-06-3
pp. 84-92

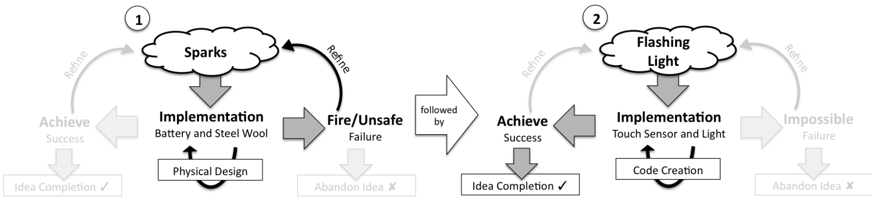

Figure 6. Idea Flow Diagram for implementation of sparks

For the implementation of fog (see Figure 7), the initial idea was to use fog to hide the presence of the Swinging Sword in order to enhance the scariness of the robot. However, this idea was quickly (only through verbal discussion, as no prototype was needed) identified as *impossible*/not a priority and quickly abandoned. In terms of project scope, the fog was most certainly considered simply a *like to have* by the entire group, which made the realization of non-implementation a fast decision. As seen in the sequence of design idea development (Figure 2), discussions occurred very early in the design process and once the idea was immediately dropped, never reemerged.

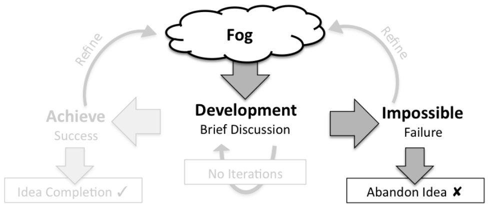

Figure 7. Idea Flow Diagram for implementation of fog

These three examples highlight ways in which the group progressed through this process, sometimes performing multiple iterations, but transitioning from step to step based on the negotiations of the different constraints and limitations within the project. At each point along the way, the positioning of the idea on the *must have*/*like to have* and *possible*/*impossible* spectrum motivated the time, energy, amount of discussion, and implementation effort dedicated to the idea (and individual step) by the group.

6 Conclusion and Implications

As educators, preparing students for future participation in the technical workforce goes beyond just transferring content; additionally, we should be helping develop student skills in the context of completing engineering projects within constrained scopes. Working in groups on open-ended projects, such as often given in robotics education, students are required to negotiate through the limitations of their own abilities and those of the group as a whole, all of which directly affect the design decisions and the eventual products they create. This work examined the performance of one group of students creating a "Scary Sword" interactive robot as part of a Haunted House themed assignment. While implementing the various ideas associated with components of their design, the students navigated the space of *must have*/*like to have* features, as well as those that fell somewhere on the *possible* to *impossible* scale. As the ideas developed, iteratively through discussion or when struggling to create, design decisions by the group dictated when students achieved success implementations, failed and abandoned the work, or refined the ideas through additional feature specifications.

While important to see students iterating, it is also necessary to identify the times when continual iteration on an idea is non-productive (e.g. spending significant time on a feature deemed *impossible*) and should be abandoned, or prolonged development on features that are only *like to have* in a time-constrained situation (e.g. when essential *must have* details still remain). In order to best train students to understand these differences, they should have exposure to situations that require struggles of this type. Thus, providing authentic assignments where students are required to balance a set of constraints (ideally personally meaningful) in order to understand the impact of these factors on their own design decisions and eventual output. Maintaining project parameters that are flexible and can be determined by the students themselves achieves both of these: allowing personalization of features and empowerment to the designer(s) with regards to the specific design decisions.

Accessing the underlying process through which the students participated in creating their final artifacts is also essential to better understand the quality of and the application of the design decisions incorporated into the project. Simply analyzing the resulting product is not sufficient for assessment of those decisions and associated transitions leveraged during development. However, given the current environments in which assignments like these are implemented, this information is often not available (or, as in the case here, requires intense labor to analyze/generate). If educators wish to utilize this information during evaluation (and, more importantly, provide the opportunity for students to self-reflect on the experience themselves), new tools for faster, automated, and more complete study of relevant data need to be developed.

Finally, this study focused on one group of students during the completion of a single assignment. While insights emerged regarding the features of the project on which efforts were focused, constraints under which the students struggled, and factors that affected important design decisions, more analysis is needed in terms of fully understanding the impact of how their time was spent and the quality of the work performed. Further, a model was developed here that captured the transitions of the group through the design space, but additional examinations of other groups and across different styles of assignments is needed to fully understand the applicability of these ideas in the generalized case. Where there exists the possibility of equivalent negotiations in other student project groups, every project is set in a unique context of environment, external influences, and internal student motivations. More work also needs to be done to fully classify this context and understand the correlation between the situation and the enactment of the engineering design process by the students. With a more detailed data analysis, across a wider range of assignment types, populations, universities, etc. it should be possible to start to understand larger trends and formulate more generalized understandings about the role of defined problem (scope, constraints, etc.) and the quality of the negotiation schemes experienced by the students.

Acknowledgments. The authors would like to acknowledge funding and support from the Department of Mechanical Engineering and the Center for Engineering Education and Outreach (CEEO) within the Tufts University School of Engineering. We would also like to thank the teaching assistants for the course for their assistance with the data collection and transcription, as well as Dr. Mary Caddle in the Tufts University Department of Education for her feedback.

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An Integrated System to approach the Programming of Humanoid Robotics

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Abstract. This paper describes a set of laboratory experiences focused on humanoid robots offered at the University of Padua. Instructors developed an integrated system through which students can work with robots. The aim is to improve the educational experience introducing a new learning tool, namely a humanoid robot, and the Robots Operating System (ROS) in a constructivist framework. This approach to robotics teaching lets students exploiting up-to-date robotic technologies and to deal with multidisciplinary problems, applying a scientific approach. By using humanoid robots, students are able to compare human movements to robot motion. The comparison brings out human/robot similarities, pushing students to solve complex motion problems in a more natural way while discovering robot limitations. In this paper, the learning objectives of the project, and the tools used by the students are presented. A set of evaluation results are provided in order to validate the authors' purpose. Finally, a discussion about designed experiences and possible future improvements is reported, hoping to encourage further spread of educational robotics in schools at all levels.

Keywords: Simulation, Humanoid Robots, Teaching Robotics, ROS, Gazebo, Robovie-X

1 Introduction

Educational Technologies (ETs), meant as the set of practices designed to enhance the learning activities, can be used as means for didactic activities in different specific contexts. In particular, Educational Robotics (ER) adapts students to current technologies, where the Automation Technology (which is related to the use of mechanical, electronic and computer-bases, in the operation and control of the autonomous systems) plays a very important role. Robotics involves several fields from computer vision to motion planning, from humanoids to manipulators and wheeled robots.

There are three main methods that can be adopted to teach a discipline: behaviorist, cognitive, and constructivist. We decided to follow the constructivist approach because of several advantages attested in different psychological

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 93-100

studies [4]. Constructivism is a theory about teaching and learning with roots in education, sociology, philosophy and psychology. The main idea is thinking that human learning is constructed: a self-regulated process of resolving inner cognitive conflicts that often become apparent through concrete experience, collaborative discourse and reflection [3]. Learners build new knowledge upon the foundation of previous one. This view of learning assumes that knowledge is an individual construction which corresponds to physical world. In this sense, student experimentations play a key role during the teaching process. So, student centered learning activities which encourage multiple representations of concepts and relations are suitable to handle the different experiences to advance to a better level of understanding. In this way, students should apply their current knowledge in new situations in order to verify their intuitions and discover if what they suppose is valid or not using a scientific approach [6]. Based on the Papert's perspective of Constructivism [1], and according to [13], a great number of robotic lectures and experimental laboratories have been introduced in classrooms of all levels of education. In Greece, Italy, Spain, France, Romania, Czech Republic the TERCoP project [2] introduced ER in primary and secondary schools [8]; the Engineering Department of the University of Padua, Italy, offers advanced laboratory experiences also to Master level students.

This paper describes the set of laboratory experiences on humanoid robots offered during the "Autonomous Robotics" (AR) course of the Master of Science (MSc) in Computer Science of the University of Padua at the Intelligent Autonomous Systems Laboratory (IAS-Lab) in the academic years 2011/2012 and 2012/2013. Instructors developed an integrated system to provide students the basic tools necessary to work with humanoid robots. It consists of a real and virtual humanoid robot, the Vstone Robovie-X [16], a simulation environment, Gazebo [5] and a robotic framework, ROS [15], equipped with the robot motion libraries and taught to provide the basis to create a development environment suitable for first step robotics users. Students are asked to solve some motion planning problems both with simulated and real platform. The goal is to make students capable to control a robot with many Degrees-Of-Freedom (DoFs).

Only few robotics courses adopt real humanoid robots in laboratory experiences. Their high cost, the efforts required to maintain their proper functioning, and the necessity to provide software packages that allow unqualified users to interface with them discourage their use as educational tools. The proposed system, instead, aims at highlighting advantages offered by these complex robotics platforms: increasing the students experience and knowledge. They will be able, for example, to compare human movements with the humanoid motion, to solve complex problems like the stability check of the robot and the resolution of complex inverse kinematics problems. Other types of robots, like the wheeled ones, do not offer these features.

The rest of the paper is organized as follows: in Section 2 the robotic course is described, together with the expertise that it aims to offer to students. In Section 3 the laboratories experiences are summarized focusing on the skills that they intend to transmit to students. Also a brief description of the integrated system

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pp. 93-100

developed and the main instruments used is provided. Section 4 contains an evaluation of the proposed approach, based on students feedback. In Section 5, some conclusions and future perspectives are discussed.

2 The course

"Autonomous Robotics" (AR) is a second year course of the Master of Science (MSc) in "Computer Science" at the Faculty of Engineering of the University of Padua (Italy). It intents to offer students methodological bases for programming autonomous robotics systems. It provides a mixture of theoretical class lectures and practical laboratory experiences. The former aim at building a strong background on robotics fundamentals, perception systems, computer vision, and navigation; the latter lets students acquiring skills on using software tools and algorithms exploited in robotics.

Students have to deal with five laboratory experiences, solving increasing difficulty problems. As presented in [9], students begin by using simple platforms (LEGO Mindstorms [7]), and gradually improve their skills coming to the end of the course by using more complex robots (VStone Robovie-X [16]). This approach confirms the constructivist line at the base of the course: it leads to an individual construction of the knowledge, because students by their own, find the better method to solve proposed problems acquiring the capability of adapting learned techniques to real robotic platforms.

3 Laboratory experiences

In the following, the set of laboratory experiences focused on humanoids proposed in the course will be described. They involve some basic challenges regarding humanoid robotics: robot control with high number of degrees-of-freedom, stabilization, and perception through sensory information. The robot motion is compared with human motion acquired by means of a RGB-D sensor: this way is possible to better find the differences between the two motion systems. Despite human movement and humanoid robot one seem to be very similar from a naive point of view, they differ considerably.

3.1 The framework: ROS

Robot Operating System (ROS) [15] is an open-source, meta-operating system that provides services usually expected from an operating system, including hardware abstraction, low-level device control, message-passing between processes, package management, tools and libraries useful for typical robotics applications, such as navigation, motion planning, image and 3D data processing. The primary goal of ROS is to support code reuse in robotics research and development and, in this direction, is designed to be as thin as possible and its

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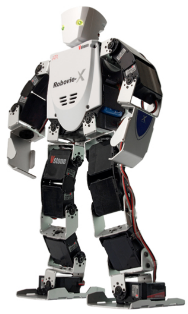

Fig. 1. The small humanoid used in this work: the Vstone Robovie-X.

libraries are ROS-agnostic and have clean functional interfaces. Among all available frameworks, ROS has been chosen since it supports Object Oriented Programming (OOP), and also because its community is very active, and represents a valuable help. A large variety of tutorials are available from which students can easily learn. In particular, the Fuerte (2011/2012) and Hydro (2012/2013) releases have been used from the students to develop their software. The effectiveness of ROS in teaching is demonstrated by a large number of robotics courses which adopted it, including Brown University (USA), Cornell University (USA), University of Birmingham (UK) and Stanford University (USA). The choice of employing ROS for teaching robotics is important to let the students have experience of a complete and modern software framework for robotics.

3.2 The humanoid: Robovie-X

During previous experiences in the same course [9], students have the possibility to work with a mobile platform: the LEGO Mindstorms. Using ROS enable them to easily handle a different robot in the experiences described in this paper. The robot adopted is a small humanoid developed by Vstone: the Robovie-X. It combines high motion performances with accessibility, with seventeen degrees of freedom (1 for the head, 6 for the arms and 10 for the legs) and the VS-S092J servos having 9.2 kg/cm of torque. These features make it capable of fast walking, dancing, flip, side-flip, standing-up, playing soccer and many other activities. It is a small, light, and relatively inexpensive platform with its 1.3 kg of weight and 343x180x71mm (HxWxD) of dimensions that makes it handy and easy to carry.

3.3 The virtual environment: RViz and Gazebo

A virtual model of the robot is also provided to the students to get it visualized in RViz [11] or simulated in Gazebo [5]. RViz is the 3D visualization environment for robotics coming with ROS, Gazebo is one of the most complete open source 3D simulators. Both of them are necessary to figure out the robot reactions to the developed algorithms before testing them on real equipment.

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ISBN 978-88-95872-06-3
pp. 93-100

3.4 Experience 1: Motion remapping

In the first experience, students have to develop a teleoperation mapping between human and robot. The human motion has been acquired by using a RGB-D sensor and a skeletal tracking system, namely NiTE [14]. An open-source ROS package [10] has also been developed to extract skeleton information and to track them as a tree of multiple coordinate frames referred to the human joints over time. Student used this standard ROS structure, called *tf* [12], in order to generate a robot motion as similar as possible to the human movements.

Robotics objectives: The main goal is to make students familiar with humanoid robots and their motion. They should analyzing the movements performed by a human actor and subsequently transposing them to the robot DOFs dealing with the differences between the two complex motion systems. During this experience, students work with some advanced ROS modules. In particular, they familiarize with the transformations and frames (*tf*) package and with different reference systems in order to learn how to change from one to another while maintaining the fundamental rototranslation constraints. Once students are familiar with these concepts, they are asked to evaluate robot characteristics in both virtual and real environment in order to obtain a good approximation of human movements without taking care of the robot stability. In fact, the Robovie-X is supported by using a bracket so that all the robot limbs can move without stability limitations. The experience involves robotics topics like motion control, online data elaboration and reaction, human-robot interaction, and teleoperation.

Computer science objectives: The experience is meant to make students face high level concepts by handling a great amount of data. In fact, RGB-D sensors can provide RGB and depth images at high framerate (30 fps), and a skeleton tracking system is also available to provide additional information. Students should be able to elaborate the raw data while maintaining an elevate framerate in the robot control process. In this experience, the problem mainly concerns robot motion from a data acquisition and a procedural solution can be easily adopted. Nevertheless, students are pushed to solve it using an object oriented approach by the ROS publisher/subscriber communication protocol they learned in the previous experiences [9].

3.5 Experience 2: Robot stabilization

The goal of this experience is to make a robot picking up an object by means of human teleoperation. The robot has to automatically avoid unstable situations by balancing the input movements coming from the system developed during Experience 1. Students should apply the knowledge of robot stability learned during theoretical lessons in order to avoid situation in which the robot could fall down. The only information available about the system come from the motion performed by the human while he is observing the scene directly.

Robotics objectives: The aim of this experience is to tackle with robot stabilization problems in a humanoid robot moving like a human. Robot stabilization is the key step of the complete process used to compute suitable joint

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 93-100

values. The algorithms developed by students have to elaborate a feedback signal to keep the robot balanced during the movement. The experience focus on a particular action the robot has to perform: grasp an object laying on the ground in front of it. Using a specific action is necessary to obtain effective results in the experience duration, since there is no sensor feedback from the robot.

Computer science objectives: This experience does not really concern a specific Computer science objective, but it allows students to apply concepts learned during previous experiences in a different environment in order to consolidate them.

4 Discussion

At the end of the course, students were asked to fill an anonymous questionnaire. The aim was to verify the correct design of the course itself. Questions of Table 1 were posed. The answer to each question is represented by a chioce among four states: *Not at all* (yellow), *A little* (red), *Enough* (blue) and *Very much* (green).

The questionnaire was meant to test key aspects of the laboratory activity:

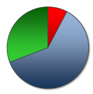
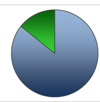
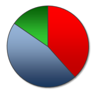
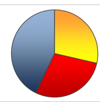
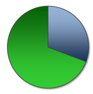
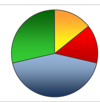
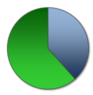
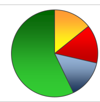
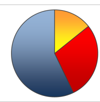
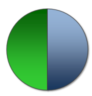
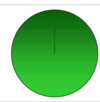
- students' comprehension of basic concepts investigated in the previous experiences by using a mobile robot;
- effort spent in switching to a more complicated robot with a lack of sensors;
- closeness within the two activities and with possible future jobs.

Answers to the questionnaire highlight similar results for both the considered academic years. The effectiveness of the adopted method is confirmed, even by using a more articulated robot like an humanoid (Question 4). Students were able to assimilate knowledge gained by using a mobile robot and to apply it in a different manner during the following experiences being aware of the gradually increasing complexity of the proposed tasks (Question 1). The elevate number of DOFs in humanoid robots forced them to change their approach to robot control (Question 3) drawing inspiration from the similarities between humanoids and human motion, but even looking at the differences behind appearances. Students had also to balance the lack of sensors mounted on the robot by estimating the Center of Mass of the humanoids while teleoperating it through human motion. Facing this complexity make them conscious of the importance of perception in robotics (Question 2) and enable a critical analysis of possible solutions when data are missing (Question 5). Finally, the adoption of a constructivist approach in teaching robotics combined with an high level robotics framework emphasize the use of new problem solving methodologies in a new class of young, versatile engineers entering the job market in few months (Question 6).

5 Conclusion and future works

This paper presented a series of experiences based on a constructivist approach and targeted to MSc students attending "Autonomous Robotics" course. Experiences focused on controlling movements and stability of a humanoid robot.

Table 1. Results of the questionnaire.

		2011/2012	2012/2013
1	The complexity of the experiences has increased with the adoption of humanoid robots in place of mobile platforms.		
2	Lack of sensors in Robovie-X platform affects robot performances		
3	The Robovie-X high number of DOFs with respect to LEGO Mindstorm NXT affected the approach adopted in controlling the robot.		
4	Using humanoid robots is the natural extension of the work started with mobile robots.		
5	Using humanoid robots gives another point of view about robotics with respect to mobile robots.		
6	In my future job I will be asked to work with modular software structures similar to ROS.		

Legend: Not at all; A little; Enough; Very much

These robot skills can be seen as a small but complete set of abilities students should gain to deal with humanoid robots. Using ROS as robotics framework pushes students to use OOP concepts thanks to the highly structured environment they have to work with and, in a broader spectrum, to deal with nowadays increasingly widespread technologies by interacting with its large user community. The analysis of a report for each laboratory experience and of the developed code made it possible to verify students' comprehension of robotics basics, their use of complex syntactic constructs and their problem-solving capabilities.

In this paper, we presented the different experiences and the way in which they were exposed to students by following an increasing complexity level. Students were asked to control robot motion and stability by means of human motion instead of analytically solving the robot inverse kinematics and dynamic in order to make them approach to the problem from a more natural point of view. The correct resolution of the assigned problems and the positive students feedback gave instructors the certainty that the proposed approach was really effective in teaching robotics.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 93-100

Our goal for the future is expanding the teaching framework to include sensors and new functionalities, even offering novel robotic platforms. These kind of framework lets students deepening their knowledge in order to make them always more involved and proactive towards robotics as discipline that brings together a wide range of fields, from technology to design, from mathematics to science education.

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Evaluating the impact of robotics in education on pupils' skills and attitudes

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Abstract. This paper presents an ongoing study investigating the impact of robotics in education, and RoboCupJunior in particular, on technical and social skills as well as science related attitudes of pupils. The empirical study uses a quasi-experimental two-group design (experimental- and control-group) conducting pre- and post-tests by applying a multiple-choice student questionnaire as assessment instrument. This questionnaire is based on different already applied and proven assessment tools and survey instruments. The evaluation covers a period of approximately eight months. After conducting a pilot study in different schools in several Austrian regions the worldwide main study will start in autumn 2014.

Keywords: Educational robotics, RoboCupJunior, evaluation, empirical study, technical and social skills, quasi-experimental design

1 Introduction and motivation

The development in the area of science education in recent years shows an increasing disinterest of young people in science and technology. Fewer and fewer students decide to go into technical studies at university level or to pursue a technical profession. As a consequence many countries are already facing a lack of well trained engineers, technicians and researchers [1–3]. In this context robotics in education has gained an increased attention over the last decades. Using robots as a vehicle to interest pupils and young children in science and technology and in addition to improve their technical and social skills has become a widespread approach in various countries worldwide [4, 5]. Besides *RoboCupJunior (RCJ)* [6] a number of other educational projects and cross-cultural initiatives aim to encourage pupils and young students to get involved in science and technology by applying a project-oriented educational robotics approach. Although there is a subjective impression that this approach works well and even though, there exists a predominantly positive feedback by involved pupils, students, teachers and researchers, only a few studies focus on the investigation of the impact in a well-founded and empirical way covering a wider region and an extended period of

* Authors listed in alphabetical order. The work has been partly funded by the European Fund for Regional Development (EFRE), the federal government of Slovenia and the Land Steiermark under the Tedusar grant.

time [3, 7–9]. In order to address this challenge we developed an evaluation concept comprising both quantitative and qualitative research methods. The basic aim is to evaluate the impact of robotics in education, and RCJ in particular, on pupils' technical and social skills and the effect on pupils' attitudes and interests towards science and technology. Quantitative methods of the study encompass pre- and post-tests using a quasi-experimental two-group design [10]. The assessment instrument designed for this empirical study is a 139-item multiple-choice student questionnaire which is based on different already proven assessment tools and survey instruments which have been validated and/or applied and tested in previous studies and theses [11–18]. To validate the basic study design and the applied instruments a eight month pilot study was initiated in autumn 2013. Based on the findings of the pilot study the main study will start in autumn 2014, covering schools worldwide. It is embedded in the *RoboCup* initiative [6] in order to gain access to schools around the globe.

This paper focuses on the empirical study applying quantitative research methods (details on the qualitative research can be found in [7]). The paper is structured as follows: Section 2 provides a review of related literature followed by Section 3 which deals with the study design and the applied instrumentation. Preliminary findings of the ongoing pilot study are presented in Section 4 whereas conclusions, limitations and further steps are discussed in Section 5.

2 Related research

The work in [19] focuses on the evaluation of the *FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition (FRC)* investigating the long-term impact of FRC on former participants. A similar study, evaluating the *FIRST Lego League (FLL)*, was carried out by Melchior and colleagues [20]. Within the scope of the *Roberta* project an empirical research evaluating the impact on participating girls' interest in science and technology and their further professional career was conducted [21]. The dissertation of Griffith [22] examines the relationship between pupils' participation in the FRC and their interests in science and technology. Data was gathered conducting pre- and post-tests using paper-and-pencil survey questionnaires. Results were compared between an experimental group (EG) and a control group (CG). One evaluation attempt focusing on RCJ was done by Sklar et al. [23] in 2004. The study did not comprise a CG nor an explicit assessment of skills was done. The dissertations of Jewell [24], Whitehead [25] and Welch [26, 2] focus on the evaluation of the impact of robotics curricula, FRC respectively, on high school students' beliefs, attitudes and interests towards science and technology. A quasi-experimental pre-/post-design with EG and CG (except for the work of Whitehead) was applied, but those studies only covered certain regions in the US and did not assess technical or social skills. Quantitative evaluations investigating the impact of educational robotics activities also on technical skills were done by Nugent et al. [11] and Cruz [12]. Again, both studies comprised only participants from certain regions in the US, examining a short period respectively. Various quantitative empirical

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 101-109

studies have been carried out in different scientific fields (e.g. medicine, sociology, psychology, economy, education, early-childhood pedagogy [27–29]). Some of the methods and assessment instruments used in other empirical studies ([11–18]) were adapted and applied for our investigation.

3 Methodology

The main purpose of this study is to investigate the impact of robotics in education, and RoboCupJunior in particular, on pupils' and young students' technical and social skills. Furthermore, the study intends to determine the effects of educational robotics activities on pupils' attitudes and interests towards science, technology and social aspects.

3.1 Study design

In order to address the research questions this empirical study relies on a quasi-experimental two-group design including pre- and post-tests [10, 9, 22, 30]. Study participants are divided into experimental group (EG) and control group (CG). The EG consists of pupils and young students up to the age of 19 who participate in robotics activities (especially RCJ) for the first time whereas the CG comprises young students who actually do not participate in those robotics activities. In this context we cooperate with schools that take part in annual national/regional junior robotics competitions (RCJ) and/or offer regular robotics courses/projects during the semester. If possible students in the control and the experimental groups should be evenly distributed and share comparable demographic attributes (e.g. age, social and educational background). Responsible teachers at each participating school are asked to recruit pupils for EG and CG.

In order to determine differences in terms of technical and social skills as well as science related attitudes and interests, results of pre- and post-tests will be compared between experimental and control group. The instrument used in this regard is a multiple-choice questionnaire comprising different already proven survey assessment tools (see Section 3.2). Table 1 schematically depicts the study design. To measure study participants' base level both EG and CG are pre-tested (indicated as O_1, O_3 respectively) at the begin of winter term (t_1), right before the intervention (robotics activities during the semester; indicated as X) starts. Since in the context of this study special focus is given on RoboCupJunior it was decided to conduct the post-tests for EG and CG (O_2, O_4) right after a national/regional RoboCupJunior competition took place (t_2). Depending on national schedules this results in a time span of approximately eight months between both surveys.

Basically the study is divided in two stages. The first stage covers a pilot study in order to validate the general study design and the applied instruments. The main focus of this pilot study is on different types of Austrian secondary schools and different Austrian regions. Robotics in education, and RoboCupJunior in particular, is well established in Austria. A large number of schools have

ISBN 978-88-95872-06-3
pp. 101-109

Table 1. Study design

	$\mathbf{t}_1$		$\mathbf{t}_2$	$t_{[1,2]}$...*time of measurement*
experimental group (EG)	O_1	X	O_2	*X...intervention (robotics activities)*
control group (CG)	O_3		O_4	$O_{[1..4]}$...*observations (pre-/post-tests)*

integrated robotics in their curriculum and participate in national and international RCJ competitions an a regular basis [1, 9]. In order to obtain results also in an international context we carry out the same study simultaneously in a selected school in Sweden. Pre-tests started in autumn 2013, post-tests of the pilot study will be completed by the middle of May 2014. Lessons learned and preliminary findings of the first series of pre-tests can be found in Section 4. Based on those findings, the second stage comprises the main study starting in autumn 2014. It will be completed by the middle of 2015 and covers young students from different countries worldwide. By applying this widespread, mid-term approach we aim to gather solid and valuable empirical data on a large geographical scale.

The overall study concept as well as the applied survey instrument (Section 3.2) was initially presented and discussed at the *Workshop on Educational Robotics (WEROB)* [9] within the scope of the RoboCup Symposium in July 2013. The feedback from experts in the field of educational robotics and national RCJ representatives flowed directly into the development of the study design. The context RoboCup eases the access to schools and mentors in order to recruit participants worldwide. Respecting legal and ethical requirements all collected information is treated confidentially. Participating pupils, their parents as well as the school administrations have to sign an informed consent stating the purpose and explaining the procedure of the study. The whole study approach was reviewed and approved by the ethics commission at Graz University of Technology.

3.2 Instrumentation

The main instrument for assessing technical/social skills and science and technology related attitudes/interests is a 120 item multiple-choice student questionnaire (MCQ) separated in several sub-sections. This questionnaire combines different standardized assessment tools as well as survey instruments which have been validated and/or applied and tested in previous studies and theses [11–18]. The reuse of proved methods gives security with regard to valid results. Permission to reuse those instruments in our work was obtained by corresponding authors in advance. In addition to the skill-/attitude-sections the questionnaire contains 14 items (partly multiple-choice, partly open-ended questions) dealing with demographic background information of study participants as well as a five item feedback part in the concluding section. Hence, the instrument comprises 139 items in total.

The process of developing the student questionnaire was done in cooperation with experts in the field of psychology respecting general rules of questionnaire-

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 101-109

designing [31–33]. The instrument ran through several refinement and improvement steps (review by experts at educational robotics workshop [9]; review by pedagogues and teachers as well as experts in robotics; test run with young students). In order to conduct the survey in different European countries the questionnaire, initially in English, was translated into German, Swedish and Slovene working together with national RCJ representatives. To allow a convenient data collection from geographically distributed study participants we use the on-line survey tool *SurveyMonkey* [34]. Responsible teachers at participating schools organize and monitor the study conducting. To ensure the same conditions across all participating schools a step-by-step manual, containing detailed instructions regarding preparation and implementation, is provided to those teachers.

The questionnaire is structured around four main sections and divided into several sub-sections covering study-relevant topics. Main sections are numbered I-IV while sub-sections are enumerated using letters (applied instruments in italics). Study questions are in ascending order of difficulty level.

I **Demographic/background information** (14 items; MCQ/open-ended)
- (a) **Student alias**: anonymous information matching pre- and post-test
- (b) **Group classification**: EG, CG
- (c) **Confounding factors**: previous knowledge in robotics and programming (questions regarding previous involvements in robotics activities and experiences with graphical and/or textual programming languages)
- (d) **Statistical information**: age, gender, school, language, grade-level

II **Technical skills** (37 items; MCQ)
- (a) **General robotics/programming** (*4-H Robotics Questionnaire* [11]): basic knowledge of robotics and programming
- (b) **Graphical programming** (*4-H Robotics Questionnaire* [11]): analyzing programs; finding mistakes and providing solutions
- (c) **Computer science** (*Beaver Computing Challenge* [13]): keeping track of state; fundamentals of algorithms; abstraction; encoding; pointers and references; linking
- (d) **Textual programming** (*Programming Skills MCQ* [15]): tracing/analyzing code; loops; ability to write programs
- (e) **Mathematics** (*4-H Robotics Questionnaire, PISA released items*[11, 14]): fraction/ratio; converting units; uncertainty/ likelihood
- (f) **Science as an inquiry** (*Science Questionnaire* [12]): controlling scientific experiments; constructing/interpreting graphical representations
- (g) **Physical science** (*Science Questionnaire* [12]): relationship input/output; comparing graphs of acceleration and deceleration

III **Attitudes and interests / social skills** (83 items; MCQ/4-and 5-point Likert scale questions [10, 22])
- (a) **Science related attitudes and interests** (*TOSRA** [16]): attitude to scientific inquiry; adoption of scientific attitudes; enjoyment of science lessons; leisure interest in science; career interest in science
- (b) **Self-efficacy in robotics** (*4-H Robotics Quest.* [11]): self-confidence in solving robotics tasks (e.g. *"I am confident that I can program a robot to move forward two wheel rotations and then stop.")*

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 101-109

   (c) **Problem solving** (*4-H Robotics Quest.* [11]): self-evaluation regarding problem solving approaches (e.g. *"I use a step by step process to solve problems."*
   (d) **Teamwork attitudes** (*4-H Robotics Quest.* [11]): attitudes regarding working together with other people (e.g. *"I like listening to others when trying to decide how to approach a task or problem."*)
   (e) **Social skills and self esteem** (*Social Skill and Self Esteem Scale* [17, 18]): ability to get along with other people; aspects of self-worth; (e.g. *"If I want my friends to go along with me, I know what to say to them."*
   (f) **Goal setting skills** (*Goal Setting Skill Scale* [18]): directing an effort to achieve a desired result (e.g. *"Once I set a goal, I do not give up until I achieve it."*)

IV **Feedback** (5 items; MCQ/Likert scale, open-ended)
   (a) Overall feedback on the questionnaire: difficulty, length, clarity, further comments

TOSRA (Test of Science-Related Attitudes): The multidimensional instrument was developed by Fraser [16]. It has been extensively tested and applied in various different studies in the field of science education research [2, 24]. The test was developed to assess science related attitudes and interests of middle and high school students. It contains seven distinct sub-scales (social implications of science; normality of scientists; attitude to scientific inquiry; adoption of scientific attitudes; enjoyment of science lessons; leisure interest in science; career interest in science). Each sub-scale comprises ten items (e.g. *"I would prefer to find out why something happens by doing an experiment than by being told."*) whereby each sub-scale can be scored separately.

4 Participants and preliminary findings

In total 242 pupils (35.5% female, 60.3% male, 4.1% not stated[1]; EG: 130 pupils, CG: 112 pupils) completed the pre-test of the pilot study. The mean age of all participants was calculated with 13.6 (20.7% aged 9-11, 65.7% aged 12-16, 13.6% aged 17-19). Pupils attend nine different schools whereby eight schools are located in different urban, suburban and rural regions across Austria and one school is located in a smaller town in western Sweden. Types of schools range from polytechnic (1), secondary modern school (2), secondary school of higher education in economy and tourism (2), high school (3) and junior high school (1). A first analysis of pre-tests as well as feedback from teachers revealed that the initial questionnaire was too difficult for pupils aged 9-11 (with regard to understanding of questions, solving tasks in the technical-skills part). It also turned out that, due to the large number of items, the time for completing the questionnaire exceeded the duration of a regular classroom lesson (which was problematic in some cases concerning timetable management). Participants

[1] all percentage values rounded

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 101-109

rated the length of the questionnaire with 40.9% as "too long" followed by 37.5% as "appropriate". The post-tests will be completed by middle of May 2015 after which an extensive statistical analyses on the gathered data will be performed.

5 Discussion and further steps

In this paper we presented our concept of conducting an extensive empirical evaluation on the impact of robotics in education, and RoboCupJunior in particular, on young students' technical/social skills and attitudes/interests towards science and technology. The goal is to conduct this evaluation using a well-proven methodology. Therefore we use a quasi-experimental two-group design (experimental- and control-group) including pre- and post-tests and applying a multiple-choice student questionnaire as assessment instrument. It is based on different already applied and tested tools and instruments. The study covers a period of approximately eight months and comprises both a pilot study (different selected schools in Austria and Sweden) and a main study (schools worldwide). The ongoing pilot study, validating the applied methodology and instruments, was initiated in autumn 2013 and pre-tests have been administered. The first series of post-tests will start by end of April 2014. Using the software package *SPSS* and applying methods of inferential statistics ([10, 30]), a comprehensive statistical analysis will be performed after finishing all post-tests. Therefore first empirical results will be available by end of May 2014.

We are aware that the quasi-experimental evaluation design applied in this study has some limitations and shortcomings (i.a. no randomized assignment of participants to EG and CG; confounding factors like foreknowledge, influence of teacher; learning effects between pre- and post-test; motivation of participants; applying the study in different countries; ...) [10]. In order to face those challenges as far as possible specific actions are taken (i.a. calculating difference between results of pre-test (base level) and post-test; assessing confounding factors in the questionnaire; eight month time-gap between pre- and post-test; providing incentive for participants; translation of questionnaire in different languages by native speakers; ensuring similar assessment situation in different participating schools; ...). Currently we are in the detailed planning phase for the main study, contacting RCJ national representatives as well as schools and teachers in order to recruit potential participants. Taking into account the findings and results of the pilot survey, the applied instrumentation will be adapted for the main study starting in autumn 2014. In this context we will reduce the overall amount of items for the questionnaire by removing non relevant/redundant items and/or sub-sections. In addition we plan to develop a special questionnaire focusing on assessing skills and interests of pupils aged 9-11. First results of the main study are finally expected by the middle of 2015.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 101-109

The Herd of Educational Robotic Devices (HERD): Promoting Cooperation in Robotics Education

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Abstract. Teaching robotics in a high school environment can not only benefit the students because they acquire technical skills, they can also learn a lot about purposeful cooperation. We developed simple, small and cheap *swarm* robots designated for high school education that allow to broaden robotics experiments in interesting ways. The paper describes design considerations, their implementation in hardware and software, additional tools important in the high school setting and presents qualitative results from evaluation of the prototype swarm in different schools and different school classes.

Keywords: HERD, Swarm Robotics, High School, Teaching with Robots.

1 Introduction

Working hands-on with robotics arouses most high school students' interest to a much greater extent than pure computer science lessons – at least this is what we experienced in our initial evaluations (cf. Section 4) of the robotics platform presented here. The interdisciplinary field of robotics addresses a diverse set of interests and skills, from the more theoretical STEM disciplines, mathematics, algorithmics, electrical and mechanical engineering, to the rather hands-on work found in programming and making. The important initial difference in student interest seems to be related to the immediate experience of real-world consequences that result from changing some numeric value in the robot's code. Without getting into the discussion about embodiment, it is simply a more holistic experience when a real, physical robot moves about instead of some pixels on a computer screen. However, most (high) schools have to cope with scarce resources and either they cannot afford or do not have the room available to work with the kind of robots used in higher education institutions.

We developed the Herd of Educational Robotic Devices (HERD), simple and small *swarm* robots with extended capabilities, which find themselves in an affordable price segment at a designated price of 50 EUR [1]. A general inspiration for the HERD platform was the Wanda robot [2] used in academic research, however, with a much higher price tag. Our design of hardware, software and supplementary tools was carried out with a high school teaching objective and hence happened in close

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 110-117

consultation with high school teachers. We implemented the resulting design guidelines in the form of 15 HERD robots (cf. Figure 1) together with an application programming interface (API), which is adjusted to beginners in programming, yet at the same time capable of being used by more advanced students. In combination with a custom Live System (DVD or USB stick), the HERD robots were used in different schools in grades 8 to 11. The students' programming skills ranged from students who never had an introduction to programming up to ones with one or two years of Java programming experience.

Fig. 1. A swarm of prototype HERD robots is shown. Each robot has a size of 8x12x5 cm. All robots within direct line of sight are able to communicate by infrared senders and receivers.

The following section will detail the considerations that we arrived at during development of our HERD robotics platform and that are much more general than the specific - open hardware and open software - prototype implementation of the robots, described in Section 3. Having described the technical side of teaching with robots, Section 4 summarizes our experiences and that of the students who used the HERD platform either as part of a regular computer science course or during school project days. In the final section, we discuss findings and consequences of the school evaluations and provide an outlook about current developments and the future of HERD.

2 Design Considerations

There are three basic parts to a robotics platform for education: robot hardware, robot software and supporting tools. Each part has specific requirements due to the boundary conditions of high schools: students as users, teachers as advisors and administrators and schools as budget and staff limited customers.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 110-117

2.1 Hardware

Capabilities. Robots have to physically interact with the world in some way. The simplest way in terms of hardware and control requirements is that the robot is mobile, i.e. it is at least able to drive on a flat surface such as a table.

In order to interact with the world in a more interesting manner, a robot requires sensors to incorporate some relevant states of the world into its actions. Due to the fact that most schools do not have room for a dedicated robotics lab, the robot's world should only consist of elements that can easily be set up and taken down for course hours. At the same time, the sensors should be cheap, their readings easy to interpret, intuitive to act on from a student programmer's point of view and still allow the implementation of interesting robot behavior.

It should be possible for the robots to interact in order to facilitate cooperation between the students and to enable interesting experiments without a robot arena. We postulate the equipment of the robots with means of swarm communication, i.e. contactless, spatially local data exchange capabilities, to meet this requirement.

Extensibility by simple hardware additions such as a better distance sensor, a display or custom electronics should be provided through an extension port, similar to Arduino [7] shields.

Manufacturing and Costs. Because we cannot directly influence the volume of produced robots to profit from bulk production costs, the key to affordability is robot design. Simple mechanics with a minimum amount of custom parts allow to keep the robot cost low and they can even increase robot reliability – something absent simply cannot break. If the electronic printed circuit boards (PCBs) can also serve as (part of) the mechanics, costs can be further reduced. All electronic components should be readily available and remain available for at least a few years. Nevertheless, owing to hardware interdependencies, it is beneficial to stay behind the state of the art components. A new high fidelity sensor requires a newer, more powerful microcontroller, which in turn often requires finer PCBs and a higher capacity battery that might increase the total weight of the robot, again necessitating adjustments such as larger motors.

The robot cost drops significantly, if it can serve multiple purposes and the school can buy the robot instead of some other hardware. For example, if the robot's microcontroller can be used for non-robotics tasks, such teaching assembler programming.

2.2 Software

API. Depending on the specific robotics aspect to be taught and the students' specific prior knowledge, the robot's API has to provide different levels of abstraction and require different subsets of the programming language syntax. If the lesson is about basic programming constructs, the robot API functions should be useable as black box one-liners. On the other hand, if more advanced students program a swarm search and

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 110-117

gather algorithm, the API should provide advanced language features such as pointers.

Bootloader. To render swarm experiments in school lessons realistic, it must be possible to program all robots simultaneously without manually attaching each one to a computer. One possibility is to utilize the robots' means of swarm communication together with a write protected bootloader to wirelessly broadcast code from one robot to all others.

2.3 Live System

Most high school IT infrastructures are rather diverse and it is often difficult for a teacher to install and maintain additional software. Therefore a live system, on a DVD or USB stick, significantly eases teaching robotics in a school context. At the beginning of the lesson all computers are rebooted to the live system, robotics programs are written, complied and transferred using the live system's IDE, afterwards all computers are rebooted to their installed system.

3 Implementation and HERD Prototype Swarm

This section describes how we implemented the general design considerations in form of the HERD robots.

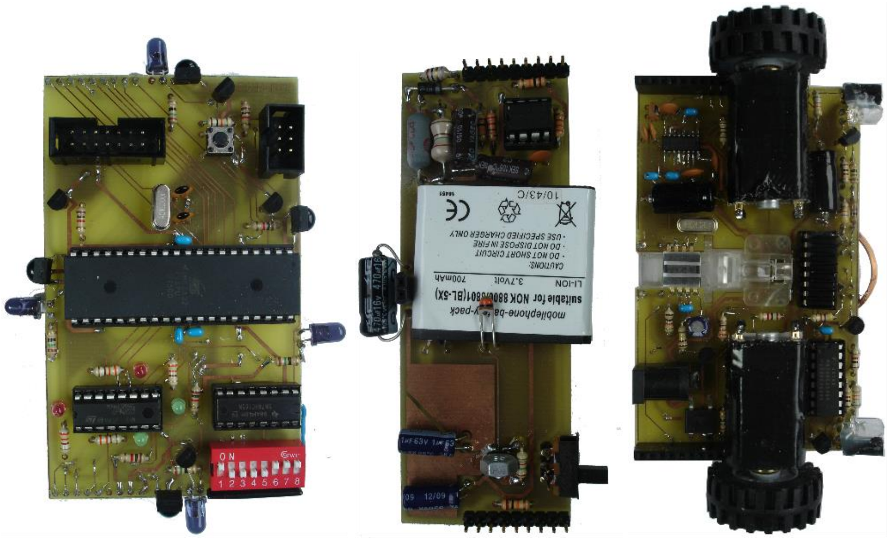

Fig. 2. The three PCBs which make up the hardware of a single HERD robot are shown. From left to right the front side of the top, middle and bottom PCB is pictured.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 110-117

3.1 Hardware

Each HERD robot consists of three printed circuit boards (PCBs), shown in Figure 2, which fit together on a single PCB eurocard (160x100 mm). They are cut out, populated and assembled through pin headers, which provide the mechanical and electronic connection (cf. Figure 3). The robot functionality is distributed to the top, middle and bottom boards, which will be described in the following. Only the most important technical properties are provided here, all low level details, e.g. port expansion, multiplexing and electronics design are left out.[1] All layouts are available as open hardware and can be modified with the open-source EDA suite KiCad [5].

Top. The top board contains an ATMega32 microcontroller, which controls all high and low level tasks. There are DIP switches to encode the robots swarm ID, to start the swarm bootloader and for user specific purposes. Four user controllable LEDs provide feedback about the robot state. One infrared (IR) sender and transmitter on each robot side provides local, line of sight based swarm communication.

Middle. The middle PCB contains all power related components. A Li-Ion battery as the ones found in (old) mobile phones is used together with a battery charger and a step-up converter to provide a regulated 5 V power source.

Bottom. The bottom board holds the differential drive together with all necessary electrical components. In order to provide more accurate movement, an optical mouse sensor is used in addition, measuring the robot's traveled distance. Furthermore, there are three different kind of sensors integrated: First, a simple distance sensor. While the robot is moving, blue LEDs are flashed and the reflected amount of light is measured. The intensity is proportional to the distance to collision objects. Second, two reflective sensors measure the ground reflectance. These measurements allow the robot to detect an abyss and stop before plunging down. The sensor can also differentiate between a white tabletop and a black line marked on top of it. Third, a RFID sensor is integrated - by far the most modern chip on the robot - which can detect RFID labels attached to objects or the table surface. This sensor is important because it allows to reliably recognize objects and positions, through the IDs stored in the RFID tags.

Extensions. An extension port is provided on the top board. Currently, there are already a few simple extension boards available such as an LC display, a serial port, multiple LED and segment displays. Since the extension port provides power and directly exposes a few microcontroller pins, custom extensions are easy to implement – both hardware and software wise.

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[1] All the technical details can be found at http://herd-project.org/wiki/Hardware.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 110-117

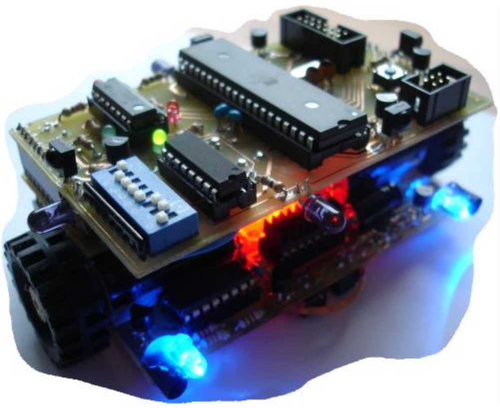

Fig. 3. The image above shows an assembled HERD robot. The three PCBs shown in Figure 2 are mechanically and electronically connected by pin headers. The blue LEDs are used for collision detection and avoidance. The mouse sensor used for position sensing is the source of the red glow.

3.2 Software

API. The API for the HERD robots uses the C programming language. We deem it is beneficial to use a “real” programming language instead of a domain-specific language (DSL) even for beginners. However, for student beginners the API does not show its C nature – apart from the syntax:

```
#include <all.h>

int main(void) {

    init_all(); /* initialize devices */

    while(1) {
        led_set(LEFT); /* turn left led on */
        delay_ms(1000); /* sleep for one second */
        led_set(RIGHT);
        delay_ms(1000);
    }
    return 0;
}
```

The reason for our assessment is that the transition from playfully exploring robotics to practicing more complex robotics should be smooth and not require world-switching, e.g. from GUI to textual programming.

Bootloader. To program a robot, the robot must be connected to the development computer and the program is flashed onto the microcontroller. Afterwards it is possible to position all other HERD robots around the programed one, toggle a switch

ISBN 978-88-95872-06-3
pp. 110-117

on each robot and the already programmed robot will transfer its code to all other robots in parallel via IR communication.

3.3 Live System

The live system (cf. Figure 4) can be booted from a DVD or USB stick and does not require or allow accessing the computer's hard drive. All software required to work with the HERD robots is provided and can be automatically updated.

Fig. 4. A screenshot of the booted HERD live system, which includes a customized Eclipse IDE, robot programming tools, an update mechanism and all required documentation.

Technically, the system is based on the Debian Live Systems project [8], running Eclipse as IDE, avr-gcc as cross compiler, avrdude as AVR programmer and git as version control system and for automatic updating.

4 Initial Evaluations

We took the 15 HERD prototypes to several schools in the vicinity of Karlsruhe, Germany, and evaluated them with students in grades 8 to 11. The students had different levels of programming experience ranging from no previous experience at all to two years of regular Java programming lessons. A few students had already used Lego Mindstorms [4] during school project days. Each pair of students had access to a computer running the HERD live system and one HERD robot.
Qualitatively, there are three main points worth stressing: First, all teachers reported that their students were eager to start using the robots and kept their motivation throughout the course material. Second, the beginners were able to learn the basic programming control structures – statements, function parameterization, loops and conditions - and utilize their knowledge to complete the exercises that required these. Third, the more advanced students quickly ran through all the single robot exercises –

ISBN 978-88-95872-06-3

apart from the line following one, but went on spending the rest of the lesson, if possible even staying extra time, to work on the swarm robot programs.
Overall, we got very positive feedback from students and their teachers. The students' feedback was that the robotics lessons were more interesting than "normal" computer science classes. The teachers emphasized the ease of use through the live system and that working with the HERD robots was not only a fun activity, but also brought the curriculum forward.

5 Discussion and Outlook

Most of the HERD development occured in 2011 and the evaluations continued in 2012, unfortunately it stagnated in 2013 because of lack of time on our side. We try to pick up the development again and attract support from other people working at the junction between (high school) education and robotics.
The near-term roadmap is as follows: 1) Substitute all through-hole components by SMD parts to bring down manufacturing costs - this part is already close to completion. 2) Improve the differential drive by either using stronger motors or adding a cheap gearbox. 3) Add a preconfigured robotics simulation environment, such as the one developed for the Wanda robot [3] or something based on Gazebo [6]. Yet, the biggest remaining challenge is to go from HERD prototypes to HERD as a product that can be ordered by interested schools.

Acknowledgments. This research has been supported by the *Scholarship for Outstanding Students Computer Science Karlsruhe (Begabtenstiftung Informatik Karlsruhe)* and the authors thank for the generous scholarship financing hardware costs.

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Robotics for Teaching Creative Activities in Primary and Secondary Schools - a Case Study

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Abstract. The good development of modern societies requires a substantial fraction of the population, and in particular of workforces, to be somehow expert in scientific and technical areas. Furthermore traditional approaches in education have proven inadequate to ensure alone the evolution towards this ideal balance. A consensus has formed on this issue in advanced countries, with the combined effort of devoted volunteers, professionals open to cross-cultural influences and finally the support also of political people and the government. The current paper reports on a case in Western Switzerland where innovative and promising actions have been progressively set into place, in particular relying on robotics, for fostering novel changes in curricula for primary and secondary education. Some enthusiastic teachers, ready to consider the necessary reorientation, are offered graduate level, adjustment training, where woodworking and metal processing techniques are now complemented with new, basic yet effective skills in electronics and programming. Federal action will follow.

Keywords: Robotics, STEM, MINT, Education, Outreach, Creative activities, Primary and Secondary Schools, University curriculum, Electronics, Pedagogy.

1 Introduction

Long after the tribal nature of early times, current human societies appear as highly complex systems, featuring millions of specialized profiles allowing virtually billions of individuals to communicate and interact with each other, and ultimately, to contribute to the general well-being.

Even though much has been done through the ages, new challenges appear. For what concerns our modern societies, novel actions are required for technical and natural sciences, as well as information-related technologies [1-6]. Researchers in education have also found that pupil's attitude towards technology is a crucial

[1] Submitted for RiE 2014 – Robotics in Education,

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 118-126

element for long term success [e.g. 7]. In our community, we have also identified this problem and have already contributed in concrete terms to its solution, as presented in this paper and references. Hopefully this experience can be useful for others, and in the other direction, possible suggestions for improvement would be welcome.

In this paper, Section 2 discusses the current need in education for technical and natural sciences as well as information related technologies in early school years. Then our case involving Switzerland, and more specially its Western, French-speaking part, is presented in 3 sections, relating first to an initiative for the promotion of robotics at country level (Robot-CH, Section 3), then to an experimental initiative bringing together professionals in pedagogical education for the young age and technical and scientific experts in robotics (Section 4), and finally, in Section 5, a graduate course in the current curriculum of students in pedagogy, ultimately aiming at raising the interest of pupils of the primary and secondary school level for technical and natural sciences as well as information related technologies.

2 Changes in education for technical and natural sciences as well as information related technologies in early school years

Education has evolved through ages. This section first gives the broad image, a general overview, and then it focuses on the specific case of changes occurring in the context of school programs for creative activities.

2.1 The general view

Evidence exists that humans appeared on Earth on the order of a million year ago, so it took all that time to reach the world population of today, actually with most of the development appearing in the last centuries [e.g. Biraben, 8]. While in early times human communities were very small and sparsely distributed, today billions of individuals may communicate, interact with each other, and contribute to the global life, so building-up a powerful, intricate network of diverse capabilities and skills.

A particular challenge we consider in this paper relates to the fact that, for these human individuals, the time from fresh, undifferentiated birth state to maturity age, as an adult with specific profile (language, culture, professional skills, etc.), has remained quite similar, mostly in the 1 to 3 decade range.

Obviously, through ages the education challenge has been somehow successfully met until nowadays; at least to the point of bringing us here. While the early resources were consisting only of parents, families and tribes, through the ages, progressively, much more elaborated structures have been added: religious guidance, public education, professional schools, academic universities, etc.

Yet changes in education have often translated into societal crises, when only the proven shortcoming of previous approaches could lead to the new, necessary, tentative, and finally successful approaches.

Today the level and diversity of requirements in education not only increase but moreover changes accelerate. For example in the experience of one of the authors, i.e.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 118-126

in a fraction of a lifetime, the classical framework for education has moved from quasi-religious school to public schools, to the contexts of continuing education, outreach, and finally workforce development; from the concept of multi-year classrooms to an organization where extended periods of time are individually allocated to students for personal work; even in academic courses, a strong evolution occurs, whereby ex-cathedra lectures on one hand seem to generalize to a scale where a massive number of students can attend online (re. MOOC – massive open online course) and on the other hand give place to interactive sessions and coaching activities.

In most modern, advanced societies, an adaptation problem has been identified in education, whereby some incentives should be given to young children so as to raise their interest in STEM disciplines (science, technology, engineering, and mathematics, e.g. [1,2] in USA, with an ultimate goal "of global leadership"), or similarly MINT (mathematics, information-related technologies, natural and technical sciences, e.g. [3-5] in Switzerland). Action is required for roughly the next 10 years, and a horizon line for results is lying somewhere within this 21st century (The situation may be different for UK, where pioneering work can be traced back for 30 years in terms of technology-oriented curriculum?). Inclusion of Arts has also been sometimes considered (re. "STEAM"), but the risk increases then of eroding otherwise more focused priorities.

Academic researchers agree of course with these political and governmental recommendations, being both, for some, at the origin of these considerations, and, for some others, on the side of an optimal implementation of this endeavor (e.g. for the French-speaking part of Switzerland [re. 6]).

The current paper precisely relates to the need of adaptation in technical and natural sciences as well as information-related technologies in this context, presenting the major aspects of our case, in the next three sections. But let us first review the changes typically occurring for the context of "creative activities" curriculum.

2.2 Changes occurring in the context of school programs for creative activities

The introduction of teaching for creative activities, focused on technology and innovation, is introduced during the discipline relating to creative and technical activities. The introduction of teaching for creative activities, focused on technology and innovation, is introduced during the discipline relating to creative and technical activities. In fact, the epistemology of the discipline of creative and technical activities is part of a dual relationship that is critical to understand before deciding on how it should be taught and how it should evolve.

First, the historical dimension highlights the fundamental elements conveyed by the teaching of manual and technical activities. The latter is meant to be a repository of manual instructions transmitted through technical, rigorous and precise actions. The relation to practice, intrinsic to this discipline, is characterized by the crafting of functional objects aiming at the acquisition of dexterity, precision, rigour and skill. For decades, these different facets, inherited from different professional bodies, were the exclusive points of its teaching.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 118-126

The second characteristic feature of the teaching of creative and technical activities comes from the way we teach this acquisition of precise and rigorous actions. The choice of objects and the sequence of planning through clearly defined stages, allow students to advance in the realisation of the object in a measured and controlled way. The way in which the instruction is organised, in the form of procedures carefully prepared by the teacher in advance, places students in the position of executor, performing the tasks assigned to them. This approach satisfies the need for organisation, speed and efficiency of production.

This dual relationship is explored in more details in the next two subsections, which relate respectively to creativity in production and innovation in design process.

Develop creativity to improve production. How can we reconcile a discipline based on the transmission of manual actions inherited from traditions with a complex multiform concept applied in an educational context aimed at producing quality objects? We hold to the following definition of creativity as "the ability to produce an expressible idea in an observable form or to realise a production that is both innovative and unexpected, adapted to the situation and (in some cases) considered to have some utility or value" (Bonnardel 2006, p. 21 [9]). This definition highlights the importance of the specific context in which objects are realised, as well as their usefulness and value. In an educational context that reconciles production with learning, we propose to introduce the activity of design as a creative process.

Design as a process towards innovative objects. The cognitive operations induced by design activities [10] lead students to enter into a contextualised creative process. Design requires identifying and analysing the problem and finding innovative and appropriate situations for realisation [11]. Design activities include the stages of creativity process and use divergent thinking, a key element in design phase, where the author/designer must abandon every day routine in order to explore the world of ideas and to propose innovative solutions [12]. Divergent thinking, underused in schools [12], is one of the key phases of the design activity. The selection of the ultimate idea must then factor in all the needs and constraints of the object. This requires convergent thinking and takes into account different subjective parameters. In this design phase, we can see the intervention of several transversal skills used in other disciplines. The task of innovation, combined with the constraints imposed by materials, as well as the implementation and functional use of the object, stimulate students and systematically teach them to anticipate. Notice that the current notions of "convergent" and "divergent" cognitive activities correspond well with the notions of abstraction and concretization in "MCS" model for cognitive sciences [13].

3 Robot-CH, for the promotion of robotics in Switzerland

In the study case we report, focusing on Western Switzerland, the convenient current adaptation of school curricula to modern requirements in the education of future

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 118-126

citizens could benefit from the initiative of various innovators joining forces to create the Robot-CH association.

Robot-CH was created in 2002, with the goal of promoting robotics in Switzerland, in order to give a more formal character to an initiative that could be traced back to the year 2000 or even earlier in 1998, in relation with the organization of robotic competitions at the Swiss and European levels [14] (e.g. also Fig. 1 and [15-17]).

Fig. 1. Example of Swiss Eurobot competition and primary and secondary school contests (re. [15] for a video, or [16]). Overview *(left)* and winners *(right)* ; on the right we can see FLL-typed contest tables for pupils, as well as three of the robots especially developed for Eurobot.

The aim is to establish at the level of Switzerland a platform where all important associations and organizations of the robotic domain, research and education institutes, public institutions as well as specialists and engineers could meet and exchange. Robot-CH has first developed, through robotic contests, outreach activities towards general public and the promotion of robotic jobs and world for the youth. Then additional activities have developed on professional and education domains.

In particular Robot-CH has coordinated, at Swiss level, major Eurobot and FLL contests, as well as, for Robocup, the participation to the international committee. It has also helped in the organization of robotic competitions for primary and secondary levels in local schools (e.g. Fig. 1 and the video [15]), and various demonstrations. Membership [14, 18] and cooperation [19] have been extended to other contest organizations, in particular the FIRST Lego League (FLL), via Hands-on-Technology, based in Germany, and Robocup [19].

It is therefore natural that Robot-CH has been approached by academic institutions in the context of pedagogical experiments and curriculum revisions, as presented in the sequel of this paper. Experts of technical science fields of could join force with teachers and professionals of teachers education at academic level. A first step was made with the introduction of a novel course, oriented towards robotics and electronics, for a Master of advanced studies at the Pedagogical University of Lausanne (HEP-Lausanne). The second step focused on the introduction of robotics

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 118-126

during the education of the teacher. Different robots (Bee-bot, Wedo and Thymio II) are used to teach the first elements of a simplified programming. The goal of this course is to introduce robotics to younger pupils and also to transform the wrong representation of robots associated to the masculine gender only. During these courses, many skills (communication, creativity, strategy of learning, collaboration) are associated with the setting-up of learning situations, in order to develop more science-oriented, logical minds and reflection attitudes.

4 MAS-HEP Course for Robotics and Electronics

In an attempt to improve education in STEM and MINT disciplines, at HEP-Lausanne, the concept matured to offer a novel course, oriented towards robotics and electronics, in the context of crafts (e.g. woodworking and metal processing) and handiwork (re. textiles) activities, at graduate level. This was experimental and, in case of success, would take a more permanent character.

Among key objectives of this 72 hour course (plus personal work), the idea was to open to many, the fields of electronics and robotics, yet considered by most people as out of reach; to bring basics for possible later extension within focused continuing education initiatives; to allow teachers to meet professionals in engineering; concretely, the assembly of a small electronic circuit, and the programming of an elementary robot was seen as an exercise to be replicated, under guidance, by future pupils. Equal parts were given for theory and for practice.

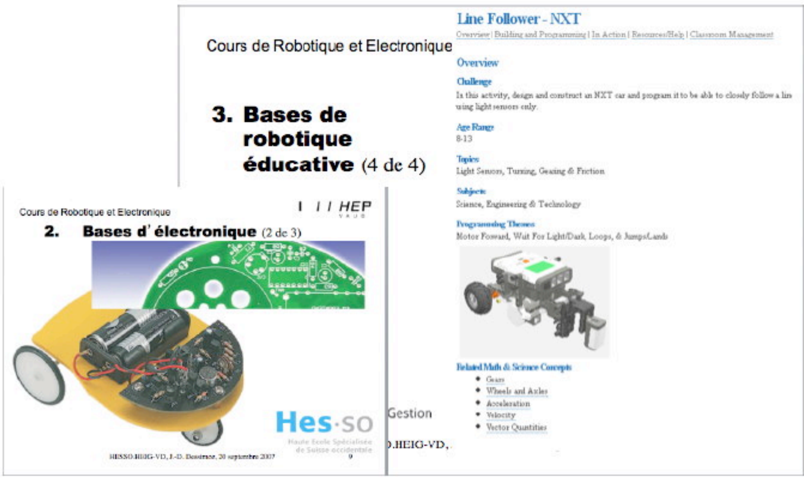

Fig. 2. Illustration of the first two thirds of the MAS Course 330-5 [20] : electronic circuit to assembly, for a system reactive to light or sound *(left)* and example of robotic task to program and implement *(right)*

The course consisted in three parts, the first one ensuring the assembly of a small, mobile, reactive system; the second one, the programming of a Lego-typed robot (Mindstorms), with NXT processor (re. Fig. 2), for an exercise comparable to what is done in FLL competitions; and the third one, essentially consisting in visiting private companies and research groups in electronics and robotics.

The rational of our choices for various, complementary robotic platforms included three critical parameters, in addition to essential pedagogical requirements : First, 1. simplicity and cost ; 2. availability on the market, with excellence of overall system concept ; and later on, 3. the proximity to dynamic local producers and experts.

Particularly positive results appeared in terms of interest from the participants; reports already useful as working documents for later teaching in classrooms (e.g. Fig. 3, [21-22]) ; and new contacts established between selected pupils and professionals in private companies, with the help of teachers who had benefited from this course.

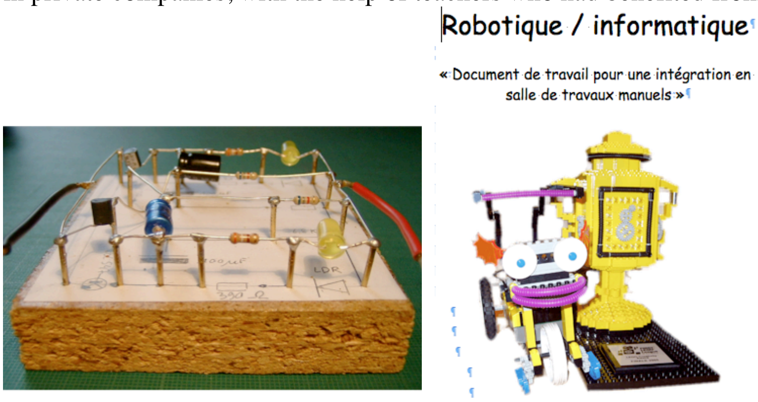

Fig. 3. Elements of reports made by MAS participants, contributing to concrete documents for subsequent teachers in classrooms: examples for electronics, Zahler [21] *(left)* and of robotic task to program and implement, Sahli and Demcik [22] *(right)*

The experience gained in this MAS Course could lead the way for a larger initiative, at Western Switzerland level, implemented in a five-year plan, as presented below.

5 "Piracef" Program

The experience gained in above described MAS course has led to a broader initiative, on a "perennial" basis.

Currently, a five-year program is under way at Western Switzerland level, where several academic institutions cooperate for a common curriculum, relating to crafts and home economics (PIRACEF).

Under the responsibility of Pedagogical Universities (HEP), a Diploma of Advanced Studies (DAS) is proposed, and novel courses extend classical craft and handwork courses, to activities in electronics ("AC 240") and, optionally, robotics ("electronics 2", "AC-277"). In addition, a special Research Methodology Day is organized, on a yearly basis (re. Fig. 4 and [23]).

A difficulty appears in terms of cost if robotic devices are widely used; currently, simpler electronic circuits, including analog and digital elements have been designed and are mostly used.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 118-126

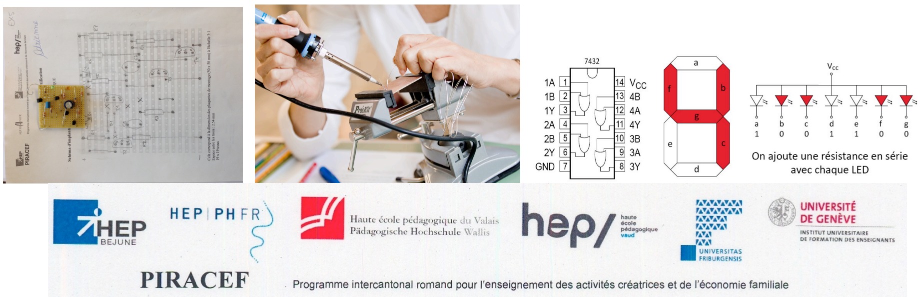

Fig. 4. As a test for knowledge acquisition, primary and secondary school teachers prove their understanding and ability to realize a simple electronic circuit *(above);* this novel initiative is coordinated at Western Switzerland level by 6 academic institutions *(below)*.

The courses and workshop laboratories take place at HEIG-VD / HES-SO, in cooperation with specialists for electronics and robotics. This turns out to be an interesting additional benefit of the program, as after this training the teachers know whom they can rely on for possible later technical support, and very importantly, they are also in a better position to inform the youth of the lifestyle and opportunities that technical sciences may bring them. As expected, some effective knowledge can be acquired by teachers and students in the basics of electronics, and robotics allow them to better understand current technological issues.

6 Conclusion

The good development of modern societies requires a substantial fraction of the population, and in particular of workforces, to be somehow expert in scientific and technical areas.

The paper has reported on a case in Western Switzerland where innovative and promising actions have been progressively set into place, in particular relying on robotics, for fostering novel changes in curricula for primary and secondary education.

This case study also shows that many "bottom-up" contributions are required for success: while, in particular, volunteers of Robot-CH, pioneers in pedagogical and engineering universities, and some enthusiastic teachers have already locally set into place a convincing novel training system for the benefit of youth, the Swiss federal government is just reaching the point to open a call for new projects in MINT context.

Acknowledgments

The authors wish to thank for their support the members and partners of Robot-CH, in particular the Town of Yverdon-les-Bains, HEIG-VD, and the Vaud Service for Economic Development (SPECo); as well as Jacques Hufschmid for his contributions to the initiative reported here. Thanks also to the reviewers for their comments.

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ISBN 978-88-95872-06-3
pp. 118-126

How We Did Introductory Lessons about Robot

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Abstract. In this article we offer findings about our introductory activities which should help students to clarify and familiarize with the various concepts in the field of educational robotics. We are not aiming at only one specific definition of the concept of robot, but over different areas and concepts that are related with educational robotics. We assume that it is important for students to explain these topics at the beginning. Within our doctoral research we created variety of introductory activities for elementary and lower secondary school students. Modified, but similar activities we conducted also with college students at university. Process of these activities and some outputs of them are described in this article. We assume that such activities should lead students to a proper understanding of the concepts and integration these concepts into existing logical structure.

Keywords: robotics, introductory lessons, students, activities.

1 Introduction

During the last three years, as doctoral students, we had opportunity to teach many different age groups of students. They have been from the first grade primary school up to university students. For every age group we tried to create age appropriate and eye catching activity for introductory lesson. So we created drafts uses constructionist methods for acquainted students with the areas, examples, components and various other concepts related to the concept of a robot. In this article we would like to introduce drafts of these introductory lessons and experiences that we have gained during the implementation.

Within our doctoral research we try to design, apply, implement and iteratively refine our activities with LEGO WeDo for primary and lower secondary school students. Some of these activities we conducted directly in the teaching of ICT at primary school, other activities we carried out during open days at the faculty with a lot of different groups of students and some activities we conducted with university students who attended our course *Robotic kits in education* for future teachers.

In available literature from field of educational robotics are common research articles with application character. Students in these researches usually designed [1] or built [2] their models. The studies very often mention competition [3] or programming environments for students [4]. In the mentioned articles, however, students come into contact with only one or a very limited number of robots or robotic kits. But their prior experiences of everyday life are quite rich and full of personal contact with robots in various forms. Unfortunately, students are usually unaware of these things which are part of robotics. Therefore we consider it is essential for students to organize this knowledge properly, to think about truthfulness of this knowledge, or extend them. We reckon that it would be great to do such activities at the beginning of the robotics lessons.

1.1 What Are Talking Definition about Concept of Robot

Before the teacher is considering to teach educational robotics, he/she first should be able to distinguish between what robots or robotic kits are and what are not, using several definitions. This task itself seems to be quite challenging, since the amount of the definitions in this area is significant. Brief overview of definitions previously used by researchers in the field of educational robotics is offered and presented in this chapter.

According to the authors [5], [6] and [7] the concept of robot is usually applied on devices that operate autonomously or by remote control, especially machines that perform specific tasks which are normally performed by human beings. Mioduser [8] writes that robot is in fact a concrete system embodying abstract ideas and concepts.

One of the most famous definitions from the year 1979 is as follows: "Robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks." (*Robot Institute of America)* Obviously, this is a committee-written definition. It's rather dry and uninspiring, think Kevin Downling [9]. Better ones for 'robotics' might include: „Force through intelligence. Where AI meet the real world."

Authors of the article [10] do not express the concept of robot by one definition, but define it by using multiple categories. For example: "A robot is a system, ...", "The robot is a *construction* ..." or "The robot is *controlled* by ...".

For our research is also quite important to define what a robotic kit is. Gura in [11] describes LEGO Robotics kits as a kit that should contain the things needed to construct a fully functioning robot: parts needed to construct the robot´s body; sensors; motors to power the robot; gears and other mechanical components; and a small processor, a programmable brick.

There are a lot of other definitions, but we haven't found any of them based on concrete examples that would declare what a robot is. Each of these definitions has its own potential and expresses the truth from a different perspective. However, we neither were able to select one, nor on the basis of these definitions to create our own definition. Therefore, we decided to create at least a few areas of focus based on the definitions and responses we have obtained from students.

2 Design of Introductory Lessons

In this chapter we would like to briefly describe activities, which were conducted with various groups of students. In the process of designing activities we considered

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 127-134

cognitive levels of learners, their ages, interests and some other aspects stated in previous chapter.

2.1 Discussion

In this activity, students rearranged their chairs in a circle, so they could clearly see and hear everybody. Discussion was conducted by a teacher and it has been taken in the form of semistructured interview. A teacher asked students several questions:

- Have you ever seen robots? (Where?)
- What types of robots do you know?
- What types of activities can robots perform?
- What components can robots consist of?
- Can robots think about something?
- Are there good or bad robots?

During discussion teacher was trying to respond to students' answers and he placed it into context with their previous experiences. This way teacher can help students with better organisation of their knowledge. Teacher was also trying to encourage all students to participate in discussion. This activity lasted 10 – 20 minutes. Our observation was that students between 10 – 11 years old were not as opened and they were not as willing to communicate with a teacher like 7 – 11 years old students. Therefore we couldn't precisely debate about all parts of discussion (we couldn't analyse every question). And that's why we've decided to design different types of introductory activity.

2.2 Mind maps

Mind map represents relations and contexts of several areas. We think it is suitable tool for students for working with the concept of robot. So we designed several variants of activities for using mind map in introductory lessons about the concept of robot or related areas. At the beginning of the activity we explained to students what represents the mind map and how they can create it. Students had not any problems with creating a mind map.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 127-134

Working in Pairs. At the beginning of this activity teacher divided students into pairs and he gave them one paper (A4 format) and two pens to each pair. Then students wrote a word robot in the middle of paper and they circled it. Thereafter they wrote all words on the same paper, which they associated with word robot. They also drew a line from new word to word robot to connect them. If they thought, that some new words were related, they could connect them too. They could even draw a picture (some students drew several pictures of different robots). Students could argue about words written on a paper. Therefore teacher had to confirm, which words fit into mind map and which weren't. After this activity teacher could continue with several other types of activities. **In lower secondary school** we (as teachers) continued with creating mind map at the black boards drawn based on students' suggestions. At first students had to select three most important words, which represented their perception of robot. Then one by one (pair) dictated those words to teacher and teacher used those words to arrange them into categories and created a mind map. We (as teachers) also created a mind map using almost the same way **with the university students**, but this time students themselves suggested names of categories in which we inserted proposed words. We were creating this map with software and we were showing it through the projector. During this activity we were discussing about relevance of names of categories and relevance of inclusion concrete words into concrete category with students. Another possibility, as further work with the created mind map, is compare this map with the prepared mind map by the teacher and trying together to find some differences and discuss them.

Creating a Mind Map with Sticky Notes. This activity is for larger group of students. We tried it with nine university students, who have been studying teaching of primary and secondary subjects for two and more years. In this activity all students worked together. They stationed around the board, laid on the table (it can be a black board or a notice-board) and they received couple of sticky notes in different colours, some pens and a twine. Then they created the mind map with the central word robot and with sticky notes around. On each note was one word, which they associated with central word robot. They used twine to link related words. During this activity students can acquaint new concepts and they can try to manage work of other students in group, they can develop collaboration, communication and many other social skills.

Selection of Words. We created this activity, because we wanted to acquaint students with specific concepts. Students could work separately, in small or larger groups (based on teachers' decision). Students received a paper with some - purposefully selected - printed words, randomly located in the paper. Students had to organize related words into categories. Then students (or groups) could compare their categories or they could compare those categories with a mind map, which was prepared by a teacher in advance. This activity took less time like previous activities, because students didn't create whole mind map but they are acquainted only with selected words or concepts. At the end students could add their own words into created categories.

2.3 Video

Video is another interesting possibility how we can show students major benefits of robotics, robotic laws or specific examples of robots. There are many possibilities how teacher can use video. For example: we created short film as a video cut of several videos, which included some movie or famous fairy tale trailers, advertisements for electrical appliances and videos from factories. Then we showed this short film to lower secondary school students and discussed it together about robotics. Another type of this activity we did with the university students. They were finding specific examples of robots on youtube and then we discussed why they picked exactly these videos. There are even other variants of using video, which teacher can combine with any of previous activity.

3 Concept of a Robot Defined by Students

In this chapter we describe how the various age groups expressed their opinions about the concept of a robot. We tried to describe also what kinds of knowledge have been typical for particular age groups and we show some examples of definition created by students. The results presented in this chapter were obtained from the data that we observed and recorded during the lessons described in the previous chapter. For collecting data we used structured observation, video and audio recordings, photo shoot and collecting mind maps. For analysing data we used multiple qualitative methods.

3.1 Concept of Robot According 8-10 Years Old Students

At the beginning of each discussion with primary school students, they did mention only a few examples of the robot, if any they knew. It was needed to guide them with extra questions and simple examples. Then they started to connect different previous experiences and knowledge, and they began to realize which things from their everyday life are robots. Subsequently primary school students during discussion about the concept of a robot mentioned very often examples of a film characters (*Wall-E, I Robot and Transformers*), household appliances (*blender, vacuum cleaner, dishwasher,* etc), different types of electronics and vehicles (*car, plane, a wheelchair motor*, etc). The main activity which should robot does according them was helping people. Students described not only specific parts of robots (*metal, iron, tow, torches*, etc), but they described also appearance and some properties of robots. Even though they had no experience with programming, they mentioned that robot is controlled in a certain way. Some of them said that someone had had to program robot. At the end of the discussion, students admitted that there are "good" and "bad" robots and they justified their arguments with examples from fairy tales, movies and from own observations based on logical thinking ("... *if the robot works, it is good, and if the*

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 127-134

robot does not work so is bad " or "*Robot would be bad if someone gave him a bad program*.").

3.2 Concept of a Robot According 10-12 Years Old Students

In this age category three groups of students attended our activities. We did activities with them using mind maps. Analysing these maps, we found the following results. Students wrote in these maps usually various types of robots (*home appliances, electronics, toys, vehicles*, etc), activities (*helping and protecting people*), control (*manual, electronic and signals*) and many other different components of a robot. Thereby areas we were starting to form: types, activities, control and components. This is exactly what we mentioned it in chapter 1.1.
One year later, two of these three groups participated in similar activities. At the end of these activities they wrote what according to them is a robot. Some students created quite short, but interesting definition of a robot such as: "*Robot is an artificial life form.*" or "*The robot is an artificial intelligence which thinks itself.*" Only one definition was short and not very general: "*Robot is a device which helps technology removing explosives.*" However, most of the definitions were longer. Students in them tried to describe the main role of the robot as it is something that is helping people. Usually they added either a description of its appearance, the list of its components or activities in which the robot can be used. An example such a definition, e.g.: "*Robot is a machine which serves for what it was programmed. In order to work it needs the processor, RAM and hard disks. It helps people and makes it what for it was composed.*"

3.3 Concept of a Robot According University Students

We conducted an activity with a mind map with the university students, in which they worked as one group and they used sticky notes to create a mind map. In this activity participated students of teaching primary and secondary school subjects (subjects: mathematics, physics, ICT and geography). They created a mind map in such a way that they can use it to explain a concept of robot to primary and secondary school children. Subsequently they were instructed to write down their own definition of a robot based on the created mind map. The examples of definition: „*People create robots to help them with different jobs and in different situations. Robots are controlled by a program, which is written by a human. Shape of robots and their function can be various – based on their purpose. Robots explore world with sensors.*“ or „*Robot is a machine, which is made by humans to help them in their work and in several fields of life – housework, robot as replacement of human organ.*“ Other definitions were similar.

3 Conclusion

Activities with robotic kits provide many opportunities to attractive, creative and playful teaching and learning. When we intend to incorporate robotic kits into learning process, we should provide students space for active exploration of deeper context of robotics and purpose of robotics in our society. Appropriately chosen activities can enhance pupil's understanding of this context and purpose. We think that teacher should select introductory activity with robotic kits, which can clarify fundamental concepts from the field of educational robotics. In pursuance of pupil's answers from our research, we created four fields, which we consider appropriate and important for educational robotics. They are namely **composition**, **controlling**, **utilization** and **types**. At the beginning of teaching educational robotics every teacher should go with students through these topics and check whether they were for pupils obvious.

Based on our experience we think, that discussion is suitable form of introductory activity for students under 10 years of age and students gladly participated in it. In lower secondary school students didn't like participating in the discussion. Therefore, it is more suitable to use different activities with the mind maps or activities with videos. That way, students have more time for thinking, reasoning and discussing about their opinions and ideas with a team partner. Knowledge of each student is different and by interacting each other they may enrich it. In each form of introductory activity is essential to coordinate and evaluate students work.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 127-134

Teaching Creative Classroom Robotics through the Student Teacher Outreach Mentorship Program

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Abstract. The Student Teacher Outreach Mentorship Program (STOMP) aims to engage all students in engineering activities during the school day by partnering university students with classroom teachers. Traditional robotics competitions may not work well in this format, since the lessons occur weekly for only one hour. Additionally, STOMP operates in traditional classrooms and aims to engage students that may not sign up for robotics or engineering activities. Due to these facts, STOMP fellows strive to develop creative robotics activities to make engineering accessible for all students, regardless of interests or abilities.

Keywords. Educational Robotics, LEGO NXT, Creativity, Diversity of Solutions, Robotics for Children

1 Introduction

1.1 Program Structure

The Student Teacher Outreach Mentorship Program (STOMP) [1] was founded in 2001 as a response to the release of the Massachusetts educational standards in engineering. Students at the Center for Engineering Education and Outreach (CEEO) at Tufts University formed a partnership with two local teachers by going into their classroom for an hour a week to teach engineering. In the past twelve years, the program has grown to include twenty-nine K-8 classrooms. 57 undergraduate and graduate student teachers (STOMP fellows) are employed by the CEEO to bring innovative engineering projects into the K-8 classrooms on a weekly basis. A detailed breakdown of the ages and genders of employed Tufts students for the fall 2013 semester can be found in Figure 1. Participating classrooms have students ranging in age from kindergarten (age 5) to 8th grade (age 14) and include a broad population of students with a wide range of abilities and backgrounds. STOMP also serves a number of English-as-a-second-language classrooms.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

STOMP Statistics	
# of Classroom Teachers	28
# of Fellows (Total)	59
Fellow Stats	
# of Female Fellows	42
# of Male Fellows	17
# of Freshmen	7
# of Sophomores	16
# of Juniors	15
# of Seniors	12
# of Graduate Students	9
# of Engineering Majors	48

Fig. 1. STOMP statistics for the fall 2013 semester.

1.2 Curriculum Development

Every semester, the STOMP fellows collaborate with their classroom teacher to develop a curriculum for eight to ten weeks of hour-long lessons. We encourage STOMP fellows to work with the teacher as they design their unit. Often, units work to build upon a subject the teacher wants assistance teaching or to integrate engineering activities with other classroom topics such as literature or history. STOMP fellows also have access to an online database of activities done in past STOMP classrooms (stompnetwork.org). Fellows add to this database every semester in order to compile a comprehensive record of STOMP activity.

1.3 Goals of STOMP

The following goals describe the key motivation of the STOMP program. Fellows and teachers strive to:

1) Introduce all students to engineering and encourage them in STEM pursuits. Engineering is not typically introduced to K-8 students. When asked, they believe engineers fix cars and build bridges [2, 3]. STOMP helps students understand what engineers really do, as they begin to think like engineers by engaging them in problem solving activities. STOMP also makes science and engineering fun, creative, exploratory and accessible.

2) Provide students with a unique learning experience that helps them build creativity. Traditional classroom activities demand one correct answer (eg: 3+3=6, or the spelling of a word.) Conversely, STOMP activities are open-ended or ill-defined, requiring students

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

to be creative and take risks. This allows students to learn that failure is not terminal, but a necessary step to finding a better solution.

3) Aid teachers in implementing engineering curricula in the classroom. STOMP strives to bring engineering into the typical classroom in an accessible way for teachers. While our first goal is the student learning experience, STOMP also partners with teachers to decrease the learning curve on new technologies and material.

1.4 A New Strategy

Over the twelve-year tenure of STOMP, we have observed that teaching robotics in our classrooms meets these three goals and also introduces students to new technology. Technological literacy is an underlying goal of STOMP: we hope that by encouraging students in engineering and bringing new technologies into the classroom in accessible ways for teachers and students, we increase technological literacy of everyone involved. LEGO NXT Robotics has proved to be an easy access point for students and teachers, and opened up the world of robotics in a nonthreatening way.

While robotics lessons have been generally well received by teachers and students, we noticed some challenges during observations of STOMP classrooms. Some robotics activities did not seem to meet learning goals defined above, in that they were not engaging or interesting all students. Specifically, building “robots” that were really just cars and then engaging in competitive challenges, was not attracting the attention and focus of female students. In one instance in a research project [4], a pair of 12-year-old girls spent two hours attempting to attach motors to their robotic brick (to build a car) with no success.

STOMP fellows observed certain activities were causing more frustration than learning. We challenged ourselves to create new and unique robotics activities that engage all students, hoping especially to reach female students. These activities were designed to allow for a wide diversity of solutions, and integrate content from other subjects. Over the last two years STOMP fellows have created new and unique robotics challenges. This paper presents the details of two of those challenges.

2 Case Studies: Sample Units

This paper highlights two creative robotics units that were implemented in STOMP classrooms during the fall 2013 or spring 2014 semester. All activities were developed and taught by undergraduate and graduate STOMP fellows. These activities were taught using the LEGO NXT Robotics kit and the MINDSTORMS NXT software program. The NXT Robotics kit is comprised of a brick, three motors, two touch sensors, one sound sensor, one motion sensor, 4 wheels, and various other beams, axles, pegs, and traditional

ISBN 978-88-95872-06-3
pp. 135-143

LEGO pieces. The STOMP program teaches a wide variety of schools and ages. We encourage the STOMP fellows to respond to their students' learning and make curriculum decisions accordingly. Depending on a school's schedule and the class's fluency with technology, each unit is taught at a different pace. While some classrooms complete six activities in one semester, others only complete four.

2.1 Unit 1: Creative Robotics

The creative robotics unit was originally designed for a 5th grade classroom in an urban public school. This unit was created to introduce students to the basics of robotics and programming and allows for a huge range of solutions, with activities that are open ended enough to stimulate creativity, while still being accessible because there is no "best way" to respond to the challenges. Difficulty level of each activity was adjusted for students working at different paces.

Introduction to Building and Programming
Before jumping in to any activities, students had a short, energetic discussion about what robots do and how they work. Students were allowed play around with the LEGO NXT kits and get an introduction to how to build with the pieces. After, students learned how computers and robots "think" differently than humans by "programming" their STOMP fellows to perform tasks around the classroom. The purpose of this activity was to emphasize that robots need very specific instructions to act how you want them to act.

Silly Walks
This activity involved students building any vehicle that moves in a nontraditional way. This is often used as the first introductory activity to the NXT Robotics platform in STOMP classrooms. Students are not allowed to use wheels that roll to make their robot move forward. The sillier the motion they create, the better! Students attached 1-3 motors to the brick and had the whole robot move as a unit. The challenge asked students to combine the pieces in unique ways to mimic feet, legs, or other types of motion to push the robot along. At the end of the period, students lined up all the projects and hit start at the same time to share what they did with the class.

Freeze Dance
The freeze dance activity allowed students to learn about the sound sensor. Students built and programmed NXT Robots that "danced" when music was on, and stopped moving when music was off. The dancing robots were either extensions built off the "silly walkers," or totally new ones. This challenge also asked students to mimic their favorite dance moves using robotic motions. For an extra challenge, some students added other sensors to responsively dance to other robots in the room.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

Perfect Puppy

Students made their "perfect puppy" which behaved exactly as they would want a pet puppy to behave. STOMP fellows introduced sensors by comparing them to animals' senses.

Fig. 2. Example of a puppy robot created for Dr. E's Robo-Zoo [7]

2.2 Unit 2: Animal Adaptations

The Animal Adaptations Unit was created to supplement a Massachusetts state science standard about animal behavior. This unit was adapted to fit the STOMP timeline from the product of a research project [5,6] that focused on creating engineering design activities integrated with science instruction. This unit asked students to remember what they had learned about animals and animal behavior and apply it to engineering design. In the communities surrounding Tufts University, animal behavior is typically taught to students in the fall of their 5th grade year.

Build an Animal Habitat

In this introductory activity, students familiarized themselves with the pieces in the NXT kit by constructing a physical representation of an animal's habitat. No motors or sensors were used in this activity. The students worked in teams, and each team chose its own animal. This activity asked students to start recalling what they had learned about animals before more complicated building and programming activities.

Fig. 3. An example of a model habitat: cacti in the desert.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

Representational Model of an Animal

To continue to gain familiarity with building, students next learned about representational models, or models that look like their animal but do not move like them. Again, no motors or sensors were used in this activity. Students used the LEGO NXT pieces to construct a physical representation of their chosen animal.

Motion Study

This is the last activity with no motors or sensors involved. Students conducted a "motion study" of their chosen animal. Students discussed joints and limbs, using humans as examples, and extended the concepts to their own animals. Students drew the joints and limbs of their chosen animals, and discussed their drawing with classmates. Students then figured out which pieces in the kit could be used to make joints and which could be used to make limbs. The final piece of the activity was for students to use the LEGO pieces to construct semi-functional models of their animal: models that move like the animal but do not necessarily look like it.

Introduce Programming and Sensors in Animal Context

STOMP fellows introduced the different sensors by comparing the sensors to the senses real animals have. For example, the sound sensor functions like ears, the light sensor and ultrasonic sensor like eyes, and the touch like paws. Human Robot (described in Unit 1:Introduction to Building and Programming) was done. The goal for this activity was to familiarize students with the concept of programming.

Functional Model of Animal Behaviors: "Translating" Animal Behaviors into Computer Language

The class brainstormed the behaviors animals need to survive (for example: find food, escape from predators, and protect their young.) They then "translated" those behaviors into sense-think-act programs for their robot. For example, escaping from predators was represented by the robot moving quickly in reverse whenever the sound sensor detected a noise above 80 decibels. Students then were introduced to the MINDSTORMS NXT software and the process of debugging a program as they collectively wrote a program, with the help of the STOMP fellows.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

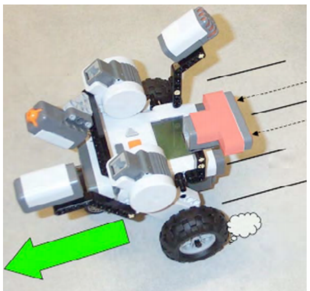

Fig. 4. A functional model of an animal, reacting to its surroundings.

Robo - Zoo

For their final projects, students built a robo-animal, which was different than the animal they focused on all semester. The animals both moved and looked like a real animal. STOMP fellows provided craft materials such as felt, paper, pipe cleaners, and more to help students be creative and get engaged in the challenge. Students often needed encouragement and help from the fellows to really think about how their animal moved and looked, and how they could mimic that. Looking at slow motion videos of animals walking, for example, was useful.

Fig. 5. A robotic snake created as part of Dr. E's Robo-Zoo [7]

3 Conclusion

3.1 Attitudes About Robotics and Engineering

Female students participating in these creative robotics activities through STOMP demonstrated positive attitudes about engineering, science, math, and robotics during interviews that took place after the units were completed. Many girls also expressed a strong understanding of what engineers do for their careers. While no formal statistical analysis was completed, two representative interviews are described below.

3.1.1 Interview 1: Divya, 5th Grade

Researcher: Do you know what an engineer does?
Divya: They help the world by designing… They design stuff, like machines, to help make the world better.
Researcher: How did you learn what an engineer is?
Divya: We had STOMPers in our classroom, so I learned from them.
Researcher: So you learned it in school, or did you learn it before then?
Divya: Yeah, I learned it in school, from the STOMPers.
Researcher: Do you have any science or engineering hobbies?
Divya: Sometimes, when there were STOMPers in my class, if I learned something, I go try it at home to see if I can do it better than I did it in the classroom.

3.1.2 Interview 2: Katie, 6th Grade

Researcher: Do you know what an engineer does?
Katie: I think that they build stuff to help people, and they use computers to program robots.
Researcher: If I said to you that girls can't be scientists or engineers, what would you say?
Katie: I would say that's not true, I would want to break that rule and want to become an engineer even more.

3.2 Future Work

We hope that future development and investigation of units such as those described here will aid in engaging students in problem solving activities and increase their technical literacy. We have observed a wide diversity of solutions we see being produced in STOMP classrooms implementing such curricula.

No quantitative data was obtained in this preliminary work. Future work must be done in STOMP classrooms involving pre and post-tests concerning robotics and engineering attitudes. By comparing student opinions and knowledge before and after participation in STOMP, we hope to clearly demonstrate the impact STOMP has on student engineering.

Additionally, comparison studies would be useful, comparing two similar STOMP classrooms doing different robotics units. One classroom will complete a traditional "cars and competition" robotics unit, while the other will engage in more unique challenges. Using a similar pre and post-test process as described above, we hope to compare student experiences and further understand student engagement in robotics activities.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

In the future, we hope to collect quantitative data, additional interviews, and classroom video to understand more specifically the types of activities that engage all students in critical thinking, creativity, and technology. We hope to continue this work to better serve the students we teach as well as help more teachers integrate engineering into their classrooms.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 135-143

Educational Robots and Computational Thinking

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Abstract. In 1969 Seymour Papert developed the idea of Logo programming and Turtle robots. His thesis was that people learn according to the mental models available to them. He envisioned the potential of the computer to make students active learners, constructors of their own knowledge through the process of programming. The floor Turtles are devices the students can program and use to explore ideas and the world around them. The Logo approach was not simply writing code, it was about developing a student's thinking skills, problem solving and other sustainable learning traits. A 2006 seminal paper by Jeannette Wing prompted renewed interest in what is now called computational thinking. This paper examines this new perspective and how they relate to the theory and practical use of Turtle type educational robots.

Keywords: Computational Thinking, Roamer, Educational Robots, TRTWR, RiE, Teaching with Robots, Logo, Seymour Papert, Turtles, Jeannette Wing.

1 Introduction

In 2006, Jeannette Wing, President's Professor of Computer Science at Carnegie Mellon University, delivered a seminal paper to the Association of Computer Machinery [1]. Wing stated that thinking processes and disciplines used by computer scientists would benefit students of all subjects. The paper inspired computer scientists and educators and has led to growing interest around the world to promote the idea to schools. These proponents cite work with educational robots as a means of engaging students in what is called Computational Thinking (CT) [2]. This paper reviews this trend from the robotic educator's perspective.

The paper explores the pre-history of the current CT movement, which is intimately involved in the work of Seymour Papert – the founding father of educational robotics. It goes on to examine the claims made by proponents of CT and summarises their ambitions and the challenges they are striving to overcome. A critical analysis of this work presents a few cautionary comments and then reviews the synergies between the ideas of CT and those of the Educational Robotic Application (ERA) Principles [3]. It illustrates these with example activities and suggestions that may help the development of successful CT strategies that can advance the objectives of both educational roboticists and educational computer scientists.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 144-151

2 Papert, Logo and Turtles

In the late sixties and early seventies Seymour Papert developed the idea of Logo as a computer language for young children. He also invented educational robots when he developed the Turtle as a real-world device that children could control with their Logo programs. Papert had worked with Jean Piaget exploring how children learn mathematics. He shared many of Piaget's notions of genetic epistemology and he believed that anything was simple to learn if you could assimilate the idea into your collection of mental models [4].

Papert recalled how, as a 2 year old child, he had become fascinated by automobiles, particularly differential gears. Brought up in the South African bush, where keeping cars going was a major challenge, this was a hands-on familiarity. In short, he loved playing with gear systems. Years later he was able to quickly grasp some powerful mathematical ideas, which bemused most of his contemporaries. He realised that this was because he could relate these ideas to his knowledge of gear systems. "*My thesis could be summarised as: what gears cannot do the computer might. The computer is the Proteus of machines. Its essence is its universality, its power to simulate"* [5].

Papert saw the Turtle robot as an "object to think with" [6]. He thought of it as a transitional object, an idea he borrowed from clinical psychology [7]. This relates to how we form relationships with the physical world, how we project our thoughts, imaginations and emotions into objects and how they trigger thoughts and help create thinking patterns. He called this process body syntonicity. Children imagine how they would navigate around, for example a square. They transfer this experience into a program that made the robot draw a square. In this way, they made contact not simply with facts about squares, but the essential structure of geometric shapes.

Papert cited the Piaget's psychogenetic theories and related these to the Bourbaki mathematical concepts as the roots of Logo [8]. He hypothesises a process in which mental structures emerge from student's experience. Children learnt by using Logo and Turtle as tools to explore environments (microworlds) rich with ideas.

George Polya was another major influence on Papert. Polya had noticed that many of his students had acquired mathematical knowledge, but did not have the ability to solve mathematical problems. In his classic book "How to Solve It" Polya introduced a heuristic approach to problem solving used by mathematicians [9]. This was a fledgling attempt at trying to do more than teach factual knowledge. The mathematics teaching community reacted enthusiastically. In the foreword to the new edition Professor Ian Stewart remarks that the 1980 yearbook of the National Council of Teachers of Mathematics in the USA had been "*marinated in Polya sauce*".

3 Computational Thinking

In her 2006 paper Wing states: *"It [Computational Thinking] represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use"*. She goes on to claim, *"Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing,* *and arithmetic, we should add computational thinking to every child's analytical ability"* [1].

What is meant by computational thinking continues to be debated and with an increased intensity. The 2014 English National Curriculum for computing opens "*A high quality computing education equips pupils to use computational thinking and creativity to understand and change the world*" [10]. It is not our intention to attempt a strict definition. We are more interested in "the sense" of its meaning, particularly where it relates to educational robotics. Journalist John Naughton refers to abstraction, decomposition, heuristics, and iteration [11]. Felleisen and Krishnamurthi argue that imaginative programming is crucial [12]. Table 1 summarises the key ideas of CT [13].

Table 1. Computational Thinking Concepts and Competencies

CT Concepts	Competencies
Abstraction	Dealing with complexity through reducing unnecessary detail
Algorithm	Identifying the processes and sequence of events
Decomposition	Breaking complex artefacts, processes or systems into their component parts
Generalisation	Identifying the patterns and commonality between artefacts, processes or systems
Logical Analysis	Applying and interpreting Boolean logic
Evaluation	Systematically (through criteria and heuristics) make substantiated value judgements

The statement that CT is not programming appears persistently in the literature. In England, the government's launch of the "Year of Code" has provoked an adverse reaction. Clive Beale Educational Director of Raspberry Pi Foundation, stated, "*...code alone was not what computing is about. Computing could be a creative discipline bringing in other subjects as music and art*" [14]. Professor Mark Guzdial, from Georgia Tech, makes the point while it may not be the aim it is the means [15].

4 A Cautionary Note

The CT literature is enthusiastic. David Hemmindinger points out that some of the claims made by the CT community are also the provenance claimed by other disciplines [16]. He wisely warns against some of the more zealous claims made in favour of CT.

It is not the first time a discipline has endeavoured to promote its thinking skills and processes as a general approach beneficial for all of K-12 Education. In 1970s England, a grassroots inspired initiative transformed the teaching of woodwork and metal work (Industrial Arts) into Design and Technology (D&T). It was not sufficient to make things, it was important to design them. It was realised that the design process offered a universally applicable intellectual discipline and problem solving process. Every manmade thing is subject, consciously or subconsciously to the design process. This includes web site design and the development of the most

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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ISBN 978-88-95872-06-3
pp. 144-151

sophisticated software and computer-based projects. The impetus of the D&T movement saw the subject introduced in several countries. In 1994 it led to the International Technology Educators Association (ITEA) launching the Technology for All Americans project [17]. Advocates like Dr. Ronald Todd, director of Project Update[1], passionately espoused ideas that are remarkably similar to those made by the CT Community [18]. The potency of this is illustrated in "The Fleet Circus Project", run in a small primary school in Lincolnshire, England, it shows an exemplar D&T project [19]. This cross-curricular work saw the students design and build a series of circus automata, many of which were computer controlled.

As a fervent believer in this approach, Dave Catlin had salutary experience trying to persuade the administrators of science teaching in Montgomery County, Maryland of the potential D&T offered. They made it clear that their interest lay in getting science students to think like scientists. To become a mathematician you need to think like a mathematician, to become an artist you need to adopt the thought processes of the artistic fraternity. Teachers of those subjects justifiably believe in the mental processes of their disciplines. This is not simply a "turf-war". Lave and Wenger's work on communities of practice clearly shows that you acquire the attributes of a profession by engaging in its practices [20].

We can draw a number of lessons from these histories. The first Hemmindinger has already identified – developing the thinking skills is the goal shared by all subjects. Just as with the original Logo ideas, programming provides the opportunity to engage students in activities with the potential to develop those skills. But, it needs to be done from within the discipline. Felleisen and Krishnamurti suggested the way forward was to align CT with mathematics – an accepted core subject [12].

We need to consider carefully how explicit we need to be about the mental processes. Papert's belief was that the structures would emerge from exploring suitable microworlds, with appropriate tools. This raises an issue beyond the scope of this paper, but something worth further investigation – the difference between experts and novices – see Bransford et al [21]. The expert's mental structures are internalised and as Lave and Wenger demonstrate they gradually emerge from exposure to a variety of relevant experiences. CT is such a structure and you cannot simply "bolt it on" to a novice. Vygotsky's defined the zone of proximal development (ZPD) as the difference between a child's independent problem solving performance and their performance guided by more capable peers [22]. Papert noted that students' ability to solve problems improved when Polya was the guide [23]. Stewart points out simply implementing the heuristics is not enough; they require the interpretation of experience. Polya used heuristics not as rigid rules, but as a set of guidelines, backed up with sound praxis. But he was an expert: a more capable peer. The Fleet Circus Project was successful because the teachers used the design process as a loose guide. Others, who systematically followed the design process, have failed. It is like trying to be an artist by "painting with numbers". The problem is, many teachers have yet to internalise CT. They do not qualify as more capable peers.

[1] UPDATE (Upgrading Practice through Design and Technology/Engineering Education) was a K-6 effort across six states, with the intent of using D&T as a means of integrating science, math, and technology for elementary students

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
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ISBN 978-88-95872-06-3
pp. 144-151

5 Computational Thinking and Educational Robots

In his blog, John Naughton stated that many UK schools taught Logo programming enabling children to control a Turtle robot to carry out complex manoeuvres. He then said, most of those schools gave up teaching Logo [11]. However, the teaching of Logo and controlling of Turtles never stopped. For over 30 years the use of educational robots, disguised as programmable toys or control technology, has been standard practice in UK primary schools. This work has not taken place in the hallowed halls of academia, but in classrooms. The protagonists of this effort have been dedicated teachers working with a few specialist companies and robots like Roamer, PIP, Pixie and BeeBot. Together they have accumulated practical experience of dealing with the issues discussed above. The ERA Principles (Table 2) were empirically derived from this work [3].

Table 2. Summary of ERA Principles

Technology	Student	Teacher
Intelligence	Engagement	Pedagogical
Embodiment	Sustainable Learning	Curriculum and Assessment
Interaction	Personalisation	Equity
		Practical

These principles provide a framework to judge the value of educational robots and robotic activities. They afford a means of supporting future design efforts and provide a set of tools for correlating data in the long-term e-Robot Research Project [24]. The Principles usually work together in a variety of ways. We now present four sample activities, which we will use to explain the relevant ERA Principles and illustrate how they relate to CT ideas.

What Did I Do? This is a simple activity for 5 year olds. The robot has a specific behaviour which demonstrates all its basic movements and actions in a sequence. The students' task is to describe what they see. At this age students generally do not have the language to describe the robots actions. Typically, they resort to their imaginations inventing non-standard units to describe how far the robot moves.

In the Dog House Students turn their Roamer robots into "dogs". This task involves science (observing and studying dog behaviours and habitats), mathematical modelling (describing the behaviour in a way that it can be programmed) and programming, testing and debugging. It also involves D&T and art and crafts and is typical of many cross-curricular opportunities educational robots offer. This type of task is open-ended – the students are not making a dog, but a machine that makes people 'think' dog [25].

Spacecraft Rescue A spacecraft has crash-landed in a ravine. The Rescue Team has to send their robot to recover it. The students design a structure that the robot can transport to the site. The structure has to be capable of lifting the spacecraft, loading it onto the robot which then transports the spacecraft and the structure back to base. Materials used, manufacturing processes and travelling are all costed. The challenge is to complete the task as economically as possible. The programming involves older students in basic vector analysis [26].

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 144-151

Going Round the Bend Turtle robots turn on the spot because both their wheels turn in opposite directions at the same speed. In this task students create a behaviour where the wheels drive independently. This allows students to make the robot move in curved paths. This is an activity in practical calculus.

Most teachers feel under pressure to deliver good test scores. If CT helps them do that then it complies with the **ERA Practical Principle** (which concerns issues relating to teacher buy-in). In this case, buy-in is satisfied through the **ERA Curriculum and Assessment Principle (CAP)**, which states: "*Educational Robots can facilitate teaching, learning and assessment in traditional curriculum areas by supporting good teaching practice"*. Felleisen and Krishnamurti were criticized for "hiding CT in mathematics" [14]. Their response based on "14 years in the trenches of outreach" was that this was essential to get teacher buy-in. This agrees with our 30 year practical experience with robotics. However, as Table 3 illustrates, with educational robots it is possible to reach a wider audience than the maths teachers. Educational robots provide a well-trodden route for CT to reach schools.

Table 3. Relationship of CT Concepts, student activity and curriculum subjects for the Dog Activity. A similar correlation can be made for all the sample activities.

CT Concepts	Student Activity	Related Subjects
Abstraction	What are the essential features of a dog?	Science/Art
Algorithm	Defining what the robot dog will do	Mathematics
Decomposition	Creating a design specification for the dog	Design Technology
Generalisation	How do dogs behave in their environment	Science
Logical Analysis	Not applicable in this activity	
Evaluation	Does my robot dog meet my design criteria?	Design Technology

"Good teaching practice" is a key phrase in the CAP definition. Good practice is exemplified in the Fleet Circus Project, but how do you capture and propagate that? It has been proposed that Assessment for Learning Methodologies (AfL) offers a resolution to this problem [27]. The Spacecraft Rescue illustrates how application of these methods can help resolve the expertise-problem highlighted by Professor Stewart [28]. It provides an effective way to scaffold activities and support non-expert teachers with the contextual knowledge essential to this sort of endeavour.

The **Sustainable Learning Principle** (SLP) resonates with many of CT ideas. Another phrase used to describe this principle is Lifelong Learning. SLP skills are transferrable from task to task and discipline to discipline. They fall into four broad categories: cognitive, emotional, personal and social. The CT Concepts in Table 2 are cognitive aspects of SLP. Generally, programming is a solitary process, whereas working with floor robots is normally done in groups. They include the social aspects of SLP and as a consequence the personal and emotional facets. This connects CT with powerful learning paradigms associated with such social learning environments.

Derived from an analysis of hundreds of different robotic activities the **Pedagogical Principle** identifies several distinct elements that combine to make up an activity. With a specific outcome, Round the Bend is a *focussed task*. It involves *mathematical modelling* and provides the students with the opportunity to engage in *inductive thinking* and *experimentation* with an authentic problem. Understanding the nature of PPs helps the developer create activities with structure and support

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 144-151

necessary to meet the **Practical Principle** and provides an analytical tool for research. Such elements are essential if the aims of CT movement are to be realised.

Robots have a history of **Engaging** students, dealing with **Equity** issues and enabling activities to be **Personalised** to suit the needs of students [29]. CT must address these issues if it is to be useful in K-12 education.

The **Embodiment** Principle states *Students learn by intentional and meaningful interactions with educational robots situated in the same space and time.* A straw poll of over 250 teachers who frequently use robots indicates a belief that there is at least a valuable qualitative difference in the experience of a real compared with virtual robots. In this sense, educational robots offer a concrete way of engaging CT. While programming is currently the main way students interact with robots. We will see tangible computing, HCI and HRI playing an increasing role. **What Did I Do?** shows how CT concepts like *Abstraction* and *Decomposition* can be engaged without programming. As Wing asserted, CT goes beyond computer science and is a general skill. The **Intelligence Principle**, predicts that behaviours beyond the Logo paradigm can and will be invented. Ensuring these behaviours engage CT will add value to educational robots.

6 Conclusions

Educational robots have grown out of ideas that represent a prehistory of CT. There is a strong correlation between the ERA Principles and the ideas embraced by CT. CT and Educational Robotics have a natural symbiotic relationship and can work together to offer exciting educational opportunities for K-12 Education.

Barr and Stephenson called for the larger computer science community to help the CT cause by providing suitable materials and taking advantage of opportunities to work with K-12 administrators [2]. Educational robots offer a substantial set of tried and tested materials that meet the need for CT resources. Robot activities bring a practical maturity that can help CT theory become a successful practice. These present teachers with the opportunity to help students develop their CT skills while meeting their obligation of delivering the curriculum and aiming for high test scores.

On the other hand, the interest and energy represented by the CT movement represents an opportunity to further the aspirations of the educational robotic community. In the USA and UK CT currently has the attention of policy makers and administrators. The educational robot community should grasp this opportunity by forging links with this movement.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 144-151

Education with micro-robots and innovation in education

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Abstract. Knowledge-driven re-industrialisation in Europe calls for changes in education systems. We address those changes by focusing on the adoption of a context-based approach to place science and technology within young people's daily lives and to promote their understanding of the relevant issues emerging in society. In particular, we propose the use of micro-robots labs in order to: (i) improve a context-based approach to technology education and (ii) spread the knowledge of working conditions, employment opportunities and industrial enterprises activities. We suggest action-research as a feasible practice to boost bottom-up changes in teaching and learning activities, and we focus on the university initiative Officina Emilia as an example. The paper proposes some concluding remarks focusing on hybrid places to foster innovation, involving not only teachers and experts on education, but also researchers in different technological domains and in the social sciences and humanities, manufacturing and services companies, civil society.

Keywords: knowledge driven reindustrialization in Europe; context-based technology education; robotics and innovation in education

1 Introduction

Re-industrialization of Europe is becoming an imperative to support a path of sustainable development characterized by social inclusion and innovation, as remarked also by the Report on EU competiveness [1]. The main rationale for strengthening the manufacturing sector in Europe is that most innovations are produced within it and through it they affect the service sector (in particular business services). Although it constitutes a decreasing share of Europe's Gross Domestic Product (GDP), the manufacturing sector is still the engine of modern economies. Because of backward and forward linkages [2], the manufacturing sector development has a multiplier effect on the growth of the economy [3]: a general increase in productivity of the manufacturing sector makes a contribution to the growth of GDP that is four times higher than that of other inputs.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 152-159

The re-industrialization process requires new skills to support changes in technology and organizational models (within the companies and in their networks). These new skills can be nurtured within workplaces. But this is not enough. They should be included into educational pathways, particularly in the upper secondary level.

The ability of actual education systems to create and develop adequate skills does not meet these needs, and the European Commission has pushed for innovation in education aiming toward new skills for new jobs [4].

In this paper we argue that, in order to strengthen re-industrialization, it is necessary to boost innovation in the whole education system, from pre-school to university, not only in the vocational and training pathways. In particular, the education and training system as a whole must take on the challenge to provide or to increase the provision of the ability to (1) apply what has been learned to different contexts, (2) understand the technological, social, economic, historical and cultural heritage of the context in which people live and work, (3) take advantage of the core knowledge of work processes. To reach these goals, the education system has to allow students to have experiences in several different environments and to be aware of the concreteness of the material conditions of life and work [5] [6].

“Officina Emilia”, an action-research supported by the University of Modena and Reggio Emilia, has produced educational laboratories, such those with micro-robots, that have fostered significant changes into contents and methods of teaching and learning, by linking science, technology, engineering and mathematics in a more effective way [7][8] At the same time, Officina Emilia’s laboratories allow students to develop soft skills – such as time management, proper allocation of resources, efficient team working, problem solving, communication, use of feedbacks from processes. Because of these characteristics, the Officina Emilia’s laboratories share many elements with several initiatives carried out over time in Italy and in Europe [9]. Its special contribution is on three related domains: (1) to combine the education with micro-robots with other activities in order to connect technologies with the knowledge of the workplaces and the enterprise activities; (2) to promote knowledge and understanding of the industrial structure of the territories; (3) to involve all young people, not only students enrolled in technical and vocational training pathways. Moreover, Officina Emilia addresses teachers’ involvement as a crucial issue for innovation processes in education. Lastly, Officina Emilia embraces the need to support bottom up changes in education through multi-agent and multi-level actions: this is why, an open public hybrid space has been designed to allow students, educators, production and technology experts, policy makers to open their mindset and improve their understanding of the issue and practices of regeneration of competence networks. Public hybrid spaces are increasingly recognized as loci fostering innovation processes, since they provide a venue in which new ideas and insights can emerge by allowing interactions and interpretative ambiguity. As Lester and Piore have stressed [10], these are often the missing dimensions in innovation processes, which are nurtured not only by analysis and problem solving, but also by generative relationships which are based on heterogeneity, aligned and mutual directedness of the relevant agents, and appropriate permissions to support agents' opportunities of action [11].

In this paper we first discuss how basic knowledge needs to be generalized in order to meet the re-industrialization and to support citizenship and social inclusion. We address the issue of developing a new approach to context-based technology. We present the Officina Emilia initiatives, with regard to its micro-robots labs designed and tested to improve a context-based technology education. The paper proposes some lessons drawn by the Officina Emilia action-research on how to support changes in education to enhance a knowledge-driven re-industrialization.

2 New basic knowledge to be generalized: the context-based technology education

Skills to be promoted in the education system must address not only employability, but also social cohesion, inclusion and active citizenship [12]. The inability of young people to understand the context in which they live could be one of the reasons why social cohesion of several local communities is too often threatened [13]. A considerable amount of evidence leads to believe that this understanding is dramatically poor among too many young people [14].

If skills and knowledge are to be used to deal also with problems of everyday and working life, the curriculum has to cope with the realm of technology and it needs to build countless connections with economics, sociology and the study of institutions that enhance the capacity to understand the multiple facets of complexity in society. Although from the 1990s onwards technology education has been promoted as a key element in all curricula, as well as an element permeating every discipline, separate and distinct courses are the most common approach to this type of education, and a certain confusion remains about what is technology [15]. The greatest attention is on information and communication technologies, but other key contents should be included to share a basic knowledge on: (i) materials' properties and their use in industrial production; (ii) techniques of production and characteristics of the industrial products; (iii) skills and work experiences of employers and employees; (iv) environmental quality and living conditions at local and regional level.

Generalizing these as basic knowledge for all young people would support their need to acquire information when they choose their education and vocational pathways, and select their careers. It would also help them to become aware consumers and active citizens.

It is almost impossible to imagine that the contents, the abilities and the skills related to the technologies of industrial production, and technologies embedded directly and indirectly in everyday products, could be carried out only in labs separated from actual workplaces, keeping apart the machines, procedures and work tasks, from the context in which they are embedded. We suggest to adopt a "context-based technology education" [16] in order to address the interdisciplinary nature of learning and to expand contents, abilities and skills. Context-based

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 152-159

technology education needs to address the labour and entrepreneurship culture, and the knowledge of human work in different places and times. This must not be confused with traditional apprenticeship pathways. In particular, a closer relationship with the workplace does not necessarily mean to train in a specific task. Conversely, it calls into question the definition of multiple complex learning objectives, the choice of appropriate teaching methods and the creation of cooperative relationships between schools and businesses. Particularly important: all the young people have to be involved in such learning processes, and not only those who want to enter the labour market early.

3 Education using micro-robots in Officina Emilia's experience

In this section we describe Officina Emilia's practices of action-research on context-based technology education, with micro-robots labs as a subset of laboratories designed to promote the understanding of the mechanisms, the machines, the know-how and the procedures of small and medium industrial enterprises. In these labs, specific stimuli are implemented to teach and learn how enterprises work, with reference to a specific territory, and which are the job positions in companies (from workshops to laboratories, R&D and management).

The Officina Emilia initiative, supported by the University of Modena and Reggio Emilia since in 2000, builds on research into comparative analysis of education systems and into industrial districts and local development policies. Officina Emilia's action-research aims at addressing the problems of re-generation of technical skills, whose shortage is critical in areas with a strong presence of engineering and manufacturing companies, as in the industrial districts of North-East Italy. It shares hypotheses, methodologies, activities and results with academic and practitioner communities in Italy, as discussed during the national workshop held in Modena in 2013 [17] and in other European countries [18] and worldwide [19].

A coordinated package of education activities, which includes education with micro-robots, has been developed to be implemented by schools within the regional curriculum. The action-research explored (a) how to disseminate the tested education activities in the pre-university education system at regional level, and (b) the more appropriate ICT tools to support hands-on activities complemented with multimedia contents[1].

Hands-on activities with micro-robots, artefacts, objects, products, tools and machine tools used in small and medium size mechanical companies combine the knowledge of production technologies with some meeting with technicians, workers and employers, inside the labs and in the workplaces. All the educational

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[1] In relation to this issue, it is worth mentioning the use of MOVIO [20], an open source web application to implement the on line version of the multimedia contents and procedure of the labs; and the production of a specific web application, Homm-sw [21] to create, and share on the web, transmedia narratives co-created by students, teachers, and experts.

ISBN 978-88-95872-06-3
pp. 152-159

activities are realised in collaboration with schools and a significant number of small and medium size enterprises (in the mechanical and industrial services sectors), as well as the representatives of multinational companies, trade unions and business associations.

A special teaching-learning environment opened in 2009. The Museum-workshop (Museolaboratorio) evokes the industrial workplaces but it is suitable for not-experts, such as students, for initial and in-service teacher training, for the networking activities at regional, national and international level.

Since 2009 until 2012, laboratories have involved approximately 5,000 students from pre-school to upper secondary education. Nearly 170 teachers have been involved in in-service training to promote changes into their everyday work, 12 schools signed a permanent collaboration agreement on innovative education to be developed with the support of the university, and 3 schools introduced Officina Emilia labs in their official curriculum.

The following table shows the involvement of students and teachers in different types of educational activities.

Table 1. Number of students and teachers involved in the action-research of Officina Emilia, by type of activity and grade of school. September 2009 - June 2013

	Primary	*Lower secondary*	*Upper secondary*	*Total students*	*Total teachers*
Age of the students	6-10 y	11-13 y	14-19 y		
Micro-robots labs	952	1.295	530	2.777	78
Machines and industrial processes labs.	1.533	67	141	1.741	80
Industrial plants guided visits	-	-	214	214	9
Museum-workshop exhibits guided visits	-	-	36	6	2
Total students	2.485	1.362	921	4.768	
Total teachers	112	36	21		169

Source: Officina Emilia database. Modena and Reggio Emilia University. 2014.

The Officina Emilia micro-robots labs usually last four hours and belong to the two following groups.

"A robot that follows a line" is a laboratory for young people from 12 to 19 years old, where teams of 3-4 students build a robot with LEGO® bricks, following instructions without verbal directions. Then, each team writes the software program to make the robot follow a black line on a white background. Teams test their robots and compete to assess the performances and the strategies adopted in programming. During the lab, students watch videos and/or meet technicians or entrepreneurs producing or using robots. A more complex version of the same lab was tested inspired by the "Roberta" international program [22]. This lab is dedi-

ISBN 978-88-95872-06-3
pp. 152-159

cated to girls between 15 and 19 years and includes the construction of four different robots, using different sensors.

"Robot-Cocco-Drillo" is a micro-robots lab for children aged between 8 and 11 years old. Students construct an automatism, in the form of animal, able to move. They learn to use a sensor in connection with a computer. The languages of verbal description, iconography, the flowchart and the programming software WeDo® are compared. Children listen to stories about workers and robots helping them to do hard work, or robots used to do surgical operations and to explore distant and dangerous lands. The last part of the laboratory is realized by the direct observation of machine tools and industrial artifacts. The age of participants allows to draw attention to the quality and weight of the materials.

The activities of educational robotics involved extensively the students enrolled at lower secondary schools (11-13 year olds). Teachers used these labs to support the pursuit of two objectives. The first is the enhancement of technology education, which they believe was adversely affected by the Italian reforms of the education system of the 2000s. The second is to help students and their families to make informed choice, at the end of their middle school period. Teachers expressed a strong need for data and tools to effectively introduce the students to the industrial structure of the area where they live, and which influences their educational, training and professional opportunities.

The experience of Officina Emilia with the schools shows that the hands-on activities, and the opportunity to observe a workplace under appropriate guidance, widens the horizons of thinking, helps the imagination, supports self-esteem in confronting technological challenges (in particular with regard to girls approaching technologies they consider as largely outside their interests), opens to insights in several domains (as in reconnecting what students do in the labs with their parents' or relatives' jobs, which they generally do not consider of any interest and they learn to appreciate in a different perspective).

The same experience highlighted a remarkable gender issue. 63% of the students who attended the Officina Emilia workshops are boys and this higher percentage than girls is a consequence of the higher involvement of technical and vocational schools, with a lower concentration of girls. But it is also the consequence of the higher rate of girls skipping technology labs. Vice versa, the proportion of men among teachers is clearly a distinct minority (9%). The participation of girls to the micro-robots labs was slightly higher than the average, but the girls experience of technologies challenges any innovation in the education system. Even the massive prevalence of women among teachers, often with an initial education in humanities, asks to urgently and effectively address the settled preconceptions about women's education that are reflected in the behavior of the younger generation.

4 Some concluding remarks

New skills are needed to cope with the changing and unpredictable situations inside organisations and society, and to foster re-industrialisation. These new

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 152-159

skills must be grounded on the interweaving of knowledge in different fields, on technical skills, on social and economic understanding and on relevant soft skills. The demand for new skills requires new learning processes and these must feed on the contributions coming from Vygotsky [23][24], Dewey [25][26][27], Papert [28] and Hutchins [29]. Contextualized knowledge and open learning environments, with multiple opportunities and cooperative ways of working, are crucial for any successful learning processes. Education and training have to meet these challenges.

Let us summarize what seems to be relevant in supporting the necessary changes. The teachers are the internal resources of the education system to be involved in innovation programs. Often, they do not find effective programs and additional resources to implement innovative processes. In this situation, the processes of innovation, spontaneously budding within individual schools, are compromised, as well as the capacity of schools to accommodate the best practices that can be learned by peer exchanges. To quickly promote the changes needed, we need to identify which other actors can produce such changes. Regional authorities and the universities can play an important role in supporting the innovation in the education system and improving its effectiveness. Some Italian regional governments proposed guidelines for the curricula in order to support the development of new skills, other regions have delayed any decision or decided to let their schools freely choose how do this in the best way they can. Universities have the institutional task to train teaching staff and they may extend their support toward multidisciplinary research (and in some cases they already do) by helping with the design of curricula and by supporting educational planning, the creation of materials, the assessment of the education processes.

In the absence of support and guidance, a low rate of innovation can be expected even if education needs require urgent attention. To pave the way of reform initiatives, there are feasible, faster and incisive changes which can be started involving local and regional actors. The Officina Emilia action-research highlights two main ingredients to support innovation. First, having an available hybrid place (fostering innovations) worked as a stimulus for teachers to produce effective education practices, with relevant agents (from university researchers to manufacturing and services companies, education agencies, civil society) acting through the action-research. Second, the robotics labs, among others, emerge as an effective means to foster a multidisciplinary perspective, crucial for the new challenges that education faces in supporting re-industrialization.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 152-159

Experimenting and validating didactical activities in the third year of primary school enhanced by robotics technology

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Abstract. This paper describe our experience of a robotic-enhanced didactical activity with 3rd grade pupils. The activity was not aimed at introducing robotics as a new subject but at reinforcing concepts and tools learned within different subjects, (e.g., mathematics, geometry, technology, etc.) though the activity was contextualized in the geography curriculum. The methodology, the detailed content of the activities, and the evaluation of the performances of the pupils are presented.

Keywords: Educational robotics, Primary education, Lego Mindstorms, Constructionism, Learning by discovery.

1 Rationale: developmental age, from 6 to 11

Primary school pupils experience a period of 5 years (from 6 to 11) in which bursts of growth occur and they reach significant milestones of maturity from multiple points of view: physical, relational, emotional, cognitive [1]. The story of life looses its imaginative connotation and gradually, around 8 years old, it moves to a more realistic view. At the same time the ability to read evolves together with a more aware and appropriate use of different languages in their specific disciplines, gradually gaining a greater capacity for abstraction. Meanwhile they develop and refine fine mobility skills. Even self-centeredness gives way, in these years, to the recognition of the other, his needs, his abilities and his point of view [2]. To achieve all this it is inevitable to pass through comparisons, exchanges and, more often, conflicts. They learn to be in a group, they adopt behaviors and relationships adequate to live in the school-community; they learn to work together, in pairs and/or in small groups, to collaborate for achieving a common goal or for solving rather complex tasks [3]. These are called 'social skills' and they are not innate. When teachers consider important not to ignore these aspects in the development of pupils and they aim at improving these cross-skills during the teaching of their disciplines and behind, they should ask the students to work on these and reinforced them in many ways and in many occasions. In this paper we propose a robotic enhanced activity aiming at

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 161-163

support the development of all these cross-skills. We designed an activity, exploiting the LEGO Mindstorm NXT robot, which aims at reinforcing these cross skills and the cooperative learning skills in the framework of constructionism [4].

2 The experience

Organization: Recipients were pupils about 8 years old, attending two 3rd grade classes of 21 students each. We used Lego Mindstorm NXT (7 for the construction phase, only 5 during the programming phase for a better management of the groups), with the support of a IWB (Interactive White Board) equipped classroom and a computer lab with 11 workstations.

Methodology: The didactical activity was designed following the guidelines of the Terecop project [5]. It had its focus on geography, but was developed in an interdisciplinary way and it also proved as a valuable opportunity to develop social skills. 1h and half was dedicate to the construction phase of the robot (about 70% of the groups completely finish the work within this time) and 5 meetings of 1h and half, divided into two rounds, for programming the robot at the computer and testing it in the lab. The basic elements of the project were: *Interdisciplinarity,* the focus was on geography and road safety education, but technology, computer science, mathematics and physics was involved as well; *Problem-solving,* i.e. fostering in pupils an attitude of problem-solving valorizing the try-and-error approach, and promoting an active knowledge process; *Co-responsibility and reciprocity,* team work makes pupils relate dialectically to the classmates, agreeing on solutions or strategies to accomplish the tasks.

Structure: the frequent practical experience with the robot, were accompanied by body syntonic actions, to achieve a conceptualization/abstraction of the topic. Means used for achieving the knowledge goals were: free drawings, generation of keywords, flow charts, mental maps. For every topic three steps were implemented: presentation of the topic by the teacher with the support of the expert; reinforcement of the argument describing similar situations; a reflection and a cognitive reprocessing involving the entire class, guided by the teacher, to clarify, fix and explain better the activity, share difficulties and successes. **Implemented robotics activities**: pupils learnt how to build and program a robot, by constructing the NXT LEGO in the basic Tribot configuration. First, they programmed the motion of the robot using LEGO NXT-G programming environment and pre-programmed blocks (4 blocks: move forward, stop, turn left, turn right (of fixed preset quantities). They created sequences of commands in order to make the

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 161-163

robot moving along a path on a grid respecting the traffic signs which where placed by the teacher on the grid. Later, the use of sensors was introduced. Using a sonar sensor, the robot could stop in front of obstacles. Using a light sensor, the robot could distinguish between red and green cardboard, simulating a traffic light. The use of sensors enabled to introduce the basic blocks of LEGO NXT-G and their usage: first the sensors' blocks and then also the WHILE and IF blocks. In the end, the pre-programmed blocks where abandoned and the pupils realized a fully reactive behavior of line following by programming the robot using the NXT-G blocks for controlling the motors and the sensors.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 161-163

New Era for Educational Robotics: Replacing Teachers with a Robotic System to Teach Alphabet Writing

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Abstract. Usage of robotic systems has been always centre of interest of educational organizations. Due to the structure and behaviour of robot, new learners feel comfortable to interact with robot while they are learning. In this paper, a new educational robotic system is proposed which is used in order to teach new learners how to write the alphabets correctly. The system is using advance computer vision algorithms such as singular value decomposition based illumination enhancement, multi-diagonal matrix filter based edge detection, and part-based tree-structured character recognition to detect the written characters.

Keywords: Educational robotic system, image processing, character recognition

1 Introduction

Routes of educational robotics are from 1960's when Seymour Papert together with Marvin Minsky developed a floor robot called Turtle [1]. Turtle was programmed with programming language LOGO. Turtle was able to drive on the floor and draw it's trajectory with pencil. Nowadays there are many robotic hardware solutions available for educational institutions [2].

There are not many studies that give good cause to use one or another approach with pupils. All of educational technology is based on Papert's theory of constructionism [3]. As educational robotics (ER) has been used mostly in extracurricular activities, students attend based on their beliefs and assumptions about robotics. Effect of ER in learning only affects those attending. ER is not considering robotics as an object but rather a tool to learn with. Learning with robots enhances learner's cognition. Authors believe learning effect is the same when robot is in role of a teacher or learning aid instead of being built by the pupils [4].

Robots are so far used mostly in education for construction and implementation of constructionism. There are few studies on improving handwriting with the help of robots. Character recognition is one of the most essential steps in many image processing applications [5]. There exist many techniques in recognition of the characters based on their orientations and shapes [6]. Palsbo and Hood-Szivek made a study in 2012 where they tried to evaluate the safety and efficacy of a small gaming console, the Falcon, in delivering training to children with poor hand writing [7].

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 164-166

2 Proposed Educational Robotic System

In this work the proposed ER system is aiming to help new alphabet learners, mainly young children, to write the characters correctly. This task is being done by firstly enhancing the illumination of the captured sequences using singular value equalization [8] and then detecting the edges of the characters by using multi-diagonal matrix filter [9] followed by detection of characters by using part-based tree-structured algorithm [10]. Fig. 1 is representing the general block diagram of the proposed method.

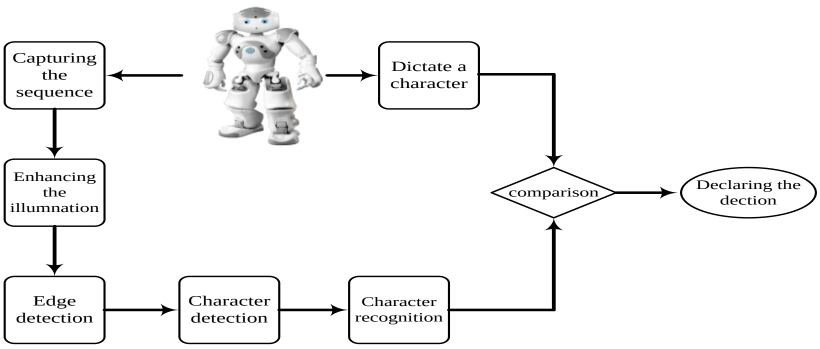

Fig. 1: The block diagram of the proposed educational robotic system

In order to enhance the illumination of each frame of the sequence, singular value equalization based illumination enhancement is being implemented [8]. The enhanced frame will be converted into binary form and the edges of the characters will be extracted by using multi-diagonal matrix filter [8]. The extracted edges are used as an input of part-based tree-structured character detection [9]. Each character is represented by a tree consisting of nodes and topological relations of nodes. In the detection stage histogram of oriented gradients (HOG) is being used as a descriptor of the characters [11]. The recognized character will be checked by the dictated character that the robot has dictated earlier. If both of them are same, the robot will congratulate the learner, otherwise the robot will encourage the learner to try again. In case of not being able to recognize the character the robot will ask the learner to re-write the alphabet.

Robot is being used as teacher aid similarly to You et al. [12] in contact free concept. That means robot is not in contact with pupils physically, but can help learning in distance. Study carried out by You involved physical humanoid robot placed in classroom as an assistant of teacher to teach English. In handwriting recognition system, robot is performing autonomously. In case of close communication with the robot, children are led to a point where they want to write clear enough to make the robot to understand their handwriting or write fast to meet requirements set by the robot.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 164-166

3 Conclusion

In this research work we have proposed a new educational robotic system is proposed which is used in order to teach new learners how to write the alphabets correctly. The system was benefiting from advanced computer vision algorithms in order to detect the written characters. Due to the structure and behaviour of the proposed educational robotic system the learners can boost their learning skills.

Acknowledgments. This work is partially supported by ERDF program "Estonian higher education information and communications technology and research and development activities state program 2011-2015 (ICT program)".

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Mendieta: low cost platform for educational robotics

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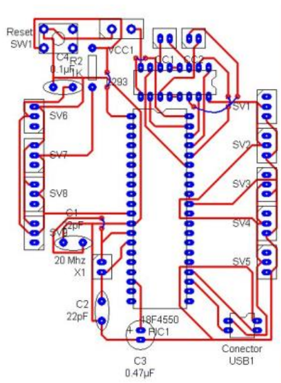
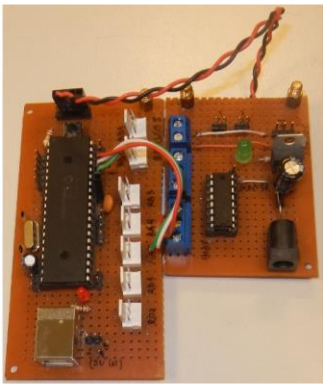
Abstract. In Argentina, the Conectar Igualdad program has distributed 3 million netbooks to students in high schools. This massive integration of technology has enabled the emergence of different projects for the effective use of computers in the classroom. In this paper we present the development of a low cost hub called Mendieta for connecting the netbook to sensors and motors for data acquisition in physics and chemistry experiences and for teaching robotics in the classrooms. We also show the development of the software platform that allows reading sensors and programming the device.

Keywords: Mendieta; educational robotics; Physical Etoys.





Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 167-169

1 Introduction

Thanks to "Conectar Igualdad" program [1], we meet in all high school classrooms with a device that can serve as a processor of data acquisition systems or a robotic device driver. Then, we created a research project with this goal: develop a low-cost hardware platform for elementary and high schools classes for learning robotics. In order to reach this goal, we have established the following specific objectives:

a) Develop a hub for connecting sensors to the USB port of the netbooks used in education.

b) Develop a motor controller with USB port connection.

c) Design the mechanical architecture of a robotic kit.

d) Incorporate the Mendieta Etoy to Physical Etoys for communicating with the hub and the developed motor controller.

e) Develop an image processing system with low processing requirements that can function on the hardware of the netbooks of the Conectar Igualdad program.

2 What have we done

We have developed a hub that allows the connection of motors and sensors to a netbook, effectively transforming it into a device capable of interacting with its surroundings. This hub, which we call "Mendieta", is composed by a single-board microcontroller that plugs in the computer through the USB port and allows the connection of multiple devices such as LEDs, switches, servo motors, photoresistors, among others. It talks to the computer using a communication protocol that allows the user to fully control the board.

The netbooks delivered by the "Conectar Igualdad" program have the following main characteristics: Processor: Intel® Atom™ N455 (512K Cache, 1,66 GHz, 64 bit bus); 2 GB DDR3; 2Mp integrated webcam; integrated microphone; Internal WiFi card; 2 USB ports.

In order to take advantage of the camera that most netbook include we developed the software needed to retrieve information from the images that the camera can provide.

3 Hardware

Since cost and availability in Argentina are our most important requirements we have compared prices of the main components in Buenos Aires stores and we concluded it would be cheaper to base our project on a PIC 18F4550 microcontroller instead of an AVR like Arduino. Mendieta will allow controlling several servomotors and up to 2 DC Motors and one AC Motor thanks to an integrated H-Bridge.

Furthermore, up to 8 analog inputs and 18 input/output pins can be used. It permits to connect directly analog and digital sensors with 3-pin Molex connectors. In order

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 167-169

to control motors, Mendieta has a L293D integrated circuit with four circuits that can handle medium power loads, specially for little motors with do not surpass 600 mA in each circuit and a voltage between 4,5 V and 36 V. The entry of this direct current to the board is performed by a terminal located at the opposite end to the USB connector. It can come from a transformer connected to the electricity network or from an optional amplification circuit that has four rechargeable AA batteries.

4 Software

The firmware developed for Mendieta allows the full control of the board by implementing a simple communication protocol based on Firmata. All messages are composed by a byte that denotes the message id followed by zero or more bytes that represent arguments, or data that will be used to evaluate this message. To distinguish each type of byte we use its first bit, being 0 for message ids and 1 for arguments. This protocol requires all data to be packed in 7 bits, then it allows a maximum of 127 types of messages. In practice, this has never been a problem because most messages expect a very small amount of arguments, and we never needed more than 20 different messages.

On the computer side, we developed a Physical Etoys [2] external module that implements this communication protocol and allows to fully control Mendieta. We also made a programmable graphical object that allows us to program Mendieta both in a visual environment specially designed for kids or, in the case of advanced users, in text mode using the Smalltalk programming language.

Physical Etoys was also extended with a new capability of image analysis. We called this tool “BlobFollower”. Usually, the algorithms used to do image analysis are very complex both to use and to configure and the student should not have to deal with that problem. To achieve this we decided that the only information to be provided is what color should be tracked, hiding all the complexity of the algorithms and settings from the user. By only giving color detection we are forcing the student to build the logic needed to interpret what does it means.

5 Future work

Mendieta is still a work in progress. The first functional prototype we have built still lacks the possibility of getting the information from the connected sensors. This needs to be incorporated both in the firmware and in the Physical Etoys interface.

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Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 167-169

Fundamentals of Robotics with MyModelRobot

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Abstract. MyModelRobot is an online application for designing and viewing robots described by ROS (robot operating system) supported URDF files [1]. The tool focuses on the simplicity of use, while teaching students the essential ability of describing robots as kinematic trees. Currently, this tool is being used in our normal curriculum, for teaching course in Fundamentals of Robotics. In this paper we report improvements made in the second version of the application and our experiences with two groups of twenty students using this tool. As a modern online application it gives students the ability to do their work in any modern browser, as well as to share their work and easily consult their work with teachers and peers.

Keywords: online simulation, URDF, ROS

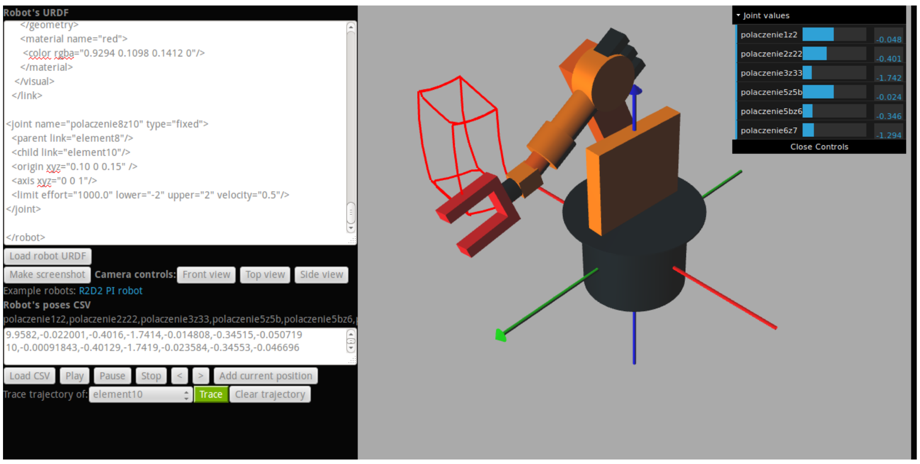

Fig. 1. Screen from MyModelRobot application, showing industrial robot with trajecory of its end-effector, modeled by Lukasz Starzec, Sylwester Kitala and Sebastian Kaluzny

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 170-172

1 Introduction

The Fundamentals of Robotics Laboratory is an important element of the Automatic control and robotics curriculum. By modeling and studying industrial robots, students consolidate their theoretical knowledge and understand what practical robotics means, while still operating in safe simulation environment.

Laboratory is based on the Robotics Toolbox by Peter Corke which is a mature tool for classic robotic topics [2]. It is however quite limited in visualisation of robots, giving only symbolic representation. For that we have used different visualisation tool - RoboWorks, developed in year 2000 and costing 750 USD, by that strongly limiting its use on new computers and at home (because of the licence fee). We are also using some more advanced simulators like Webots, Gazebo, Sim Mechanics and EasyRob but they are much more complex and are practical when complete simulation of robotic scene, sensors and controllers is necessary. Most of them are also licensed, and so available on the limited number of machines, which further complicates usage. This motivated us to design a modern, open and online replacement that would fit our needs.

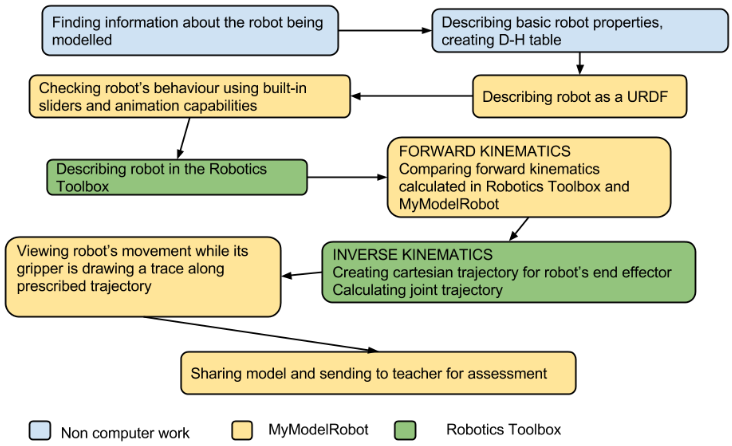

Fig. 2. Diagram showing fundamentals of robotics laboratory course, with tools utilised

2 MyModelRobot

MyModelRobot app was designed as a simple visualisation tool for URDF files used in ROS, now it evolved to an online modeling, visualisation and animation tool (see screenshot in Fig.2), that allows:

1. **modeling and visualisation of URDF files**. Our program allows for visualisation of URDF files, that describe kinematic and dynamic properties

of robots, without the need to install Linux's ROS, Rviz or Gazebo. ROS is increasingly used in other, more advanced labs in offered curricula and familiarity with its modeling format makes ROS introduction easier.
2. **interactive robot control**. While modeling robots, there is a need for a simple visual feedback, to make sure that the robot behaves correctly. Our application automatically generates controllers for all rotational and prismatic joints described in URDF.
3. **animation and trajectory visualisation**. MyModelRobot enables easy animation of robots, using poses described in csv files. Files can be generated by recording sequences of poses in the application itself or by using an m-file converting joint trajectory generated in the Robotic Toolbox to a file read by MyModelRobot. The trajectory of of any part (link) of the robot's model can also be visualised which is important in checking results of inverse kinematics generated in Matlab.
4. **full online access and sharing capabilities**. MyModelRobot is a free to use and publicly available (`http://www.MyModelRobot.appspot.com`. There is no plugin needed and it works on all modern browsers. This allows students and other users to work from home as well as to share (3D models and trajectories, in editable and locked modes) with teachers but also friends, collaborators and family, providing motivation for work.

3 Results

MyModelRobot was used to model industrial robots basing on their datasheets. Using Robotic Toolbox, students then calculated forward and inverse kinematics and generated trajectories that could be viewed in MyModelRobot and shared with other students and teachers. Students responded in survey that the new tool was easy to use and understandable. They have also completed approximately the same amount of tasks as with the previous tool.

Acknowledgment Research was partially supported by the National Centre for Research and Development under grant No. PBS1/A3/8/2012.

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Adding Code and Robotics to Curriculum: An Introduction to the Programming and Robotics for Kids with Special Educational Needs (KSEN)

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Abstract. This experience is based on practical exercises in the areas of technology and math related to the "Robotics and Computer Science" secondary science curriculum. Students do not need any programming skills to enter the world of programing and robotics. The program offers an attractive way to motivate students for entrepreneurship ideas. Secondary school students designated as Special Education, such as those with a learning delay, aspergers or attention hyperactivity disorder (AHD), play a central role in our study.

Keywords: Technology, Code, Curriculum, Special Educational Needs, Java, Asperger, Robotics, Secondary School

Fig. 1: Visual programming tools: Left, codeHS; Right, Robotics.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics & 5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 173-175

1 Introduction

The project includes an introduction to students to the world of programming with visual programming tools (VPT) at their disposal. (See Fig. 1 and 2). On the other hand, we also aim to introduce them to the design of mobile phone applications and to use some dynamic mathematics [3] for programming micro robots [4]. More activities are carried out in English.

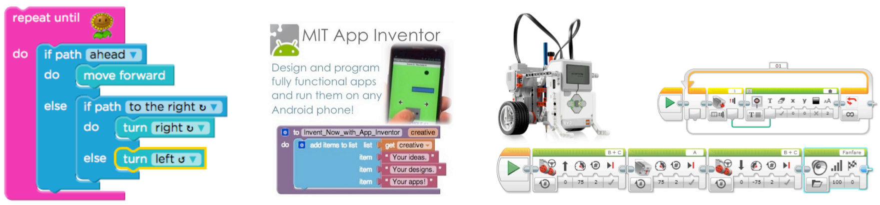

Fig. 2: Visual programming tools: code.org; MIT App Inventor; Lego EV3.

The activity has been developed with a group of 12 students with varying degrees of AHD, it also includes a low level asperger student. These students are part of a group who study technology.

2 Project objectives

The main goals includes to use, in a suitable level, the computational thinking (CT) into the curriculum. Building on this knowledge and understanding, pupils will be equipped to understand how instructions are stored and executed within a computer system, how data of various types can be represented and manipulated digitally, and how to create and debug simple programs using logical reasoning and CT [6].

3 Methodology

The methodology consists in to introduce students with special educational needs and time along with other classmates a programming language Java [6] in that case as well as using Geogebra [3] as a mathematical tool. Furthermore, an elemental programming level in robotics is complemented with the rest of the platforms [6], in order to both build and program educational robots, like EV3 [5] or Moway [4].

By means of sequenced didactic units, the student begins in the field of robotics and mathematical functions by simulating elementary robotic systems, based on real applications such as: logistics control, rescue, exploration, smart car and so on. For example, simulation of elementary linear (1) and nonlinear functions (2) as :

$$f_{(x)} = mx+b \; ; \quad f_{(y)} = | y-3 | \; ; \quad (1) \qquad f_{(x)} = \sin(2x+1) \quad (2)$$

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 173-175

Activities has been finished in a brainstorming session to identify potential real world applications and the development of entrepreneurship.

4 Conclusions

As a result, we conclude that there is a high impact on these students while they use these technologies. It was detected that they get an exponential learning curve. There were a total involvement of students with these VPT. Furthermore, the concentration and academic performance is improved. Also, they had an acceptable immersion in the classroom and they improve better his self-learning, order and self-esteem.

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