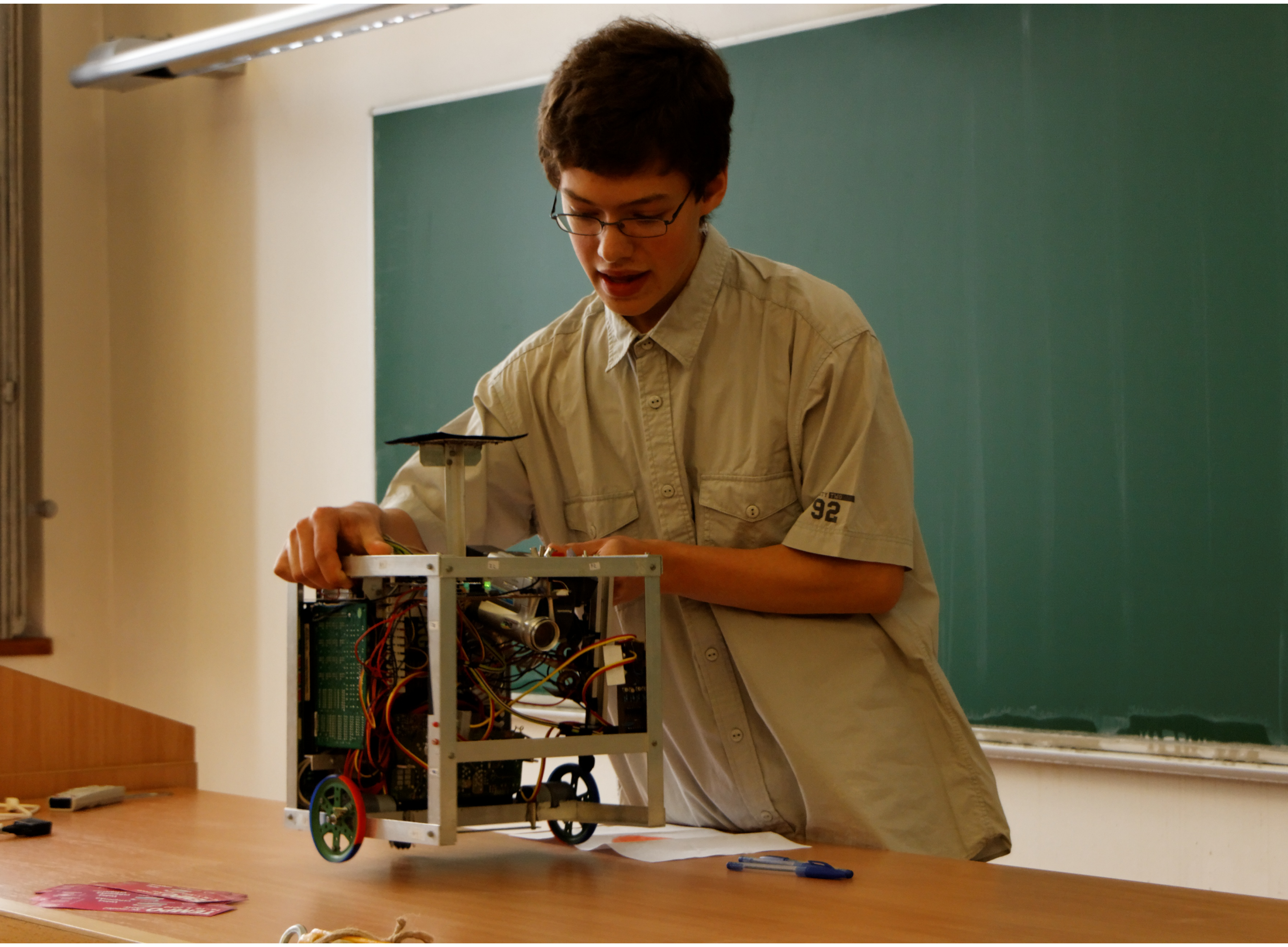


RiE 2012

3rd International Conference on

Robotics in Education

September 13 – 15, 2012
Prague, Czech Republic

Editor: David Obdržálek

RiE 2012

3rd International Conference on

Robotics in Education

September 13 – 15, 2012
Prague, Czech Republic

Conference Proceedings

Editor: David Obdržálek

www.rie2012.eu

matfyzpress
VYDAVATELSTVÍ MATEMATICKO-FYZIKÁLNÍ FAKULTY
UNIVERZITY KARLOVY V PRAZE

Published by MATFYZPRESS
Publishing House of the Faculty of Mathematics and Physics Charles University in Prague
Sokolovská 83, 186 75 Praha 8, Czech Republic
as the 413. publication

Printed by Reprostředisko UK MFF Sokolovská 83, 186 75 Praha 8, Czech Republic

First published

Prague 2012

ISBN 978-80-7378-219-1

This volume contains the papers selected for presentation at the 3rd Robotics in Education Conference, RiE 2012, held at Charles University in Prague (Faculty of Mathematics and Physics), Czech Republic, September 13-15, 2012.

We would like to thank all the authors who submitted their papers as well as all the people involved in the conference organization. For the conference review process, the EasyChair system was used; we want to thank the authors too.

September 2012

David Obdržálek
Conference Chair

Organization

RiE 2012 Conference was organized by:

Charles University in Prague, Faculty of Mathematics and Physics (Prague, Czech Republic)

in cooperation with:

FEI STU – Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology (Bratislava, Slovakia)

INNOC – Austrian Society for Innovative Computer Sciences (Wien, Austria)

Robonika Association (Prague, Czech Republic)

technically sponsored by:

IEEE Czechoslovakia Section

General Chair

David Obdržálek	Charles University in Prague, Czech Republic

Program Committee

Dimitris Alimisis	School of Pedagogical and Technological Education, Athens, Greece
Richard Balogh	Slovak University of Technology in Bratislava, Slovakia
Jenny Carter	De Montfort University in Leicester, Great Britain
Jean-Daniel Dessimoz	Western Switzerland University of Applied Sciences, Yverdon-les-Bains, Switzerland
Hugo Ferreira	Instituto Superior de Engenharia do Porto, Portugal
Grzegorz Granosik	Technical University of Lodz, Poland
Alexander Hofmann	University of Applied Sciences Technikum Wien, Austria
Peter Hubinský	Slovak University of Technology in Bratislava, Slovakia
Boualem Kazed	University of Blida, Algeria
Tomáš Krajník	Czech Technical University, Czech Republic
Miroslav Kulich	Czech Technical University, Czech Republic
Dariusz Marchewka	AGH University of Science and Technology in Kraków, Poland
Martin Mellado	Universitat Politècnica de València, Spain
Michele Moro	University of Padova, Italy
David Obdržálek	Charles University in Prague, Czech Republic
Pavel Petrovič	Comenius University in Bratislava, Slovakia
Colin Sauzé	University of Wales in Aberystwyth, Great Britain
Alexander Schlaefer	Universität Lübeck, Germany
Dietmar Schreiner	Vienna University of Technology, Austria
František Šolc	Brno University of Technology, Czech Republic
Gerald Steinbauer	Graz University of Technology, Austria
Roland Stelzer	INNOC - Austrian Society for Innovative Computer Sciences, Austria
Francis Wyffels	Ghent University, Belgium

Table of Contents

Robotics in Education & Education in Robotics: Shifting Focus from Technology to Pedagogy

Dimitris Alimisis
School of Pedagogical and Technological Education, Greece
alimisis@otenet.gr

***Abstract*—In this work we highlight the role of constructivist pedagogy and consequent educational methodologies either while using robotics in school education (*Robotics in Education*) or while training teachers to use robotics for teaching purposes (*Education in Robotics*). In this framework, constructivist methodologies for integrating robotics in school physics and informatics education and in professional teacher training are suggested. Exemplary projects from each case are reported to demonstrate the learning potential of the proposed educational methodologies involving teachers and students while using robotics to study kinematics and programming concepts in physics and informatics classes of secondary education respectively.**

***Index Terms*—Educational robotics, teacher training, informatics education, physics education**

I. Introduction: "There's Nothing so Practical as Good Theory"

Over the last few years, robotics in education has emerged as an interdisciplinary, project-based learning activity drawing mostly on Maths, Science and Technology and offering major new benefits to education at all levels [1], [2]. The use of robotics in education is aimed to enable students to control the behavior of a tangible model by means of a virtual environment. Very often these efforts are limited in just introducing robotics technology (following the axiom "the more advanced the better") in education and underestimate the role of pedagogy that should support any such attempt.

However, the successful introduction of an educational innovation, like robotics, is not just a matter of access to new technologies. As important as the technological advancements are in the development of robotics, the real fundamental issue from educational perspective is not the technology itself; it is the educational theory and the curriculum guiding the use of robotics in any educational context. The robot is just another tool, and it is the educational theory that will determine the learning impact coming from robotic applications.

Alignment with theories of learning, proper educational philosophy, well designed curricula and supportive learning environments are some of the important elements leading any educational innovation, including robotics, to success. Thus, the emphasis in this work is on shifting from technology towards partnership with education putting the emphasis on pedagogy than on technology and especially on pedagogical principles and methods coming from sound learning theories, such as constructivism and constructionism.

During 2006-09 the European educational project *TERECoP* (*Teacher Education in Robotics-enhanced Constructivist Pedagogical Methods*, www.terecop.eu) worked to this direction and developed a methodology for training teachers and for introducing robotics in school both as learning object and more importantly as learning tool [3], [4]. The TERECoP method was inspired from the educational philosophy of constructivism [5] and was mostly based on project-based learning. In the "after TERECoP era" we have continued working to implement the ideas of the project in collaboration with teachers and schools in formal and informal educational settings. Our efforts are focused on teacher training and on supporting teachers to implement robotic activities in school classrooms [4].

Following this framework, this paper presents in the next sections a methodology for introducing robotics both in teacher training and in school classes and two exemplary projects realized in two different contexts: in training courses for future teachers of technology and in further training for experienced in-service science teachers. The transformation of each training action into consequent learning activities in school classrooms is also exemplified. Finally, conclusions from these case studies and future plans are presented.

II. Introducing Robotics in Teacher Training and in School Classes

A. Methodology

Our methodology views robotic technologies not as mere tools, but rather as potential vehicles of new ways of thinking about teaching, learning and education at large. We appreciate much the importance of learners' pre-existing knowledge, conceptions and culture, as well as of their interests and varied learning styles. Our approach encourages learners to participate actively in the learning process.

Through robotics learners build something on their own, preferably a tangible object, that they can both touch and find meaningful. In robotics, learners are invited to work on experiments or problem-solving with selective use of available resources, according to their own interests, search and learning strategies. They seek solutions to real world problems, based on a technological framework meant to engage students' curiosity and initiate motivation [3].

The robotics industry so far mainly aims at humans using pre-programmed pre-fabricated robots. The ways in which the robots are made and programmed is a black box for their users [6]. It is a paradigm compatible with the traditional educational paradigm of the teacher or of the curriculum book revealing and explaining ready-made ratified and thus unquestioned information. Very differently from this approach, our methodology suggests the transition from "traditional" black-box technologies to the design of transparent (white-box) digital artifacts where users can construct and deconstruct objects and have a deep structural access to the artifacts themselves. The white-box metaphor for construction and programming might generate a lot of creative thinking and involvement in learners [7].

When students can have control of specific robots in a rich learning environment embedding the construction of robots and programs to control them, the emphasis might move on interesting learning activities in the frame of specific learning areas such as science and technology. The design of robotic construction activities is associated with the fulfillment of a project aimed at solving a problem. In such a learning environment, learning is driven by the problem to be solved. To engage students in activities requiring designing and manufacturing of real objects, i.e. robotic structures that make sense for themselves and those around them [5], we should devise activities that will encourage students to construct robots but also to encourage them (providing the necessary support) to experiment and explore ideas that govern their constructions.

The robotic activities may take the form of a research project posing problems that are authentic, multidimensional and can have more than one solution. It is particularly important that the problems are open and allow students to work with their own unique style and the way they prefer. The proposed work should actively involve students in learning opportunities by giving them control and ownership of their learning, encouraging creative problem solving and combining interdisciplinary concepts from different knowledge areas (science, mathematics, technology, etc.). The learning activities are as open as possible so that learners have opportunities to participate in the final configuration of them and ultimately provide opportunities for reflection and collaboration within the team.

B. The role of the students

When preparing a work with programmable robotic constructions, students first discuss the research problem through a free dialogue in their group and after that in the plenary session of the class and devise an action plan to solve it. Then, they work in groups to implement their plan taking into account the feedback they receive from the educator. Students experiment with simple programmable mechanical devices (e.g. a car-robot, motors, gears, pulleys, shafts, sensors, etc.) and associated software. Students may redefine the research plan after the experience gained during this preliminary work. They are invited to synthesize their findings and reach conclusions and solutions to the problem under investigation. The final products and solutions of the groups are presented in the class, are discussed and evaluated. Finally students are invited to reflect with critical mind on their work, to express their views and to record their experiences in the form of a diary.

C. The role of the teacher

The teacher in such a constructivist theoretical framework like that described above does not function as an intellectual "authority" that transfers ready knowledge to students but rather acts as an organizer, coordinator and facilitator of learning for students. S/he organizes the learning environment, raises the questions / problems to be solved, offers hardware and software necessary for students' work, discreetly helps where and when necessary, encourages students to work with creativity, imagination and independence and finally organizes the evaluation of the activity in collaboration with students.

III. First Case Study: Robotics in Informatics Education

A. Integrating robotics in training courses for future teachers of technical secondary education

In the framework of the one-year training programs held for future teachers of secondary technical education at the School of Pedagogical and Technological Education (Patras, Greece), starting from the academic year 2010-11 a robotics module has been integrated in the course of educational technology.

The robotics module starts with a short "theoretical" part that includes discussions about the theoretical background and the educational potential of robotics, suggestions on the potential use of robotics in school classes and presentation of the LegoMindstorms NXT package, of the programming environment Lego Mindstorms NXT Education software (http://www.legoeducation.us), and of the Lego Digital Designer (software simulating robotic construction and used to facilitate students during their first constructions, http://ldd.lego.com).

A laboratory part follows when students participate in a series of practical activities taking place in the Educational Technology Laboratory (Patras, Greece, www.etlab.eu). An illustrative scenario implemented in these activities follows:

a. Students are divided into groups of 3-4. Each group is allocated a Lego Mindstorms NXT kit and is invited to plan and discuss the construction of a vehicle. They are asked to design first with paper and pencil their artifact; they can also use Lego Digital Designer to design a virtual model of their robot if they wish; finally they build the mechanical vehicle using the Lego Mindstorms kit. Each team designates a representative to present their work to the plenary of the class.

An excerpt from the worksheet given to the students is quoted below:

Worksheet 1: Use your Lego Mindstorms kit to build a car.
The car should have ...
- *A frame (chassis) like this in picture (Fig. 1)*
- *4 wheels*
- *An engine that will actuate the two front wheels*
- *The "smart brick" Lego Mindstorms should give*

instructions to the motor to rotate
Talk to your team and draw roughly the car here as you imagine to build it. You can use the model available from Lego Digital Designer for your construction if you wish…
Make now the car and be prepared to present it in the class…

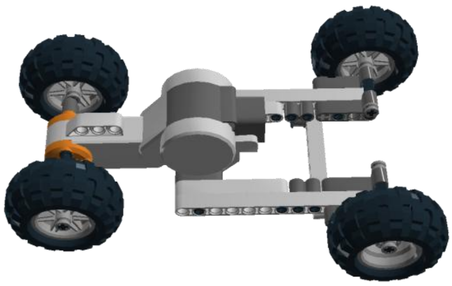


Fig. 1. Focus on simplicity: a purposely simple car proposed to student-teachers

b. Introduction to programming using the Lego Mindstorms Education NXT software.

The students practice with the basics of Lego Education NXT software starting with the Block "*move*"; they continue with the controller to load programs from the computer to the robot, the touch, light, sound and distance sensors, they learn to control the block "*wait*" and more. Students are free to experimenting with the software and the robotic vehicle they have already constructed. The trainer helps discretely the students when necessary without restricting their inventiveness and self motivation. Each group appoints a representative to show in front of the class the results of their work. The trainer comments and makes suggestions where appropriate.

c. The lab activities continue with specific problems involving control of motors and sensors, such as:

Take your car to move forward with the throttle (Power) at 70% for 1 second and brake, repeat for 2 seconds, then for 3 seconds and so on. What do you conclude from this experiment? How can you make the robot-car, as it moves, detect the obstacles that touch, stop and turn back? (excerpt from worksheet 2).

d. Design and implementation of a team project by the students.

The trainer invites students to design and realize their own scenario; they work in groups to realize their ideas by programming the robot-car; they are called to describe in their own words the solutions provided; each team designates a representative to present their work to the class; the trainer comments and makes recommendations where necessary.

Upon completion of this training, students are encouraged to transfer the robotics activities in classroom on topics of their choice. For this purpose we use the context of teaching internship and our partnership with local schools which accept our students to work as temporary teachers. A case study from such a classroom project is reported in the next section.

B. Teaching programming concepts in school informatics through robotics

This project was realized by two of our student-teachers specialized in informatics who had attended the robotics training course mentioned above (academic year 2010-11). Robotic vehicles built with Lego Mindstorms kits were introduced for 2 teaching sessions (2 hours for each session) in a lower secondary school class of informatics with 21 pupils aged 13 (April 2011, Patras, Greece) to support the learning of making decisions and loop control programming concepts. Robots (simple cars with four wheels, one motor and one ultrasonic sensor) should be appropriately programmed by the pupils to perform simple motions and actions which would involve the use of making decisions and loop behaviors in computer programs.

The student-teachers explained in the class using concrete examples just the basic building blocks of a program (move, wait, conditional wait, loop, switch etc.) along with the steps necessary to build a program and download it to the robot. After that, pupils were called to imagine a behavior for their robot involving decision making and/or repetition and then to describe it using paper and pencil before programming it to their robots in the second part of the activity. At the end, the groups were asked to present the behaviors they had thought of and to demonstrate them with their robots in front of the whole class. Most groups managed to program the intended behaviors after some trial and error attempts. The student-teachers acted rather as experienced advisors, encouraging the pupils towards the solutions but not doing the work for them. Finally, they evaluated their whole teaching intervention based on the analysis of pupils' work as it had been saved on the computers of the laboratory and on the analysis of pupils' diaries [8].

After the end of the project, the student-teachers' experiences were recorded through a written report and a non-structured oral interview. As the student-teachers reported [9], the feedback collected from the classroom had verified their initial assumption that a robotics activity would be appealing to the students and could help in bringing abstract programming concepts closer to the pupils' understanding. They appreciated the opportunity they had to explore the difficulties encountered by the pupils working out the new programming concepts, to understand how students preferred to work and finally to gain insights on how future educational activities should be planned and designed. The robotic activity had enabled student-teachers to see the results of their actions in the school class reality and to get immediate feedback from pupils, which as they reported had increased their self confidence in using robotics in school [9].

Evaluating this teaching intervention, we can first identify the obvious similarities between the methodology proposed in the training course and that applied by the student-teachers in the school class. We can claim that student-teachers successfully implemented the robotics-based methodology they had been taught, on a topic of their own choice and specialization in a real classroom setting. Second, this connection between training course and school class proved useful for them because they were provided valuable feedback from pupils' work which convinced them that the use of robotics according to the proposed methodology is realistic and feasible and finally strengthened their self confidence for future use of robotics in school.

IV. Second Case Study: Robotics in Science Education

A. Integrating robotics in further training for in-service science teachers

In the framework of further training courses for in-service physics teachers held at the University of Athens (September-December 2011), we introduced robotics in the curriculum of the course for 10 teaching hours for a group of 6 trainees; all of them had long in-service experience, high educational qualifications and after their training they would act as trainers of their colleagues in their schools. The main aim of the robotics curriculum was to explore together with the trainees ways to use robotics as learning tool focusing on the phenomenon of motion and the basic kinematics concepts: time, distance, speed, motion at constant speed, motion at accelerated speed.

After the necessary familiarization with the Lego Mindstorms NXT kit (5 from 6 trainees were novice in robotics), where we followed the same methodology described earlier in this paper, we focused on laboratory activities intended to teach the phenomenon of motion and the relevant kinematics concepts.

Trainees worked in two groups of three exploring the following questions/problems and designing suitable laboratory activities focused on a robotic car. An ultrasonic sensor had been attached to the car to provide data for the position of the car (actually the distance from a wall).

1st question/problem: What is the relationship between the time of the motion which you type in the Lego Mindstorms interface and the real time motion of the robot?

The trainees chose different times through the software interface to move the robot and checked the relationship of those data with real time motion data of the robot measured with a timer. They filled in a table of values and a subsequent graphical representation. They found that software times were equal to those recorded by the timer.

2nd question/problem: What is the relationship between the number of rotations of the robotic motor you type in the Lego Mindstorms interface and the distance traveled by the robot?

The trainees measured the radius R of the wheels of the robot and calculated the theoretical distance expected to be traveled by the wheel in one full rotation ($2\pi R$). Then they checked experimentally whether the theoretical values (number of rotations x $2\pi R$) coincided with the actual distance traveled in each case by the robot. They made again a table of rotations and distance values and a subsequent graphical representation graphing the linear relation between the number of rotations typed in the software interface and the real distance traveled by the robot. Real distance was found almost identical to the theoretically expected and analogous to the number of rotations.

3rd question/problem: What is the relationship between the power of the motor you type in the Lego Mindstorms interface and the speed of the robot?

The trainees chose different values of motor power and measured the actual distance traveled by the robot at a certain length of time for each value of power. They filled in again a table of values and a graphical representation showing a linear relation between the two variables.

After these basic explorations they were invited to design an experimental activity of their own choice that would be useful for their students to study the rectilinear motion at constant speed. At this point the data logging function provided by the software Lego Mindstorms was introduced.

After several trials with the robot moving on the floor, the trainees devised the programming solution given in fig. 2 resulting in the linear graph (fig. 3).

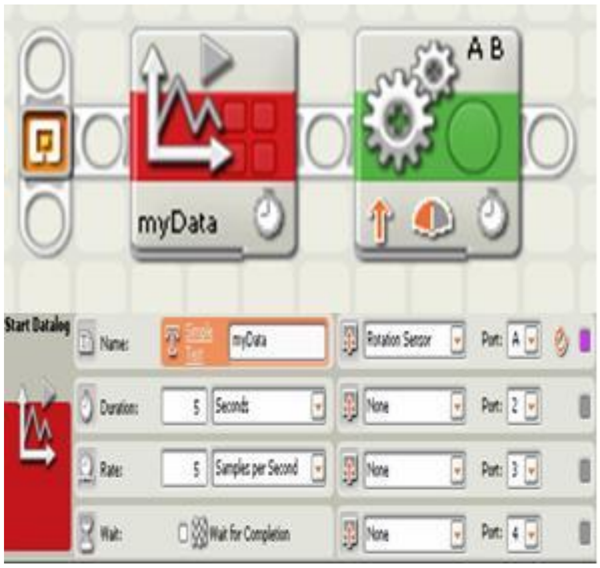


Fig. 2. Trainees' program for rectilinear motion at constant speed

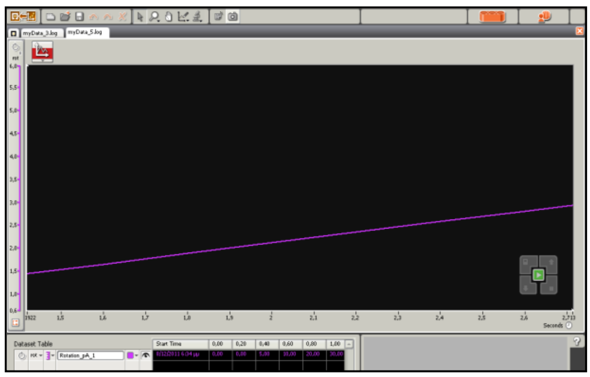


Fig. 3. Constant speed motion: Position-time graph (screenshot from data logging)

The next challenge was to make the robot move in rectilinear motion accelerated at constant rate. For this purpose, the programming technique of repetition and arithmetic operators were introduced. The result from trainees' programming work appears in fig. 4 and the subsequent position – time graph in fig. 5

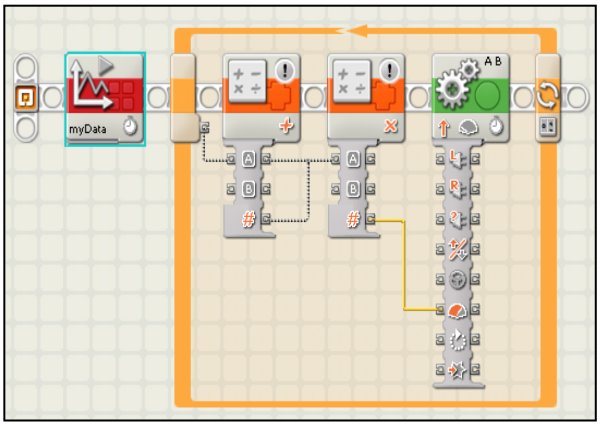


Fig. 4. Trainees' program for rectilinear motion accelerated at constant rate

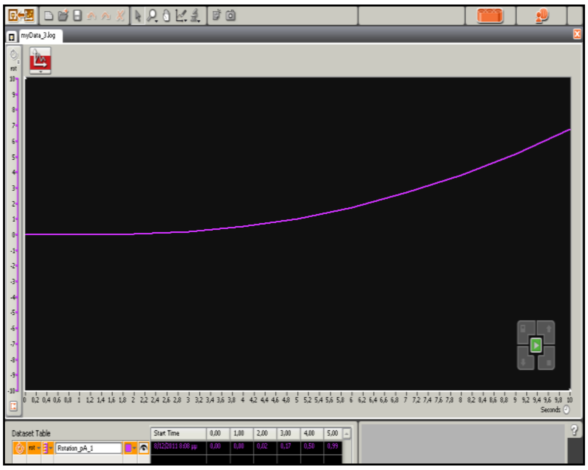


Fig. 5. Rectilinear motion accelerated at constant rate: position-time graph (screenshot from data logging)

In the discussion that followed for the evaluation of this training experience, we concurred with our experienced trainees that the methodology followed had resulted in a study of kinematics concepts through active participation of the learners; it could build step by step a deep understanding of the concepts triggering curiosity and encouraging further study and research. The use of robots had allowed repeated and controlled by the user interesting experimentations. Programming the motions and devising appropriate algorithms that result in rectilinear motion with constant speed or constant acceleration could help students in understanding the underlying kinematics concepts.

Finally, the execution of the programmed movements of the robot could help students to see their thinking, as expressed in the algorithm, to come alive with the robot moving on the floor and to understand their failures or achievements.

B. Teaching kinematics concepts in a school physics class through robotics

The methodology described in the section above was tested in a physics classroom (April 2012) by an experienced teacher, who had already been trained on the same methodology. In collaboration with the teacher the methodology was determined according to the needs of the school classroom. It was a class of 9 students aged 13 in a lower secondary school located in a poor rural and mountainous area of Western Greece (Ilia Prefecture).

Specific teaching materials including worksheets and assessment tools were developed for teaching and learning of basic concepts of kinematics including:

– rectilinear motion at constant speed
– relationship between distance and time of motion
– conceptualization and measurement of speed
– position-time and speed – time graphs.

More specifically, the students were divided into groups of three and initially became familiar with the Lego Mindstorms kit and the icons-based programming environment that comes with it. Then each group built their own vehicle.

We tok care to avoid detailed instructions for building because we wished to encourage students' initiatives, imagination and creativity in building the car in their own way.

Thus, the following purposely simple instructions were given through a worksheet:

Worksheet 1.

With your Lego Mindstorms kit build a car that has

– *Four wheels*
– *One motor that will actuate the 2 front wheels*
– *One Lego "smart brick" on the car*

Show your car in the classroom and put it in motion.

The 1st day activities ended with racing between the three vehicles, with the children to amuse and enjoy their artifacts.

During the 2nd day activities pupils worked according to the following instructions:

Worksheet 2

Put the car in motion.

Change the "throttle" of the motor, what do you observe happening in the movement of your car?

Although some confusion between the terms "speed" and "force" was observed in students' answers, they indicated understanding of the function of the motor power and its relation with the speed of the car. An indicative answer: "When we raise the throttle the speed and force goes up and when the throttle is lowered the motor power and speed is reduced". In our question: "What do you mean by the word force", they answered that the word "force" meant the "throttle" or "power" of the engine.

Then students were invited to experiment with the time of motion.

Worksheet 3

Put the throttle to 50% and do not change.

Put your car to move for 1 second

Then for 2 seconds
Then for 3 seconds
Observe what happens in the movement of your car when you change the time of motion?

All the three groups found that the distance traveled by their car was proportional to the time of motion: "as time of movement grows, the distance traveled by car increases". Then the students were challenged to make their car move faster and faster.

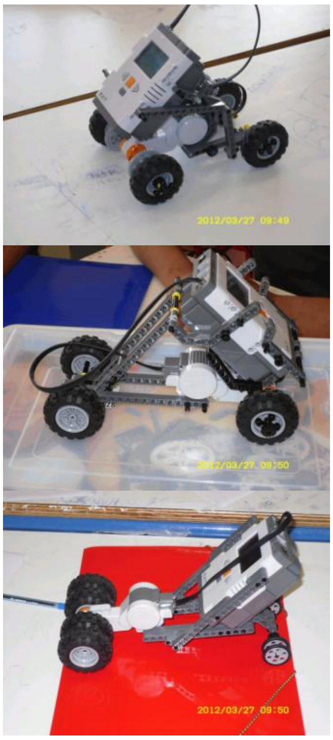


Fig. 6. Each student group constructed a different vehicle

Worksheet 4
How can you make the car move faster?
Again from the beginning: make it move even more quickly
Faster again and again ...
Try the solution you thought.
Enter here the solution you provided…

Students easily found that dragging up the slider of the power their car was moving faster: "Through the computer we increase the throttle and the car moves faster"

In the next activity the conceptualization and measurement of the speed was introduced.

Worksheet 5
How fast your car runs every time? Think of a way to measure how fast the car is running
Apply the way you thought and measure how fast your car goes.
Write the way you thought …

The students essentially defined the concept of speed. They measured the distance traveled by the vehicle at a time specified through the Lego Mindstorms interface. For measuring the distance, they adjusted the tape very properly on the front wheels of the vehicle at a certain point and measured the distance traveled by that point. "*We went to the computer and set the car moving for 2 seconds at full power (100%). Then we went and measured the distance moved and found that the car does 80 cm in 2 seconds*".

Then the teacher insisted asking questions to detect students' understanding about speed: "*Can you tell what it means for you that the car goes fast or slow? Write your thoughts here*". Some students gave a numerical example that showed a good understanding of the concept: "*when two cars are running, one travels 500 cm in 2 seconds and the other 80 cm in 2 seconds*". The teacher insisted: "*Can you explain what is the 'swiftness' of your car? Write here…*" (we used on purpose a simple Greek word from everyday life meaning speed and not a scientific term in order to challenge students to express spontaneously their conceptions). "*Swiftness is when the speed and power of the car is big and make the car move faster and more comfortable*" was an interesting answer which tried to explain the informal term of "swiftness" using the scientific ones of speed and power. The day activity ended (as usual!) with improvised races between the vehicles.

Finally, during a 3rd school day, the students studied the linear motion at constant speed working with the following activities.

Worksheet 6
Keep the "throttle" of the motor constant at 50%.
Count distances your car makes when it moves for different times.
Calculate each time the speed of the car. What do you observe?
Make a table with your data and graph the values of distances, times and speeds measured.

Students successfully approached the concept of a linear motion at constant speed; they easily found that the speed remained constant at each measurement they had made; the concept was also reflected in the graphs distance-time and speed-time made with paper and pencil.

Diaries were written in the end of each day with students' experiences: "*What went well today in what you did with your team? What did not go well? What you liked most of what you did today? What did not you like from what you did with your group today?*"

From the diaries it appears that the most enjoyable moments of the children were at the end of each day when they used their cars in improvised racing: "*I liked most when we put the battle carts and although ours is the heaviest it came out first*", "*I didn't like that sometimes we were defeated in the race by the other children due to our engine failure*".

The children's excitement with the game of racing introduced in the learning activities some fun which seems that resulted in game-based learning and motivated the students to make improvements and interventions in the construction of their vehicles to make them faster and more competitive. As stressed by Lund & Nielsen, learning is easier, faster and more effective when combined with the game and turns education into a fun activity [10].

When students were interviewed in the end of the course, they mentioned that across the whole educational process they had found as most interesting the assembly and construction of the vehicle. They emphasized the excitement they had felt "*when we set in motion our car*" and their satisfaction from their collaboration and team work.

Answering the question "*what new did you learn in this course?*" the students appreciated the understanding they had gained for the kinematics concepts. However they were impressed with their achievement in construction and programming the robotic vehicle. To put it in students' words "*it was surprisingly easy to build the robot…*", "*at first we thought we would never be able to build robots that we had seen only in pictures… but we did*".

Fig. 7. Students' car racing

After the end of the course the teacher reported his experiences from the course [11]. It is interesting to quote some of them: "… I obsereved that students' behavior showed that they had tried to impose their own ideas, ignoring or modifying the instructions given by the teacher. For example the red team did not use equal-sized wheels which resulted in a non-robust construction, but they insisted on their original idea that eventually changed gradually…. the white group used initially six wheels (instead of the proposed four) because they found it more attractive from an aesthetic point of view".

In another case the teacher noted the efforts of some children to experiment with different solutions while constructing their vehicle: "*in this group there was a strong tendency for many tests in the construction and use of many different parts*". Interestingly, he noted that the students who come from agricultural families and are dealing in their everyday life with agricultural and manual work from an early age had performed better in the construction of the robot. As he commented "*these children had learnt to use and operate agricultural machinery; this had strengthened their skills in assembling and manufacturing mechanical vehicles*".

The teacher's report concluded that "*the robotics-based teaching method followed in this project had effectively helped students to achieve cognitive goals in physics and technology, to acquire skills and competencies and solving problems*". Finally, "*the students had appreciated the value of teamwork and cooperation*".

V. Conclusions and Future Plans

This work highlighted two pathways for integrating robotics in teacher training: first in the initial education courses for technology teachers and second in the further training programs for in-service science teachers. A constructivism-inspired learning methodology was proposed in both cases specified according to the specialization, needs, interests and existing educational experience of learners. The active involvement of the trainees in all the phases of the training course was an important characteristic of the training methodology. From the beginning of the course, trainees were encouraged to participate in all the practical activities of the course, in discussions in small groups, and finally in presentations in plenary sessions. In line with previous findings [12], teachers appreciated the rotation of their role acting first as learners in the training courses, then as designers and developers of their own robotic projects in school classes. In this way teachers had the opportunity "to see themselves as designers of technologically rich curricula, and not merely consumers" [13].

In the second case of the experienced teachers a specific methodology was selected that focused on utilizing the existing rich experience of trainees and on sharing with them the effort to explore new ways to use robotics in learning science. Teachers achieved, after an initial familiarization with the necessary tools, to create through their own efforts and in collaboration with their trainer experimental robotics-based activities which they considered useful for their students in order to understand the intended in each case scientific concepts by following the constructivist methodology proposed in the training course.

In both cases, training was followed by development of projects in school classes by the trainees themselves where they were asked to implement the pedagogic ideas offered and discussed during their training. The classroom experiences, as demonstrated by the two reported case studies, offered a criterion of success of the training program itself and confirmed the effectiveness of the proposed robotics-based methodology in understanding scientific concepts from the field of informatics and physics, and developing skills with a more general value for students beyond the two mentioned specific fields. Furthermore, the reported activities seemed to have triggered the students' interest and turned, to a certain extent, learning into a game thanks to their invention of the competitive car-racing. We concur at this point with Polishuk et al. [14] that the combination of competitive with developmental activities is suitable for fostering both creativity and learning excellence.

The field of science and technology is a privileged one for the development of robotics either in school education or in informal settings. Acting in close collaboration with both enthusiastic young and experienced teachers we plan further experimental activities including teacher training and classroom interventions which are expected to provide valuable new ideas and data for the successful integration of robotics in the school curriculum of science and technology. Ideally, this work might result in a proposal for a school curriculum that would highlight the role and value of robotics in teaching and learning in a broad range of school disciplines with emphasis on science and technology.

ACKNOWLEDGMENT

I'd like to thank all the school teachers and student-teachers involved in the case studies reported above for their helpful collaboration and contribution and especially Nikolaos Detsikas and Antonios Litinas (Patras, Greece) who organized and conducted the two robotics school projects reported in this paper.

REFERENCES

[1] Alimisis D., Arlegui J., Fava N., Frangou S., Ionita S., Menegatti E., Monfalcon S., Moro M., Papanikolaou K. and Pina A. "Introducing robotics to teachers and schools: experiences from the TERECoP project", in J. Clayson and I. Kalas (eds.) Proceedings for Constructionism 2010, American Univ. of Paris, 2010.
[2] Bredenfeld A., Hofmann A., & Steinbauer G. "Robotics in Education Initiatives in Europe - Status, Shortcomings and Open Questions", In Proceedings of Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR 2010) Workshops, pp. 568-574, Darmstadt, 2010.
[3] Alimisis D. (ed.), Teacher Education on Robotics-Enhanced Constructivist Pedagogical Methods, School of Pedagogical and Technological Education, Athens, 2009.
[4] Alimisis D. "Introducing robotics in schools: post-TERECoP experiences from a pilot educational program", in Proceedings of Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR 2010) Workshops, pp. 575-585, Darmstadt, 2010.
[5] Papert S., The Children's Machine, Basic Books, New York, 1993.
[6] Kynigos C., "Black-and-white-box perspectives to distributed control and constructionism in learning with robotics", In Proceedings of SIMPAR workshops 2008, pp. 1-9, Venice, 2008.
[7] Resnick M., Berg R. & Eisenberg M. "Beyond Black boxes: Bringing transparency and aesthetics back to scientific investigation", Journal of the Learning Sciences, vol.9, pp. 7-30, 2000.
[8] Detsikas N. & Alimisis D. "Status and Trends in Educational Robotics Worldwide with Special Consideration of Educational Experiences from Greek Schools", In Proceedings of the International Conference on Informatics in Schools: Situation, Evolution and Perspectives (ISSEP 2011), Comenius University, Bratislava, 2011.
[9] Detsikas, N., Using Robotics in Education with the Lego Mindstorms Kit: Implementation of Activities in School Class and Evaluation, Unpublished dissertation, School of Pedagogical and Technological Education, Patras, 2011 (in Greek).
[10] Lund H. & Nielsen J., "An Edutainment Robotics Survey", In Proceedings of the 3rd International Symposium on Human and Artificial Intelligence Systems: The Dynamic Systems Approach for Embodiment and Sociality, Fukui, 2002.
[11] Litinas A., Design, implementation and evaluation of laboratory activities using robotic technology as educational tool for teaching the phenomenon of motion, Unpublished dissertation, Hellenic Open University, 2012 (in Greek).
[12] Alimisis D., "Robotic technologies as vehicles of new ways of thinking, about constructivist teaching and learning: the TERECoP Project", IEEE Robotics and Automation Magazine, IEEE Robotics and Automation Society, vol. 16 (3), pp. 21- 23, 2009.
[13] Bers M., Ponte I., Juelich C., Viera A. & Schenker J., "Teachers as Designers: Integrating Robotics in Early Childhood Education", Information Technology in Childhood Education Annual, AACE, vol. 2002 (1), pp. 123-145, 2002.
[14] Polishuk A., Verner I., Klein Y., Inbar E., Mir R., Wertheim I., "The Challenge of Robotics Education in Science Museums", IJREA: International Journal of Robots, Education and Art, Vol. 2, No. 1, pp. 30-37, 2012.

Appealing Robots as a Means to Increase Enrollment Rates: a Case Study

Jaime Alemany and Enric Cervera
Jaume-I University, Castelló, Spain
ecervera@uji.es

***Abstract*—As teachers of an elective robotics course in a computer science degree, we have frequently faced the lack of interest of students to enroll, thus stimulating us to introduce attractive robot platforms in the classroom, and to promote robot competitions among students. As a result, course enrollment rates have significantly grown up, even in a context of decreasing number of people undertaking computer science studies. This paper summarizes our experiences during the last 20 years, and some ideas for the near future, aiming to keep those appealing elements, while balancing the load for course preparation and teaching. The use of realistic simulations for virtual robot competitions is expected to provide the same appeal and learning possibilities of robotic hardware platforms, yet minimize the amount of technical work for setting up the course.**

***Index Terms*—Robot programming, competitions, simulation.**

I. INTRODUCTION

This paper presents our experiences during two decades of teaching an introductory robotics course in a B.Sc. in Computer Science at Jaume-I University (Castelló, Spain). Since its very beginning, robotics teaching was closely tightened to the Robotic Intelligence Laboratory[1].

The course consisted on an introduction to robotics, focused on industrial manipulators, covering the basic concepts of robot arms, and its direct and inverse kinematics. Influenced by our particular research interest in manipulation, only minor contents about mobile robots were included in the first editions of the course. Besides that, real robot arms being costly at that time, most laboratory work was done on simulators.

The idea of using small mobile robots in teaching was mostly influenced by two initiatives which became extraordinarily popular: the 6.270 M.I.T. course [1] and the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC) [2].

The LEGO Robot Design Competition (M.I.T. course number “6.270”) began in 1987 as a student-organized programming contest, inspired a course on industrial design developed by Professor W. Flowers [3]. In this course, students were given a kit of identical parts at the beginning of the term, and the specifications of a competitive task. Their goal was to build a remote-controlled machine that would solve that task faster and better than the other students' machines. This pedagogical approach had roots in the constructionist theories of learning developed by Seymour Papert [4].

The TCFFHRC aimed to increase awareness of robotic fire fighting while encouraging use of robotics as a theme for teaching engineering design. Many students found that development of a successful autonomous fire-fighting mobile robot was the most engaging and challenging project encountered in their undergraduate years.

With the advent of cheap robot kits, teaching with robots has become increasingly popular not only in universities but in high schools, and it has raised a large interest among the educational community to assess its benefits and drawbacks. Robots have been used to ease the learning process of introductory programming courses [5]. Inexpensive robot kits are claimed as a cost- and time-effective means of reinforcing behavioral robotics principles to students of different disciplines (computer science, engineering, psychology) with limited programming skills [6].

With robotic design contests becoming increasingly common, it is claimed [7] that competitions can be an important tool for fostering intellectual maturity, as defined by the Perry Model [8]. A competition involves a clearly defined yet open-ended problem, with many possible solutions. Students are encouraged to work collaboratively in teams, and the goals provide the contextual aspect of applying knowledge.

Using robots in the introductory computer science curriculum has attracted lots of attention in recent years [9]. This approach is meaning to challenge the Computer Science teaching community to move from the premise that computation is calculation to the idea that computation is interaction. Robots provide entry level programming students with a physical model to visually demonstrate concepts or ideas traditionally taught using abstractions.

Robots may add another benefit, since they could become an attractor to Computer Science studies. Number of undergraduates declaring a computer science major is dropping steadily in the last years [10]. Women, always a minority in the field, have become even scarcer than before. Use of robots in introductory computer science has been proposed as a means to fight the enrollment decline [11]. Some experiences report that student enrollment has grown over 2 fold since the introduction of robots [9].

Videogames are a serious alternative to using real robots, since their playability and realism may enhance the experience of simulation. This reduces significantly the cost of preparing the course, while maintaining the motivation of students [12].

The rest of the paper is organized as follows: in Section II we describe the progressive introduction of small mobile

[1]http://www.robot.uji.es

robots in our teaching. Section III presents our recent years of teaching with small humanoids, and the associated trends in student enrollment. Our motivation for turning back to virtual robots is explained in Section IV, together with a description of the environment for next editions of our robotics course. Finally, we summarize in Section V our feelings after two decades of teaching practical robotics.

II. MOBILE ROBOTS ARE SO COOL (1993-2002)

Robotics was created as an elective course in the degree in Computer Science. These studies started in 1991 with the creation of Jaume-I University, and the first edition of the course was held in 1993. Since then, a small number of students chose the course, roughly 10%, with a maximum of 15% of the enrolled students in 1996. It should be taken into account that the degree in Computer Science was mostly oriented to programming and software engineering.

Laboratory work consisted on simulation of manipulators, in order to learn the kinematics of a robot arm, by using Corke's Robotics Toolbox.

Fig. 1. Student programming a small mobile robot at the laboratory.

With the advent of cheap mobile robot kits [13] [14], it became feasible to use real robots in the classroom. Thus in 1999, we introduced laboratory works with small mobile robots (Fig. 1), and promoted a sumo competition among the students [15]. Needless to say, the competition tremendously boosted the interest of the students in the work. Since it was the first event of this type in the university, it raised a large interest not only among the students in Computer Science, but in the whole community, as seen in Fig. 2. This interest was also widespread in the media, with several references in local newspapers.

Fig. 2. Robotics sumo competition at UJI, academic year 1999/2000.

We believe that both the use of robots and the competition were the reasons for the sudden yet sustained increase in the ratio of enrollment in the robotics course. As depicted in Fig. 3, the percentage of students who chose this course was nearly doubled starting from year 2000, and it kept increasing up to a previously unseen 26% by year 2002. Such numbers roughly represent a 2-fold increase over the mean value of the editions prior to the use of small mobile robots in the classroom.

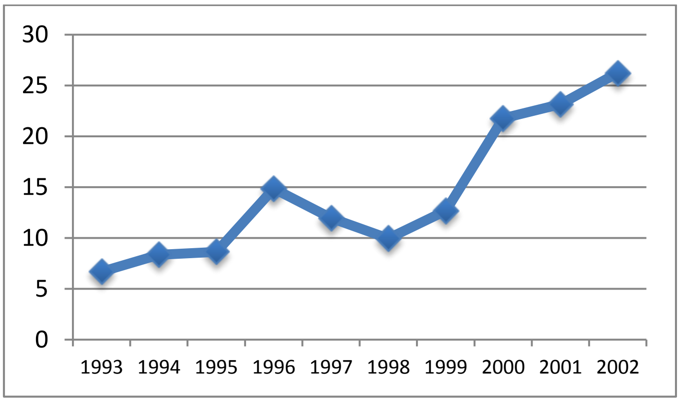


Fig. 3. Percentage of students enrolled in the elective robotics course between years 1993 and 2002.

III. HUMANOIDS RULE! (2003-2011)

In 2001, a major change in the organization of the degree in Computer Science was taken. Two three-year degrees were created, oriented to software and hardware respectively, and the five-year degree was re-organized in three itineraries, one of them being devoted to industrial informatics.

The reorganization did not represent any increase in robotics credits, though. Despite its popularity, the academic commission kept robotics as an elective course, which was offered only in two of the three degrees. Possibly due to incomplete information about the changes, the enrollment in the course decreased significantly in its first edition in 2003. By that time, we used small mobile robots in the classroom, and the numbers were slightly recovering in the following years, but the next major breakthrough was produced after the introduction of a new robot platform.

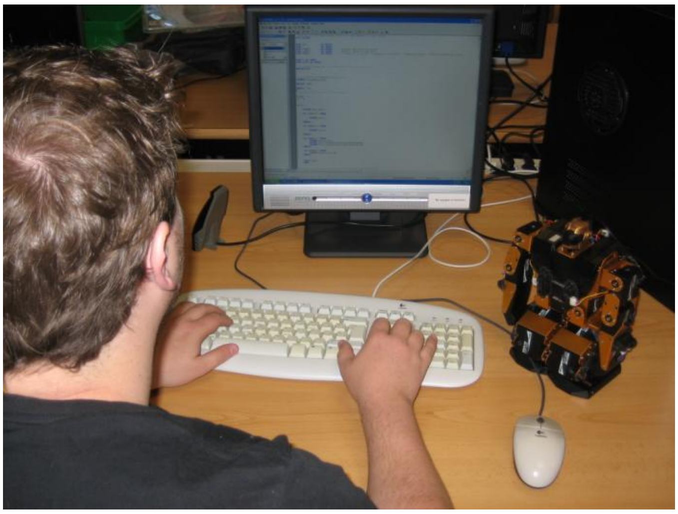


Fig. 4. Student programming a small humanoid robot at the laboratory.

After some months of previous testing, we introduced in 2006 a small humanoid robot in the classroom (Fig. 4). It consisted on a kit with all the parts and servos to build a highly autonomous robot, and the students were challenged not only to program simple behaviors but to participate in a sumo competition with their partners.

In addition, the winner of this local competition would qualify for a national competition against other Spanish universities (see Fig. 5). This time, the news spread not only on newspapers but also in television and radios. As a result, the enrollment rate grew significantly in 2007 and beyond, achieving an unprecedented 46% in 2009, and keeping over 40% in successive years, which represents roughly three times the ratio of the former editions (excluding the first year). Another major factor of this increase could be that our university team won the national competition during three consecutive editions.

Fig. 5. Humanoid sumo combat at CEABOT'08 competition between UJI and UHU teams.

With the advent of Internet video and social networks (Youtube, Facebook), there are many opportunities to disseminate the experiences on robot teaching and competitions, and to stimulate present and future students in the discipline[2,3] thus contributing to increase the enrollment rates.

Fig. 6 depicts such undeniable growing trend, which is even more impressive when compared with the absolute global number of students enrolled in the degrees in Computer Science. This number has been decreasing steadily since 2005, not only in our university, or in Spain, but worldwide. Though some claim [10] that robotics could attract more students to computer science disciplines, we have not experienced such effect. Nevertheless, the visibility in the media, and the activities promoted in primary and high schools could bring some fruits in the future.

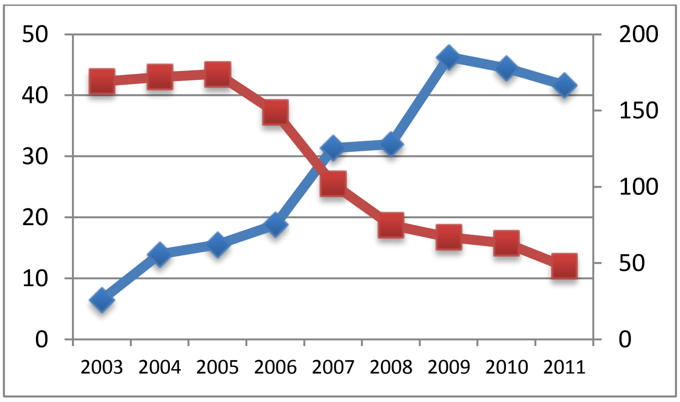


Fig. 6. Percentage of students enrolled in the elective robotics course (blue line, left scale), and absolute global number of students in the degrees of computer science (red line, right scale).

IV. Virtual Robot Competitions (2012-?)

A. *New Academic Context*

Ten years after the first reform, we are now facing a major change in order to adapt to the European Higher Education Area[4] (EHEA). The EHEA was meant to ensure more comparable, compatible and coherent systems of higher education in Europe, and it was finally launched in March 2010. In Spanish degrees, the process was implemented by extending the bachelor level to 4 years, while keeping 1 or 2 years for the master level. As a result, in the field of computer science, a single 4-year B.Sc. replaced the former 3- and 5-year degrees. A specialized M.Sc. in Intelligent Systems has also been introduced as an intermediate step towards PhD. The master students can choose between two majors on service robotics and interactive systems respectively. In the new B.Sc. the former robotics course has been merged with another course on Artificial Intelligence to become a single compulsory course on Intelligent Systems. This course will be started on Autumn 2012.

B. *Videogames and Learning*

This context of changes has lead us to make modifications in the subjects, in an attempt to reverse the declining trend in

[2]http://www.youtube.com/user/RobInLabUJI
[3]http://www.facebook.com/pages/Robotic-Intelligence-Lab/55085509725
[4]http://www.ehea.info/

student enrollment. With this goal, we have taken into account some considerations.

Research over many years indicates that the use of digital videogames for learning leads to improved general learning, increased motivation, and higher performance. It has been found that students provided with computer-based or console-based videogames to facilitate learning score significantly higher on tests. Although experts differ greatly in other aspects, they share similar opinions on which are considered the key gaming features necessary for learning and engaging: *fantasy, representation, sensor stimuli, challenge, mystery, assessment* and *control*. Videogames overcome the rules of reality in order to use their own rules, whereas simulators attempt to model a system in a manner that is consistent with reality. Nevertheless, despite the differences between videogames and simulators, they contain many common elements. Furthermore, key gaming attributes are important to increase the "game-like" feel of simulators. Also, fidelity in simulators is rather variable: low-fidelity simulators simplify systems in order to highlight only its key components, whereas high-fidelity ones try to model systems as realistic as possible and tend to be more game-like [12].

Experiences of the National Institute of Standards and Technology (NIST) demonstrate that competitions are an effective means of stimulating interest and participation among students. So, we can find many worldwide virtual robotics competitions such as RoboCup Rescue[5], or Virtual Manufacturing and Automation Competition[6]. These competitions tend to get the students engaged and encourage larger participation in the research community.

Virtual environments are needed for teaching robotics in distance learning. When teaching technologies, the need for laboratories in many courses steps back universities from offering such disciplines. Realistic simulators may replace the need for real equipment, thus allowing the enrollment of students who either work part-time or live in distant countries [16].

Last but not least, setting up a virtual environment is less time-consuming than keeping a collection of real robots in working condition.

C. *Realistic Virtual Environments for Teaching Robotics*

Consequently, we have organized a course that allows students to acquire robotics knowledge and use a realistic virtual environment, which includes a challenging robot sumo competition. The course is based on freely available (mostly open-source) off-the-shelf software components:

a) ROS[7] (Robot Operating System) is an open source framework for robot control that provides libraries and tools to help software developers create robot applications. [17].

b) UDK[8] (Unreal Development Kit) is a free edition toolset powered by Unreal Engine 3 (3D engine of Epic Games first person shooter Unreal Tournament III) that includes a world editor. Unreal Engine 3 offers graphical realism and smooth gameplay.

c) USARSim[9] (Unified System for Automation and Robot Simulation) is an open source high fidelity 3D robot simulator built on top of UDK. In addition, USARSim provides detailed models with high quality physics of interaction and let users to build their own robots and sensors [18].

So, we have combined these tools to obtain a virtual environment of simulation trying to preserve those attributes that make videogames so motivating [19].

Regarding fantasy (element in a game that represents something that is separate from real life and evokes mental images that do not exist), we have included a sumo ring surrounded by water (see Fig. 7).

Concerning representation (physical and psychological similarity between a game and the environment it represents), we have modeled the building with many details to achieve realism (see Fig. 8 and Fig. 9).

Fig. 7. Virtual environment for robot sumo competition: the ring is surrounded by water; animated flags and torches are added for enhancing visual realism.

Fig. 8. Outdoor view of virtual building.

With reference to sensory stimuli (visual, auditory, or tactile stimulations with the purpose of distorting perception and using temporary acceptance of an alternate reality), we have introduced some visual and audio effects for water, fire and wind, e.g. distortions, reflections, light flashing, moving shadows, etc.

[5]http://www.robocuprescue.org/
[6]http://www.vma-competition.com/
[7]http://www.ros.org
[8]http://www.udk.com
[9]http://usarsim.sourceforge.net

Fig. 9. Indoor view of virtual building with a mobile robot.

V. Discussion

In two decades of teaching robotics, we have used many simulation environments and real robot platforms. We have witnessed the enthusiasm of students with small real robots, and their commitment to challenges posed by robot competitions.

But we have experienced ourselves the overhead in course preparation needed for setting up and keeping a fleet of small robots in working condition.

Together with the advent of powerful yet inexpensive video cards, we advocate for the use of virtual robot competitions in teaching. We believe that many benefits of robot competition can be also grasped in virtual environments, as demonstrated by the appeal of videogames.

Nowadays, virtual environments with tremendous realism are possible in a standard computer, and software tools are freely available for setting up a virtual robotics laboratory or competition. The simulation of physics makes programming in virtual robots almost as challenging as in real ones, while keeping maintenance work to a minimum.

Virtual worlds allow the introduction of enhancing fantastic elements that enrich the gaming experience, thus we expect that students will enjoy the course, making robotics attractive for them, and increasing the enrollment rates.

Acknowledgment

The authors thank A. Milanes and M. Guerrero for their support in the administration and maintenance of the computers in the robotics laboratory; J. C. Garcia for his mastery with the humanoids; A. Morales, P. J. Sanz, A. P. del Pobil for the many hours spent in setting up and teaching the course; and countless students for their enthusiasm in robotics.

This research was partly supported by WCU (World Class University) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (Grant No. R31-2008-000-10062-0), by Ministerio de Ciencia e Innovación (DPI2011-27846), by Generalitat Valenciana (PROMETEO/2009/052) and by Fundació Caixa Castelló-Bancaixa (P1-1B2011-54).

References

[1] F. Martin, "Building Robots to Learn Design and Engineering," in *Frontiers in Education Conf.*, 1992, pp. 213-217.

[2] D. J. Pack, R. Avanzato, D. J. Ahlgren, and I. M. Verner, "Fire-fighting mobile robotics and interdisciplinary design-comparative perspectives," *IEEE Trans. on Education*, vol. 47, no. 3, pp. 369-376, 2004.

[3] W. C. Flowers, "On engineering students' creativity and academia," in *ASEE Annual Conf. Proceedings*, 1987.

[4] S. Papert, "Constructionism: A new opportunity for elementary science education. Proposal to the National Science Foundation. ," MIT Media Laboratory, 1986.

[5] V. Dagdidelis, M. Sartatzemi, and K. Kagani, "Teaching (with) robots in secondary schools: some new and not-so-new pedagogical problems," in *IEEE Int. Conf. on Advanced Learning Technologies*, 2005, pp. 757-761.

[6] A. Gage and R.R. Murphy, "Principles and experiences in using legos to teach behavioral robotics ," in *Frontiers in Education*, vol. 2-F4E, 2003, pp. 23-28.

[7] R. R. Murphy, ""Competing" for a robotics education," *IEEE Robotics & Automation Magazine*, vol. 8, no. 2, pp. 44-55, 2001.

[8] M. J. Pavelich and W. S. Moore, "Measuring maturing rates of engineering students using the Perry model," in *Frontiers in Education Conf.*, 1993, pp. 451-455.

[9] E. Wang, "Teaching freshmen design, creativity and programming with LEGOs and Labview," *in Frontiers in Education Conf.*, vol. 3, 2001, pp. 11-15.

[10] B. Lester, "Robots' Allure: Can It Remedy What Ails Computer Science? ," *Science*, vol. 318, no. 5853, pp. 1086-1087, 2007.

[11] J. Bergin, R. Lister, B. B. Owens, and M. McNally, "The first programming course: ideas to end the enrollment decline," in *SIGCSE Conf. on Innovation and Technology in Computer Science Education*, New York, 2006, pp. 301-302.

[12] K. A. Wilson et al., "Relationships Between Game Attributes and Learning Outcomes: Review and Research Proposals," *Simulation & Gaming*, vol. 40, pp. 217-266, April 2009.

[13] F. G. Martin, Robotic Explorations: *A Hands-On Introduction to Engineering*. Upper Saddle River, NJ, USA: Prentice Hall PTR, 2000.

[14] F. Klassner and S. D. Anderson, "LEGO MindStorms: not just for K-12 anymore," *IEEE Robotics & Automation Magazine*, vol. 10, no. 2, pp. 12-18, June 2003.

[15] E. Cervera and P. J. Sanz, "Experiences with minirobot platforms in robotics and AI laboratory," in *Robotics Education and Training*, A. Casals and A. Grau, Eds.: UPC Publications, 2001.

[16] C. Perez-Vidal, L. Gracia, N. Garcia, E. Cervera, and J. M. Sabater, "The on-line teaching of robot visual servoing," *Int. Journal of Electrical Engineering Education*, vol. 48, no. 2, pp. 202-216, April 2011.

[17] S. Cousins, "Exponential Growth of ROS," *IEEE Robotics & Automation Magazine*, vol. 18, no. 1, pp. 19-20, 2011.

[18] S. Carpin, M. Lewis, Jijun Wang, S. Balakirsky, and C. Scrapper, "USARSim: a robot simulator for research and education," in *IEEE Int. Conf. on Robotics and Automation*, 2007, pp. 1400-1405.

[19] J. Alemany and E. Cervera, "Design of high-quality, efficient simulation environments for USARSim," in *IASTED Int. Conf. on Robotics*, Pittsburgh, 2011, pp. 226-233.

National Mechatronics and Robotics Elective Course for Upper Secondary School Level

Heilo Altin
Institute of Technology, University of Tartu, Tartu, Estonia
Heilo.Altin@ut.ee

***Abstract*—Recent studies show that pupils are very enthusiastic when using robotic systems and robots in schools. However, in Estonia, these are mainly used only in extracurricular activities to learn about the robots, take part in various contests or for research purposes. Robotics increases the level of problem solving skills and enhances pupils' better understanding of various aspects of math and physics. Robots could be used for that but the work done so far in schools in Estonia has been at interest level. To make teaching robotics more systematic, a facultative course of mechatronics and robotics was developed to be available for all high school pupils (aged 16-18). This paper describes the developed course, its structure and methods of teaching.**

***Index Terms*—Educational robotics; Mindstorms; Homelab; facultative course**

I. Introduction

Integrating various subjects has been a downside in the Estonian school system for years. In addition, several subjects in the upper secondary school curriculum are very abstract, such as laws of Physics, regulations for Math calculus or the construction of a cell in Biology. ICT has been seen as a helpful tool for integrating subjects, however, it can only reach its goals through methods of active learning, projects in school and on international level. These methods can be used very easily at upper secondary school level. The purpose for developing this course was to use robotics more systematically in Estonia to gain more.

Robotics is a tool for integration on its most simple level [1]. When teaching robotics, it is crucial and unavoidable to use methods of active learning [2]. Robotics enables to connect all the subjects of natural and exact sciences as well as technology. Courses in comprehensive schools in Estonia are 35 school hours long. For the existing 35-lesson timetable, each topic is connected to Physics or Math or Information Technology. As pupils will encounter a lot of new notions, the terminology of robotics and the particular topic involved will be provided in English. It will provide useful when the pupils wish to do further research on their own or, for example, use some sources in English when writing a summary. In principle, robotics enables to relate many other subjects, from Music to Physical Education. During the 35-lesson-course, authors would like to see that the pupils become more interested in robotics and STEM subjects. Authors wish pupils could feel enthusiasm and success over the fact that they can control the robots and by doing so, better understand the mechanisms of natural world. The schools can choose which platform (MINDSTORMS NXT [3], Homelab [4]) will be used to conduct the course. The particular facultative course aims at combining manual work with abstract understanding, integrating several subjects through the practical work done within a group and offering some joy of learning that seems to be lacking in schools.

II. Course Methods

The course of mechatronics and robotics is conducted in pair lessons for one lesson is too short to introduce the theory and then conduct a practical task. Should there be a pause in between the theory and practical work; the course would not be as beneficial. Furthermore, setting up and taking down the hardware of a robotics class is time-consuming.

During the course, marking is based on practical tasks, which have been chosen to revise the theoretical knowledge of the previous classes and give the pupils a chance to use these in creating their own solutions. Practical tasks are conducted as collaborative work in pairs. This study form has already proven to be the most effective robot-user ratio in Estonia. In addition, the course includes some more challenging practical tasks that require teamwork. Practical tasks have been compiled keeping in mind that they are interesting to pupils and so that they would create the wish to try out new ideas and improve the solutions created. At the same time, the plan and phases of creating a solution will be followed and the activities will be documented. All tasks are presented as problems for which pupils need to find solutions in project based work.

The practical tasks and the project of robotics will be conducted with the given hardware solution – the study sets of robotics. It is recommended to use the sets supported by the University of Tartu and the Tallinn Technical University – LEGO MINDSTORMS NXT / NXT-G or NXC and the Robotics Homelab. Some other suitable solutions, such as Arduino, TI Development Toolchain, etc, could also be used. Course material is divided into two levels for the aspect of simplicity. For pupils, it is possible to finish the course with generic understanding of how robots act and work, but if they are already at that level, they could find more detailed information on the second level. The theoretical part of each chapter ends with revision questions and an online test which purpose is to check if pupils understand the theory. Otherwise, they would face more problems during the practical work. The online test and questions are not compulsory and it is teacher's decision whether to let the pupils take them or not. This is a possibility for teachers to evaluate pupils' work. As this course takes advantage of e-learning methods, teachers have a possibility to change tests as needed. Teachers are not obligated to require pupils to have working solutions after the practical lesson is over. In many cases, the purpose is not to finalize a working robotic system but to see what pupils learn during the design process and how they apply this knowledge. The purpose of examples and tasks is not to gain new knowledge, rather to systemize skills and knowledge and create links and better abstract view of the topic. To gain all this, pupils should have the opportunity to think about the subject independently to generate links and conclusions. General suggestion to teachers would be to have lots of discussion after independent work to eliminate false conclusions pupils might come up with. The most important part of evaluating pupils is the final project of the course. Other than the developed system, also team work, documentation, presentation and software are under assessment.

III. Course structure

The course is made up of 35 lessons which are divided into pair school lessons. The course is made up of six topics:

- Main principles of robotics – 4 lessons
- Actuators – 4 lessons
- Sensors – 8 lessons
- Robot motion and positioning – 2 lessons
- Data processing – 8 lessons
- Project – 9 lessons

1) *Main principles of robotics:* 4 lessons

a) Lesson 1-2 (Introduction/lecture): Robotics' history, everyday use, sample platforms and safety. Learning outcomes: pupils should know what a robot, robotics, a manipulator, mechatronics, a sensor, an actuator and a controller is. In addition, pupils can determine whether a robot belongs to the first, second or third generation and can explain robot-human interaction through I. Asimov laws.

b) Lesson 3-4 (Robotics system/lecture and practical work): Robotics system as a sensor-brain-actuator system, microcontrollers, programming, debugging and compiling. Learning outcomes: pupils know what a mechatronic's system, its parts and structure are.

2) *Actuators: 4 lessons*

a) Lesson 5-6 (Displays/lecture and practical work): Various types of displays. Learning outcomes: pupils can name visual information transmitting devices and can select the most appropriate device for a robot to transmit information.

b) Lesson 7-8 (Motors/lecture and practical work): Various motors, electrical, DC, servo and stepper motors. An overview of alternative actuators such as a linear motor, a solenoid, an artificial muscle is given. Learning outcomes: pupils know which motors to select for the robot, H-bridge and control mechanisms for servo and stepper motor.

3) *Sensors: 8 lessons*

a) Lesson 9-12 (Analog Sensors/lecture and practical work): Analog sensors with various examples, A/D converter. Learning outcomes: pupils know how analog sensors and a A/D converter works. They also know what A/D converter resolution is and how to find it.

b) Lesson 13-16 (Digital Sensors/lecture and practical work): Different digital sensors and examples. Learning outcomes: pupils can name different digital sensors, know how these sensors work and the structure of a digital signal.

4) *Robot motion and positioning: 2 lessons*

a) Lesson 17-18 (Robot Motion and Positioning/lecture and practical work): Various ways of robot motion (wheels, omni wheels, treads, legs) and positioning (GPS, sensor). Learning outcomes: pupils know how to select the most suitable motion device for the robot. Pupils also know how the simplest positioning algorithm works and how to use it.

5) *Data processing: 8 lessons*

a) Lesson 19-22 (Data Communication/lecture and practical work): Various ways of data communication between robots (bluetooth, cable). Learning outcomes: pupils understand digital data communication, can name the positive and negative aspects of various data communication.

b) Lesson 23-26 (Data Collection and Manipulation/lecture and practical work): Various ways of data collection, reasons, principles are explained. Learning outcomes: pupils can name robots that collect and process data, can give reasons for using robots for collecting data, know how data is stored.

6) *Project: 9 lessons*

a) Lesson 27-35 (Project/practical work): Practical assignment that applies all knowledge learned before. The work includes project management, research, teamwork, wireless data communication, documenting, reporting, presenting.

The course has five various books which are also printable in paper format. The first book is theoretical textbook which includes all the theoretical information about all the six topics, see "Fig. 1". The theoretical part is not platform dependent, so pupils can read it whether they use MINDSTORMS or Homelab. It is also possible to give the course without a platform, but it is considered to be a downside and should be discussed carefully as probably the course would not fulfill its purpose to give pupils practical skills in mechanical and robotics system engineering.

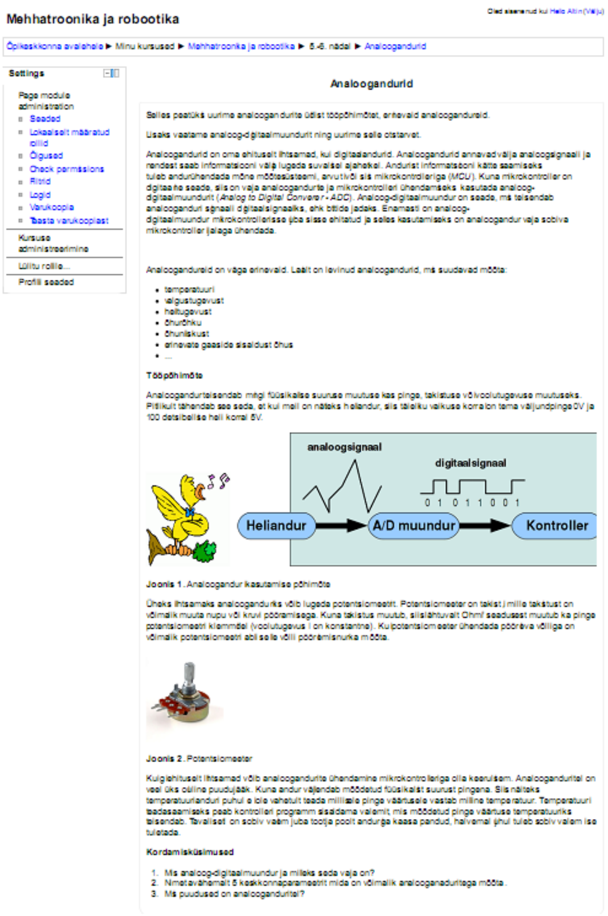


Figure 1. Chapter "Analog sensors" of theoretical workbook which explains the idea of changing an analog signal to digital form.

The textbook also includes support for the teacher in form of teacher textbook which includes more notes, links and hints to have the discussion going in the classroom. First, pupils read the theoretical part, then continue with practical work. Two platforms are supported and so there are two various workbooks, see "Fig. 2". Each lesson has up to four assignments which in most cases are not all to be solved during the lesson. The teacher can make a choice of the assignments. For each workbook, there is also support for the teacher in form of teacher's workbook. This includes all solutions for the assignments and ideas for new assignments. There is also a glossary of the new concepts. It is linked to the theoretical textbook. As mentioned, theoretical part is divided into two levels for reading.

First level is easier as it explains all the important aspects in one topic but does not go into details. Second level explains the same aspects but in more detail. This division leaves to teachers and pupils a choice whether they want to know more if they could understand a technical text. This kind of differentiated textbook was developed because some schools in Estonia are not as advanced as others, but the authors wanted the target group to be as wide as possible.

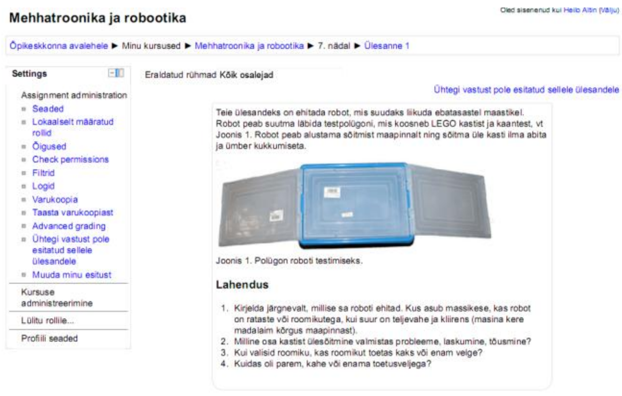


Figure 2. Example of one assignmenet in Mindstorms workbook where pupils have to build a robot that could climb over LEGO box.

IV. Course Piloting

The course was piloted in four schools as a part of the standard curriculum, but the lessons were carried out as the last lessons during one school day. This was also recommended in the teachers handbook as pupils frequently find themselves wanting to do more or to finish practical activities even when the time is up. Each week included two school lessons, eighteen weeks altogether. Two schools used Homelab and others MINDSTORMS platform. Twenty pupils from grades ten (aged 16) and eleven pupils from grade eleven (aged 17) used MINDSTORMS platform. Eleven pupils from grade eleven and twelve pupils from grade eleven used Homelab platform. The course was set up in Moodle environment. At the beginning, this seemed to be an obstacle because schools were not able to set up our course in their Moodle environment without problems. This led the authors to setting up a central course in a central server that all the schools were able to access. Teachers were added to Moodle environment according to their role and they were able to add pupils. Feedback was collected via forms in Moodle environment from pupils and teachers. For that, various questions were used. Among other questions, teachers had to evaluate how the course supported upper secondary schools to fulfill requirements of the general competence of the national curriculum. Pupils had to assess the theoretical part of each chapter in Likert scale (1-5) by:

- clearness (1 – material was not clear at all, 5 – material was completely clear)
- novelty (1 – all material was new, 5 – there was no new information)
- level of interest (1 – material wasn't interesting, 5 – material was very interesting).

Besides piloting in schools, another method was used during the development of the course. An eight-day-long teacher training was applied. First four days were set up on MINDSTORMS platform, the last four days on Homelab. During the training teachers were able to give feedback as they worked through the topics. Thirty teachers took part in this training.

V. RESULTS

Feedback from schools revealed that the course has a substantial amount of material, so pupils were not able to finish the project in the end. That was partly based on a teacher's decision. Another reason for that which was also mentioned by the teachers was that they were teaching this course for the first time which led them to setbacks. These problems are not connected to the course but to their level of experience. In the coming years, teachers know what to change in their methods in order to finish in time. The system of having a central server with Moodle running was approved by the teachers. That did not pressure them or the school staff with technical problems. Piloting with Homelab showed that Homelab needs a high level of previous knowledge about electronics and programming in C. That led to great time consumption when solving the textbook for Homelab. Other problems raised were connected to the sets used for practical assignments. One school mentioned that they did not have a sufficient number of MINDSTORMS sets to have these only for the pupils of the particular course. As the sets had to be used by other pupils as well, it was difficult to maintain the built solutions over the weeks. Most of the pupils (more than 37 %) always assessed the clearness of the material as very clear. In some topics, pupils also answered that the material was not clear to them at all. When it comes to the novelty of the topics, most pupils found some new information for them. Again, in some cases, pupils did not get any new information. That might be due to the teacher's decision of the pupils piloting the course. Pupils' knowledge before taking the course was not measured, but teachers selected pupils they had been working with before during extracurricular activities in robotics. The interest level of the topics varied, but most of the pupils found the material to be suitable or interesting. In teachers' feedback, it was mentioned that the theoretical workbook is complete and motivating for pupils to read it.

One reason for developing this course was the promotion of STEM subjects. When pupils are about to graduate high school and make their choice for the future during the last upper secondary school year, this course would guide them towards engineering in university. From the feedback, it turned out that starting this activity in upper secondary school level is too late. The age group for using robots for the mentioned reason should be as low as lower secondary or elementary school. This course is not to be used on the elementary school level, but teachers gave positive feedback about the possibility of using it in lower secondary schools with the first level of the theoretical part. All in all, some changes were conducted to the course according to piloting in schools. The most positive effect rose from teacher training. It was not expected to collect that amount of feedback that authors got from the training. Another unexpected positive effect took place in Estonia due to the course. This course will be leased as a national facultative course for mechatronics and robotics at the beginning of 2013 and a large amount of schools joined the educational robotics school network. The reason for joining was the will to be able to teach this course from the beginning of 2013. The competition between schools is mentionable as the course became a key point for some schools to gain more pupils on upper secondary school level.

VI. CONCLUSION

The decision of using Homelab as a technical platform for the course must be analyzed carefully by teachers and the school staff. As MINDSTORMS is intuitive and easy to use, it did not encounter so many problems as Homelab. Homelab could be the next level for the same pupils after passing the course with MINDSTORMS. Ministry of Education and Science in Estonia is aware that schools might get held up with setting up Moodle courses. This can also cause problems while teaching pupils. The decision of whether there should be a central course has not been made. A positive side of this could be that fact that technology changes on a daily basis and the theoretical book expires quickly; a central place for the course will allow authors to make changes if needed and these will reflect immediately in all schools. Server requirements for this course were not substantial. The course will go through the process of book reviewing and language check before it is released to the schools. Some teachers are planning to use the course also in lower levels in school because they find some classes being able to do that. In the end, this course has a systematic approach into robotics and mechatronics which also reflects in all of the learning materials. Schools can continue with robotics from extracurricular level to the curricular level. The next step is using robots as natural part of physics [5], math, informatics and chemistry.

REFERENCES

[1] S. Hussain, J. Lindh, and G. Shukur, "The effect of LEGO Training on Pupils' School Performance in Mathematics, Problem Solving Ability and Attitude: Swedish Data " *Educational Technology & Society*, vol. 9, pp. 182-194, 2006.

[2] I. Markelis, S. Atmatzidou, and S. Demetriadis, "Introduction of Educational Robotics in Primary and Secondary Education: Reflections on Practice and Theory," in *Lessons Learnt from the TERECoP Project and New Pathways into Educational Robotics across Europe* Athens, 2009, pp. 25-27.

[3] 28.01). Available: http://www.lego.com/eng/education/mindstorms/

[4] Available: http://home.roboticlab.eu/

[5] O. Krikmann, J. Susi, and H. Voolaid, "Dependence on Usage of Physics Misconceptions by Year of Study among Estonian Pupils," in *Annual Symposium of the Finnish Mathematics and Science Education Research Association*, Helsinki, 2004, pp. 391-415.

Simulation of Robotic Sensors in BYOB

Javier Arlegui[1], Michele Moro[2], Alfredo Pina[3]
[1]Psychology and Pedagogy Department, Public University of Navarra
Campus Arrosadía, Pamplona, Spain
arleguip@unavarra.es
[2]Department of Information Engineering, University of Padova
Via Gradenigo 6/A-B, Padova, Italy
mike@dei.unipd.it
[3]Mathematics and Computer Engineering Department, Public University of Navarra
Campus Arrosadía, Pamplona, Spain
pina@unavarra.es

***Abstract*—The paper presents a proposal to simulate several robotic sensors through an implementation in the BYOB authoring environment. The possibility to define custom blocks as specialized reporters is exploited to represent the information usually returned by relevant physical sensors in real robots. Some motivations to use simulated sensors and robots for educational purposes in a well know and not so complex environment like BYOB are also given.**

***Index Terms*—Scratch, BYOB, Robotic sensors, Simulation, Educational robotics**

I. Introduction

A reliable and rich sensorial endowment is crucial for an autonomous robot to realize effective behaviours. Thus the comprehension of the role, potentialities and limits of real robotic sensors is important under the educational point of view [1]. This knowledge can be initially promoted through easy-to-use simulation environments before working with real robots and facing all the uncertainties of a real scenario. Nonetheless younger students could find too hard to use sophisticated simulators able to reproduce 3D objects with all their physical parameters [2] [3] [4].

In [5] we showed that a widely spread authoring system like Scratch [6] provides 2D simulation features sufficient to permit a student to make significant robotic experiences. BYOB [7] goes further thanks to its powerful extensions, e.g. the possibility to define custom blocks, to use (recursive) procedures as data, to program in an object-oriented style. Both Scratch and BYOB have been used to make robotic simulations, for example Karel [8] and Valentino [9], and include commands to interact with external robotic components (Pico/Scratch boards, and LEGO WeDo natively but also other robots like LEGO NXT and Arduino-based architectures).

This paper aims at presenting a broad spectrum of possibilities to simulate robotic sensors without using external hardware with respect to the standard PC resources. Thus it presents a sequence of proposals, based on the realization of BYOB custom blocks, in order to simulate, among the others, the most significant sensors that in real robots support their autonomy. The focus of the paper is how to exploit the more advance features of the language to make simulated sensors able to report reasonable environmental data. This can help teachers in designing interesting 2D demonstrative robotic examples and in motivating their students to deepen some relevant scientific issues before working with real robots.

II. Some motivations

Sensors in robotics play a fundamental role, particularly when autonomy is concerned. Their variety, precision and complexity influence the control of the behaviour of a robot and make it more or less completely and effectively fulfil its tasks. Sensors are used both in finely controlling the robot's actuators and to permit it to take strategic decisions.

The simulation of a sensorized robot presents a fundamental difficulty: in a complete 3D environment objects have their physicality and the interaction between a sensor and the simulated reality must rely on that, i.e. an object occupies a certain volume within its surface and 'responds' following specific rules when subjected to some physical phenomenon like an ultrasonic emission. On a 2D simulation the situation is only a bit simpler: an object occupies an area of a plane within a close curve (its boundary) and any physical phenomenon takes essentially place planarly.

Scratch is widely adopted as an authoring system to give young students the possibility to experiment, in a pleasant and constructive way, several important aspects related to story telling, maths, geometry, computer graphics, computer programming. It promotes the knowledge of important but not so easy concepts in computer science like multitasking and message passing synchronization, hiding their most difficult details behind simple interfaces and procedures and exploiting the full potential of its hybrid (graphical/textual) programming style. BYOB reintroduces in Scratch first class (possibly recursive) procedures, lists and objects which were for decades fundamental elements of the previous LOGO available environments. These improvements make it possible to use BYOB as a powerful programming language to teach basic programming concepts like complex data structures, recursion, object-oriented programming and information hiding, etc.

BYOB, like Scratch, provides a set of sensing features associated with sprites which, when encapsulated into recognizable and simply interfaced functions, may be assimilated to several types of robotic sensors as discussed in the following section. Though most of these sensing functions are inherited from Scratch, for the sake of conciseness in this paper we refer only to the BYOB environment.

III. SENSORS IN BYOB

In the following we provide a uniform interface for sensing functions so that the robotic-oriented programming of sprites' scripts results enough simple and self explaining. This interface is based on the concept of 'port', an input connection between the robot and the sensor device, like what you can find, for example, in the LEGO NXT brick. In a configuration phase the robot is 'connected' through its ports, indexed with integer numbers, to one or more sensors which can be read calling a custom block, specific for each type of sensor. Therefore these blocks have always the connection port as one of their input parameters.

We assume that the reader has already a basic knowledge of BYOB in order to understand the proposed examples. The code is provided with a syntax which is a personal extension of the Scratch's Block Plugin Syntax [10]: the details of this extension will be presented gradually along with the examples.

A. Embedded sensors

Some state parameters are more or less directly returned by basic BYOB reporters, for example a sprite's position and direction. In these cases the realization of the equivalent of fundamental robotic sensors are straightforward and is presented as the first, simplest case.

The first example we propose is a **Compass** sensor, used to return the robot's orientation. In BYOB orientation is reported by the *direction* command and it is measured in degrees. The following correspondences with the cardinal points hold: S=±180°, W= -90°, N=0°, E=+90°. Here is the first code:

```
   def (Sensing reporter, for all, report[direction])
compass (port=1 Number)
     if < (item (port) of [ports v]) = [compass] >
//check port
       report (direction)
     else
       report [Error!]
```

`def(desc)` represents the header of a custom block definition; *desc* describes the category, the type of the block and the reported value type when applicable. In this example the new *Sensing* block named *compass* takes one parameter, the port, a Number with 1 as its default value, to which the sensor should be connected, and reports the direction in degrees. Its implementation checks if the port is actually connected to the correct sensor: for this purpose let's imagine that, in a configuration phase, for each sensor you have orderly assigned its descriptive keyword to the *ports* list. In all our examples we assume a *config* custom block, local to each robot-sprite, initializing the *ports* list and other possible configuration parameters, like the following:

```
   def (Variables command, for this) config
     delete (all v) of [ports v]
     add [sensor1] to [ports v]
     add [sensor2] to [ports v]
   ...
     add [compass] to [ports v]
```

One of the interesting feature of BYOB, due to the fact that sprites are first class objects, is the way one sprite can ask another sprite to execute a script or a block: in this case even a custom block defined local to the called sprite (not global) can be executed and the execution can refer to the called sprite's local variables. One sprite can also ask another sprite to execute a command or a script concurrently. This permits the realization of a remote version of the *compass* reporter that could be imagined as one robot sending a request to another robot through a wireless connection to receive the latter's orientation. This modified version of the custom block, called *rcompass*, takes one further parameter, the name of the sprite whose orientation is requested (*myself* corresponds to the calling sprite). Its realization follows.

```
   def (Sensing reporter, for all, report[direction])
rcompass [sprite=myself Text] (port=1 Number)
     if < < (sprite) = [myself] > or < (sprite) =
(attribute [name v]) > > // the calling sprite
       report (direction)
     else
       report (ask (object (sprite)) for {(rcompass
(sprite) (port))} )
     end
```

Curly brackets indicate the special procedure of inserting a Reporter-type input parameter that BYOB provides to delay the evaluation of the reporter to the moment the parameter will be used by the called function, *ask* in our case. This procedure is illustrated as a 'grey border' in the BYOB documentation. *ask* is a library block that shortens the remote call of another sprite and it is defined as follows:

```
   def (Control reporter, for all, report[something])
ask (object) for (message) (args...)
     report call ((message) of (object)) [with input
list] (args)
```

With these definitions, the two calls executed by *Sprite1*:

rcompass [myself] (1)

rcompass [Sprite2] (3)

report respectively the orientation of *Sprite1* and of *Sprite2*, provided the compass sensor is respectively 'connected' to port 1 for *Sprite1* and 3 for *Sprite2*.

The second example is the simulation of a **GPS** sensor: such a device usually returns the current absolute position of the robot. In BYOB a sprite's position is represented by a couple of Cartesian coordinates: a sprite can ask its own position calling separately the two reporters *x position* and *y position*. We define a new *gps* custom reporter which returns the two coordinates of the calling sprite in one single list of two elements, orderly *x* and *y*.

```
   def (Sensing reporter, for all, report[position
list]) gps (port=1 Number)
     if < (item (port) of [ports v]) = [gps] > //check
port
       report (list (x position) (y position))
     else
       report (list [Error!])
```

Also in this case you can easily define a remote version *rgps* with the additional sprite parameter. With this variant a *Sprite1* can smoothly reach the position of *Sprite2*, with a gps sensor on port 2, for example with the following piece of script code:

```
    set [gpsval v] to (rgps[Sprite2] (2))
    glide (1) secs to x: (item (1 v) of (gpsval)) y:
(item (2 v) of (gpsval))
```

If you define this sequence as a private custom block *reach* of *Sprite2*, *Sprite1* can force *Sprite2* to concurrently reach it with the command:

```
launch ([reach v] of [Sprite2 v])
```

Take notice that, in order to save space, in the following examples we will omit to include again the port check.

If in the definition of the *compass* block you substitute *direction* with the basic *loudness* reporter, you obtain a **Sound** sensor: the so defined *sound* custom block reports a sound level between 0 and 100 as measured on the PC sound input (the microphone or whatever selected as input source).

Instead of using the PC sound system, a sound function can also be simulated imagining the robot-sprite provided with a device able to measure a sound level and the scenario includes just one sound source represented by a sprite of known name, namely 'bell'. Imagining a punctual source, we are interesting in a theoretical 2D circular sound diffusion. The sound pressure level at distance *d* from the source is given in decibels by:

$Lp = Lw - 20 \cdot \log_{10} d - 11$

$Lw = 10 \cdot \log_{10} (W/W_0)$

where *Lw* is the acoustic (constant) power level of the source that is emitting the sound with power *W*, and W_0 is the minimum audible power, conventionally set at 10^{-12} W(att). Now assuming a certain value for *Lw* and evaluating the current distance from the robot-sprite and the source, you can realize a *mic* custom block reporting the virtually measured dBs.

```
  def (Sensing reporter, for all, report[sound level
dB]) mic (port=1 Number)
    report (((LSource)  - ((20)*([log v] of ( (distance
to [bell v]) / (Scale) ))) ) - (11))
```

LSource represents the source power and *Scale* is an accessory scale factor.

The next example is slightly more elaborated but it refers again to a basic sensing function, the touching predicate of one color with respect to another color. For this example imagine a rectangular robot provided with two colored small rectangular probes on its front, one red and one blue. Imagine also that on the stage some circular orange 'objects' of different radiuses are drawn (Fig. 1). Unfortunately neither Scratch nor BYOB allow to use a color code for this touching feature. Therefore we define a **Bumper** sensor for every type of probe, one for blue and one for red: in the block definition you must use the GUI to set the pertinent colors. Nonetheless we use color codes in our scripting language to describe the block implementation, as taken from the BYOB color palette.

```
  def (Sensing reporter, for all, report[pressed or
bumped]) bumperblue (port=1 Number) (type=pressed Text)
     if < color [#0042FF] is touching [#FF9500] ? >  //
blue touching orange
       if < (type) = [pressed] >
         set [bub_state v] to <true>
         report <true>
       end
       if <(bub_state)> // bumped not complete
         report <false>
       end
       set [bub_state v] to <true> // bump started
       report <false>
     end
     else
       if < (type) = [pressed] >
         set [bub_state v] to <false> // not pressed
         report <false>
       end
       if <<not (bub_state)>>  // no bump
         report <false>
       end
       set [bub_state v] to <false>  // bump complete
       report <true>
     end
```

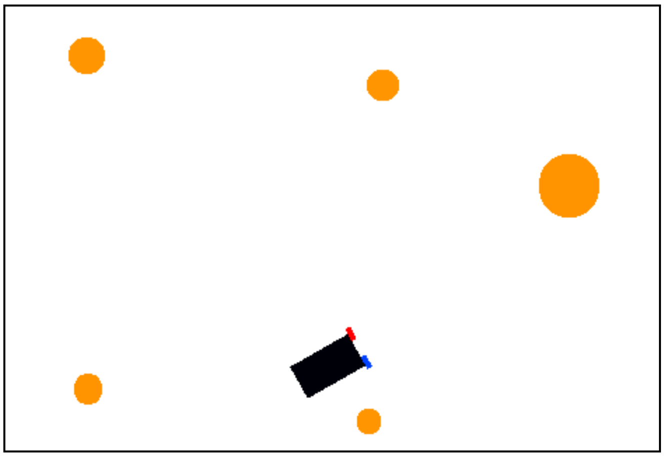


Fig. 1 Bumpers as colored probes

You can choose between two types of sensing: *pressed* and *bumped*. The second has memory and returns true when a transition between pressed and not pressed is sensed. A similar *bumperred* custom block can be defined substituting the touching color code with [#FF0000].

You can also define a similar *key* custom block substituting the first *if* instruction with:

if < key [k v] pressed? >

This block may be used to signal the robot with a user's action represented by typing the *k* key on the keyboard.

Here an example that makes the robot avoid the orange obstacles and turn when the *k* key is bumped:

```
  when green flag clicked
    config
    forever
      if < (bumperred (1) [pressed]) >
        rtglide (-30) steps in (0.5) s
        turn left (60) degrees
      end
      if < (bumperblue (2) [pressed]) >
```

```
      rtglide (-30) steps in (0.5) s
      turn right (60) degrees
    end
    if < (key (3) [pressed]) >
      turn right (90) degrees
    end
    move (5) steps
    if on edge, bounce
  end
```

The *config* block sets port 1 connected to the red bumper, port 2 to the blue one, port 3 to the *k* ‘key sensor’, and initializes all the sensors’ state variables. *rtglide* is a auxiliary custom block, a relative-motion alternative to the basic *glide* command: *rtglide* accepts a relative steps parameter instead of an absolute value. We propose also a *rvglide* variant accepting a speed parameter in place of the duration parameter. Their implementations follow.

```
   def (Motion command, for all) rtglide (dist=1 Number)
steps in (time=1 Number) secs
     glide (time) secs to x: ((x position) + ((dist) *
([cos v] of (90 - (direction))) ))
       y: ((y position) + ((dist) * ([sin v] of (90 -
(direction))) ))

   def (Motion command, for all) rvglide (dist=1 Number)
steps in (speed=1 Number) steps/secs
     glide ((dist) / (speed)) secs to x: ((x position) +
((dist) * ([cos v] of (90 - (direction))) ))
       y: ((y position) + ((dist) * ([sin v] of (90 -
(direction))) ))
```

Another demonstrative application is a black/white maze: the robot has a red probe on the left side and a blue prove on the front edge and the example applies the so called ‘left-hand’ algorithm establishing that the robot must continuously follow the left wall until it reaches the exit point (Fig. 2).

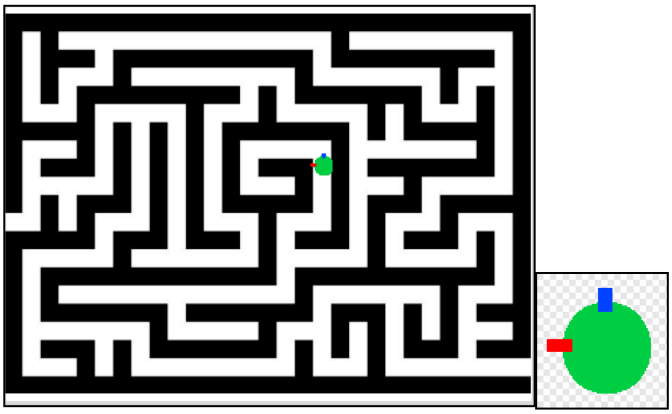


Fig. 2 a) The maze b) The ‘robot’

```
   forever
     if < (bumperblue (2) [pressed] >
       turn right (90) degrees
     else
       move (16.5) steps
       if < not (bumperred (1) [pressed]
         turn left (90) degrees
       end
     end
     if < (x position) > (224) >  // exit reached
       stop all
     end
   end
```

B. Light and color sensors

When you want to simulate a sensor which cannot be directly associated with one of the PC devices or which is not directly simulated by the BYOB environment, a very simple solution is to represent the sensor value with a variable which is changed as effect of some user’s actions (e.g. typing some keys on the PC keyboard), and to provide a general read custom block. We adopt this approach to simulate an **Ambient Light** sensor, returning a light level between 0 and a configurable maximum value (*maxlight*). When you type the up/down arrows keys, you modify the value from that moment returned by the *lightlev* custom reporter. This modification is performed by two specific scripts fired by the user’s action, like an interrupt routine.

```
   def (Sensing reporter, for all, report[light level])
lightlev (port=1 Number)
     report (lightvar)

   when [up arrow v] key pressed
     if < (lightvar) < (maxlight) >
       change [lightvar v] by (1)
     end
   when [down arrow v] key pressed
     if < (lightvar) > [1] >
       change [lightvar v] by (-1)
     end
```

In the next example we provide the robot of the equivalent of a **Light** (grey level) sensor reporting a level in the range 0..100. This sensor can be used for example to recognize objects or markers on the ground or to realize a line follower. Imagine to equip your robot somewhere with a colored probe, for example a small red rectangle on the front edge, and to put some other sprites on the stage, each having a uniform color, that is with a specific, known grey level. Such a level must be initially set for every sprite, included the Stage, who has a uniform color, into a local *lightlev* variable. The *light* custom block reports the grey level of the sprite which is touched by the colored probe.

```
   def (Sensing reporter, for all, report[light level])
light (port=1 Number)
     script variables (i) (sp)
     set [i v] to [1]
     set [sp v] to (object [allSprites])  // list of
sprites
     repeat (length of (sp))
       if < < not <(item (i) of (sp)) = (object
[myself]) > > and < ask (item (i) of (sp)) for {(touching
color [#FF0000] ?)} > > // the calling sprite excluded
         report (ask (item (i) of (sp)) for {(lightlev)}
)
       end
       change [i v] by [1]
     end
     report (ask (object (Stage)) for {(lightlev)})  //
report the stage light level
```

An almost identical approach can be adopted to define a **Color** sensor: this time the *color* custom block reports the value of the touched sprite's *colorcode* variable that keeps the initially assigned color code string of the sprite.

C. Touch and Bump sensors

This kind of sensors, realized in a simplified version in section A, can be generalized exploiting the same enumeration of sprites done in the realization of the *light* custom block. Now imagine to put one green probe and one orange probe on different position of the border of the robot-sprite. We propose three custom blocks, *touch*, *bumpergreen*, *bumperorange* whose meaning is similar to the blocks of section A.

The **Touch** sensor, represented by the *touch* custom block, exploits another one of the touching basic sensing reporters: it returns true if the robot's border touches another sprite's border.

```
def (Sensing reporter, for all, report[touching condition]) touch (port=1 Number)
    script variables (i) (sp)
    set [i v] to [1]
    set [sp v] to (object [allSprites])
    repeat (length of (sp))
      if < < not <(item (i) of (sp)) = (object [myself]) > > and < touching (item (i) of (sp)) ?  > >
        report <true>
      end
      change [i v] by [1]
    end
    report <false>
```

bumpergreen and *bumperorange* can be realized with the structure of the preceding *bumperblue* and *bumperred* blocks but enumerating all the other sprites like in *touch* above, and storing in a state variable the touched sprite as an object instead of a simple Boolean value (the robot-sprite itself if not touching):

```
def (Sensing reporter, for all, report[pressed or bumped]) bumpergreen (port=1 Number) (type=pressed Text)
    script variables (i) (sp)
    set [i v] to [1]
    set [sp v] to (object [allSprites])
    repeat (length of (sp))
      if < < not <(item (i) of (sp)) = (object [myself]) > > and < ask (item (i) of (sp)) for {(touching color [#00FF52] ?)}  > >  // light green probe
  // change this color code to #FF9400 for bumperorange
        if < (type) = [pressed] >
          set [bug_state v] to (item (i) of (sp))
          report <true>
  . . .
      change [i v] by [1]
    end
    if < (type) = [pressed] >
      set [bug_state v] to (object [myself]) // not pressed
      report <false>
  . . .
```

D. Proximity and sonar sensors

So far we have taken advantage of several basic sensing reporters referring to sprites' position, orientation, color and, in one case (*touching <sprite>*), partly taking into account the actual border of the sprites' costumes. Unfortunately the 'physicality' of a sprite cannot be completely sensed by another sprite without some pre-knowledge of its shape and dimensions. Thus for a sake of simplicity, we assume that we have some 'obstacles' on the stage represented by sprites for which we know the minimum radius of a circle completely covering their costume: for this you can refer to the maximum of the two dimensions of the picture representing the costume. This radius is stored during a configuration phase in the local variable *orad*. We assume also that, for our sensing purposes, the border of the actual covering circle is also the border virtually limiting the obstacle: we will measure the distance robot-sprite/obstacle with respect to this virtual border. With these assumptions we propose the following *prox* custom block:

```
def (Sensing reporter, for all, report[minimum distance]) prox (port=1 Number)
    script variables (i) (sp) (min) (dist)
    set [i v] to [1]
    set [sp v] to (object [allSprites])  // list of sprites
    set [min v] to [1000]
    repeat (length of (sp))
      if < < not <(item (i) of (sp)) = (object [myself]) >
        set [dist v] (((distance to (item (i) of (sp))) - (((ask (item (i) of (sp)) for {(orad)}) * (ask (item (i) of (sp)) for {(attribute [size v])})) / 100)) - (sensoff))
        if < (dist) < (min) >
          set [min v] to (dist)  // update minimum
        end
      end
      change [i v] by [1]
    end
    report (min)  // return the minimum
```

The loop is repeated for every sprite and it evaluates the distance between the centres of the robot-sprite and the current sprite, minus the 'radius' of the sprite, for taking into account the area it occupies, and the relative distance of the simulated sensor on the robot-sprite with respect to its centre, kept in the *sensoroff* configuration variable. The minimum among these distances is regularly updated and finally returned by the reporter.

Consider now the following auxiliary custom block *vdir*:

```
def (Operators reporter, for all, report[vector direction]) vdir (x  Number) (y Number)
    if < (y) > [0] > // upper half of the plane
      report ([asin v] of ((x) / ([sqrt v] of ( ((x) * (x)) + ((y) * (y)) ) )) )
    else
      if < (x) < [0] > // left lower quadrant of the plane
        report ( [0] - ([acos v] of ((y) / ([sqrt v] of ( ((x) * (x)) + ((y) * (y)) ) ))) )
      else // right lower quadrant of the plane
        report ([acos v] of ((y) / ([sqrt v] of ( ((x) * (x)) + ((y) * (y)) ) )) )
      end
    end
```

This block returns the orientation of a (directed) vector whose components are the two parameters *x* and *y*.

Now, starting from the implementation of the *prox* block, if you select only the objects that are positioned within ±*semiview* degrees with respect to the robot-sprite axis (the one defining its direction), you obtain the value that could be returned by a **Sonar** sensor, oriented in the same direction of the sprite: in fact this type of sensor presents a limited angle of view like the abovementioned one. To implement this selection, it suffices to verify that the absolute value of the difference between the direction of the vector connecting the robot-sprite's and the obstacle's centres, and the direction of the robot-sprite itself is less than (*semiview*+1).

```
def (Sensing reporter, for all, report[minimum distance]) sonar (port=1 Number)
  script variables (i) (sp) (min) (dist) (dirr)
. . .
   if < < not <(item (i) of (sp)) = (object [myself]) >
     set [dirr v] to (vdir ( ([x position v] of (item (i) of (sp))) - (x position)) ( ([y position v] of (item (i) of (sp))) - (y position)) ) - (direction))
     if < ([abs v] of (dirr)) < ( (semiview) + [1]) >
       set [dist v] . . .
. . .
```

To show the use of this simulation of the so important contactless distance sensor, we briefly present an emulation of the ultrasonic system that a bat uses to identify the position of a possible prey. This emulation has been physically realized with an NXT robot and illustrated in [11]: in this realization we assumed to know the distance *a* between the two ultrasonic sensors that represent the bat's ears, alternatively used to measure the distance from each one of them and the 'prey'. It is rather simple to calculate the (signed) distance *x* of the prey with respect to the axis orthogonal to the segment joining the two sensors (considered as punctual sources). Say *d1* and *d2* the respective distances measured by the two sensors (Fig. 3) it holds:

$x = (d1^2 - d2^2) / (2 \cdot a)$

from which the distance of the prey with respect to the line joining the two sensors may be calculated as:

$y = \text{sqrt}\ (d2^2 - (x-a/2)^2)$

We used these relations to move the bat towards its prey, re-evaluating in a loop the two relative coordinates above.

```
forever
  set [d1 v] to (ask (object [ear1]) for {(sonar (1))} )
  set [d2 v] to (ask (object [ear2]) for {(sonar (1))} )
  set [x v] to ((((d1)*(d1)) - ((d2)*(d2))) / ((2)*(a)))
  set [y v] to ([sqrt v] of ( ((d2)*(d2)) - (((x) - ((a) / (2))) * ((x) - ((a) / (2))))) )
  if < (((x)*(x))+((y)*(y))) < (threshold) >
    stop all
  end
  glide (0.5) secs to x: ((xposition) + ((x) / (3))) y: ((yposition) + ((y) / (3)))
end
```

ear1 and *ear2* are the names of two little sprites, representing the bat's ears, 'anchored' to the bat at a distance *a* one another. *threshold* is a suitable value equal to the square of the minimum distance bat-prey which has to be reached to stop the hunting.

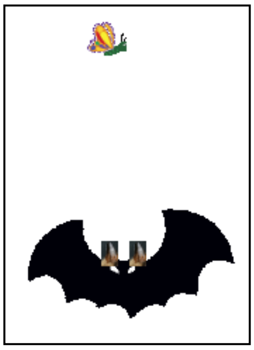


Fig. 3 The bat

E. A range scanner

This type of sensor is very powerful: it can report direction and distance of all the objects not 'hidden' by other objects in the whole arc of 360°. We can simulate this **Scanner** sensor combining the techniques presented so far. The *scan* custom block reports a list of two elements which are in turn two lists: the first one is the sequence of directions of the other sprites, the second one the sequence of their distances measured similarly as in the *prox* block. Directions and distances are evaluated with respect to the current position and direction of the robot-sprite. For simplicity, our simulation does not check whether one sprite could hide another sprite: *scan* reports measures for all the sprites different from the robot.

```
def (Sensing reporter, for all, report[the list of the lists of directions and distances]) scan (port=1 Number)
  script variables (i) (sp) (min) (dist) (dirr) (objDir) (objDist)
  set [i v] to [1]
  set [sp v] to (object [allSprites])  // list of sprites
  set [objDir v] to (list ()) // init with empty list
  set [objDist v] to (list ())
  repeat (length of (sp))
   if < < not <(item (i) of (sp)) = (object [myself]) >
     set [dirr v] to (vdir ( ([x position v] of (item (i) of (sp))) - (x position)) ( ([y position v] of (item (i) of (sp))) - (y position)) ) - (direction))
     set [dist v] (((distance to (item (i) of (sp))) - (((ask (item (i) of (sp)) for {(orad)}) * (ask (item (i) of (sp)) for {(attribute [size v])})) / 100)) - (sensoff))
     add (dirr) to (objDir)
     add (dist) to (objDist)
   end
   change [i v] by [1]
  end
  report (list (objDir) (objDist))
```

A demo program, which moves the robot subsequently towards the border of the various sprites around it, is the following (Fig. 4):

```
when green flag clicked
broadcast [config v] and wait
config
script variables (i) (ris)
point in direction [10 v]
set [ris v] to (scan (1))
set [i v] to (1)
repeat (length of (item (1 v) of (ris)))
  turn right (item (i) of (item (1 v) of (ris))) degrees
  rtglide (item (i) of (item (2 v) of (ris))) steps in (1) secs
  wait (1) secs
  rtglide ((0) - (item (i) of (item (2 v) of (ris)))) steps in (1) secs
  turn left (item (i) of (item (1 v) of (ris))) degrees
  change [i v] by [1]
end
```

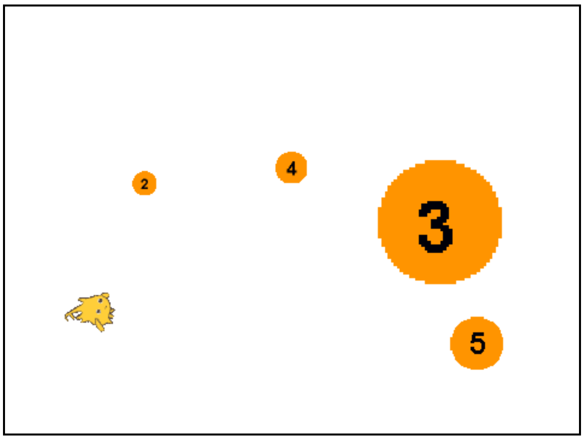


Fig. 4 The scan sensor

The *config* script is locally defined in every sprite to set the *orad* variable (see *prox* block above), apart from the robot-sprite which initialize this variable in its *config* block.

F. Acceleration and gyroscopic sensors

In this last example we simulate an **Accelerometer**, assuming for simplicity that the motion is on a horizontal straight line. Consider the following code:

```
when green flag clicked
config
go to x: (0) y: (0)
reset timer
broadcast [gosensor v]
forever
  go to x: ((200) * ([sin v] of ((angspeed) * (timer)))) y: (0)
  if < ([abs v] of (acc (1))) > [18] >
    change [color v] effect by (2)
  end
end
```

This code moves the sprite along a horizontal segment with a sinusoidal offset with respect to its medium (0, 0) point. The *angspeed* (angular speed, also called angular frequency) parameter is set in the *config* custom block to a reasonable value (for example 360/20 = 18 degrees/s, 20 s being the period). In the fragments when the evaluated acceleration is greater than 17, the sprite's costume changes color. These values are compatible with the following theoretical formulas:

$x(t) = A \cdot \sin_r(\omega_r \cdot t) = A \cdot \sin_g(\omega_g \cdot t)$

$v(t) = dx/dt = A \cdot \omega_r \cdot \cos_r(\omega_r \cdot t) =$

$= A \cdot \omega_g \cdot (\pi/180) \cdot \cos_g(\omega_g \cdot t)$

$a(t) = dv/dt = -A \cdot \omega_r^2 \cdot \sin_r(\omega_r \cdot t) =$

$= -A \cdot (\omega_g \cdot \pi/180)^2 \cdot \sin_g(\omega_g \cdot t)$

being ω_r and ω_g the angular frequency respectively in radians and degrees and $\sin/\cos_r$ and $\sin/\cos_g$ the sinusoidal functions with the parameter again in radians and degrees. Thus the maximum acceleration in absolute value is reached at the two extremes of the motion and it is given by:

$a_{max} = A \cdot (\omega_g \cdot \pi/180)^2 = 200 \cdot (18 \cdot \pi/180)^2 = 2 \cdot \pi^2 \cong 19.7.$

Now we imagine that the sensor is mounted over the robot-sprite so that it can measure the component of the acceleration parallel to the sprite's motion orientation. This example shows how to simulate a sensor through a separate concurrent thread that updates a common variable (*acc*) which can be reported to the main thread by the *acc* custom block. To preserve a sufficient precision the updating thread executes periodically on the basis of the internal timer, first calculating the speed *v* as the ratio *Δoffset/Δt* and then the ratio *Δv/Δt*.

```
when I receive [gosensor v]
script variables (pos) (newpos) (t) (newt) (vel) (newvel) (next)
set [pos v] to (x position) // starting position
set [vel v] to (0)  // starting speed
set [t v] to (timer)  // starting time
set [next v] to ((timer) + (0.5)) // next period
forever
  wait ((next)-(timer)) secs // wait next period
  set [newt v] to (timer)  // ending time
  set [newpos v] to (x position)  // ending position
  set [newvel v] to ( ((newpos) - (pos)) / ((newt) - (t)) )
  set [acc v] to ( ((newvel) - (vel)) / ((newt) - (t)) )
  set [t v] to (newt)  // update time
  set [pos v] to (newpos) // update position
  set [vel v] to (newvel) // update speed
  change [next v] by (0.5) // update next period
end
```

With a substantially similar approach we can also simulate a **Gyroscope**, a sensor that measures angular speed with respect to one of its axis. In our simulation we imagine that the sensor is mounted over the robot-sprite centre and therefore it must measure the turning speed of the sprite: that means that in the simulation you must read the sprite's direction through the homonymous reporter.

Obviously, due to scheduling of threads, angle resolution and other inaccuracies, the simulations in this sections have more a qualitative value than a quantitative one.

IV. Conclusions

The paper aspires to prove that a known and powerful environment like BYOB, through the realization of suited custom blocks and, in some cases, of supporting service scripts, can include several fundamental robotic sensors provided of a homogeneous interface, becoming a rather complete 2D robotic simulator. With little modifications to the adopted approach and code you could also easily add some uncertainty to the sensors' model in order to better reproduce a real environment.

Though testing in class will be conducted in future, we would emphasize that a student coming from previous experiences with Scratch, and possibly BYOB, can be smoothly leaded to challenging robotic experiences which anticipate the following work with real robots in real environments. We are convinced that this learning progression constitutes a valuable tool for promoting a deep consciousness of important facts regarding perception, algorithms, control theory, programming and technical aspects of robotics with a pleasant and rewarding approach. Moreover, this approach does not prevent from successively making students to work with real robots: Scratch already provides a general interface to connect its environment to external devices. For example this interface has been adapted in *Scratch for Arduino* (S4A) [12] to control an Arduino board. A little effort would be required to adapt the API here proposed to the S4A commands in order to support external real sensors.

V. References

[1] R. Siegwart, and R. Nourbakhsh, *Introduction to Autonomous Mobile Robots*, Cambridge, MA: MIT Press, 2004.

[2] J. Åkesson, U. Nordström, and H. Elmqvist, "Dymola and Modelica_EmbeddedSystems in Teaching – Experiences from a Project Course", in *Proc. 7th Modelica Conference*, Como, Italy, Sep. 20-22, 2009, pp. 603-611.

[3] D. M. Lofaro, T. T. Giang Le, P. Oh, "Mechatronics Education: From Paper Design to Product Prototype Using LEGO NXT Parts", in *Progress in Robotics, Communications in Computer and Information Science*, 2009, Volume 44, Part 3, 232-239, DOI: 10.1007/978-3-642-03986-7_27.

[4] (2012) The NXT-ROS wiki. [Online] Available: http://www.ros.org/wiki/nxt

[5] J. Arlegui, M. Moro, and A. Pina, "How to enhance the robotic experience with Scratch", accepted for: *Contructionism 2012: Theory, Practice and Impact Int. Conf.*, Athens, Greece, 2012.

[6] (2012) Scratch website. [Online] Available: http://scratch.mit.edu

[7] (2012) BYOB website. [Online] Available: http://byob.berkeley.edu

[8] R. E. Pattis, J. Roberts, and M. Stehlik, *Karel the Robot: A Gentle Introduction to the Art of Programming*, 2nd ed., John Wiley and Sons, Inc, New York, NY, 1995.

[9] M. Ben-Ari (2012) Software and Learning Materials for Computer Science Education. [Online] Available: http://www.weizmann.ac.il/sci-tea/benari/home/software.html

[10] (2012) Scratch's Block Plugin Syntax. [Online] Available: http:// scratch.mit.edu/wiki/Block_Plugin/Syntax

[11] M. Moro, E. Menegatti, F. Sella, M. Perona, *Imparare con la robotica: Applicazioni di problem solving*, Ed. Centro Studi Erickson, Trento, Italy, 2012 (in Italian).

[12] (2012) Scratch for Arduino (S4A) website. [Online] http://seaside.citilab.eu/scratch/arduino

Extending Mechanical Construction Kits to Incorporate Passive and Compliant Elements for Educational Robotics

Dorit Assaf
Artificial Intelligence Laboratory
Department of Informatics
University of Zurich
Zurich, Switzerland
Email: assaf@ifi.uzh.ch

Jørgen Christian Larsen
Modular Robotics Research Lab
The Maersk Mc-Kinney Moller Institute
University of Southern Denmark
Odense, Denmark
Email: jcla@mmmi.sdu.dk

Markus Reichardt
Reichardt Informatik AG
Höhenweg 22
Münchenstein, Switzerland
Email: markus@reichardt.ch

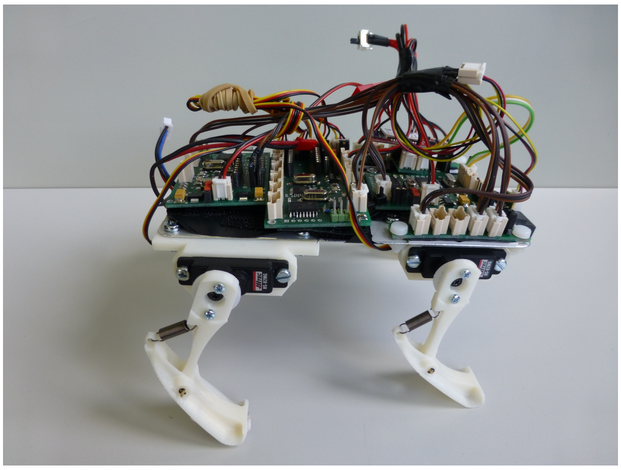


Fig. 1. A puppy robot used for educational purposes.

***Abstract*—Robots are a popular educational tool to introduce science, technology, and engineering to students. The field of educational robotics is growing and consequently a number of educational robot kits have been developed within the last decade. Our laboratories have a tradition of teaching embodied artificial intelligence and biomechanics to students with different backgrounds. The robots we use both for research and education are usually built incorporating compliant materials as well as passive dynamics. These kind of properties are often not available in classical robot kits or mechanical construction kits. In this paper we describe some of the robots we use for education. So far we built the robots using 3D printing technology which is convenient but too expensive for class use. Our aim is to find cheaper, commercially available solutions. After a short review on educational robot kits and mechanical construction kits we describe interface solutions between several kits. Further we show some solutions to incorporate compliant materials and passive dynamics to traditional mechanical construction kits by using cheap and widely available materials.**

I. Introduction

The notion of embodiment, which has formed the major research target of the Artificial Intelligence Laboratory (AILAB) over the last 15 years, has dramatic implications for our understanding of intelligence [1]. For example, behavior is not the result of brain processes only, but of a subtle interplay between brain, body (morphology and materials) and environment; an insight that contradicts the classical Cartesian position. According to the embodied artificial intelligence perspective, morphological and material characteristics of an organism can take over a large part of its functionality [2]. We use the term morphological computation to designate the fact that some of the control or computation can be taken over by the dynamic interaction derived from morphological properties (e.g. the passive forward swing of the leg in walking, the spring-like properties of the muscles, and the weight distribution) [3]. By taking morphological computation into account, an agent will be able to achieve not only faster, more robust, and more energy-efficient behavior, but also more situated exploration by the agent for the comprehensive understanding of the environment.

Our laboratories (AILAB, Modular Robotics Research Lab) have a tradition in teaching the principles of embodied intelligence to students with different backgrounds. For instance in the context of an informatics degree program for high school teachers, we (AILAB) conducted a LEGO NXT robot competition where solely the morphology was allowed to be changed in order to achieve faster locomotion [14]. The initial LEGO robot morphology has been inspired by a robot built by Rinderknecht et al. [5]. In a variety of other teaching activities we used robots that locomote using passive dynamics (Fig. 1), inspired by the quadruped robot of Iida et al. [4] as well as unusual robots inspired from both research and arts. We used for instance a smaller version of the RHex robot [6] (Fig. 2) and an actuated one of Theo Jansen's Strandbeest[1] (Fig. 3) for several robot workshops.

With the exception of the LEGO NXT robot competition example mentioned above we usually use our open toolkit "EmbedIT" for the robot control (electronics and software)[7].

[1] http://www.strandbeest.com/

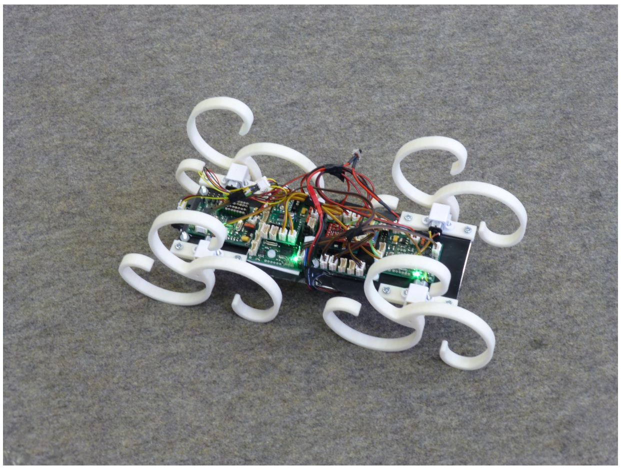


Fig. 2. A smaller version of the RHex robot used for educational purposes.

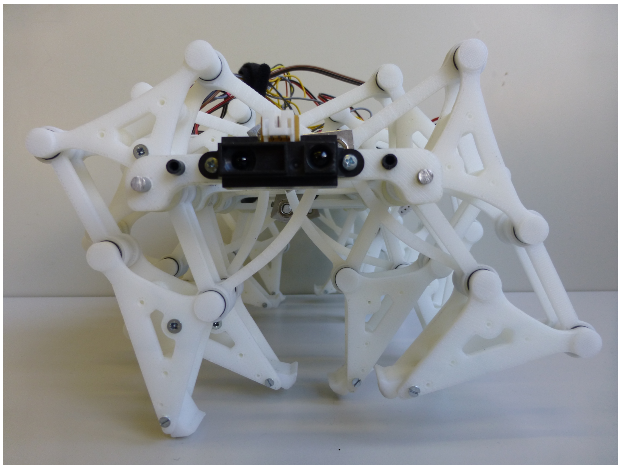


Fig. 3. An actuated version of Theo Jansen's Strandbeest used for educational purposes.

For the mechanical construction we custom built the robots in the past, using 3D printing technology (all the white plastic parts in Fig. 1,2,3). The possibility to 3D print the desired parts is convenient and fast. They are lightweight, high in precision such that generally no additional machining is necessary. The parts are further surprisingly stable, considering the strong impact forces that act especially on RHex's wheels and Puppy's legs. Even after several classes not a single 3D printed part had to be replaced (opposed to the motors which frequently broke due to jammed gears). However, 3D printing is still expensive, not particularly environmental friendly and not necessary if reasonable alternatives are available. Additionally, many institutions don't have 3D printing infrastructure, the required software licenses and knowledge to design parts using CAD. In trying to solve this, a trend is emerging towards low-cost personal fabrication solutions with projects such as RepRap[2], fab@home[3] or MakerBot[4]. However, if the robot parts are not too specific and complicated, a cheap off-the-shelf solution of mechanical construction components is still preferable, especially if they are made out of reusable, stable and lightweight material such as aluminum.

[2]http://reprap.org/wiki/RepRap
[3]http://www.fabathome.org/
[4]http://www.makerbot.com/

Building objects (cars, trucks, planes etc.) using mechanical construction kits had been very popular at the beginning of the last century. Brands such as "Meccano" are widely known in the generation born in the 1940's. These kind of playing activities are no longer popular with young people and thus traditional manufacturers such as Meccano, Märklin and Stokys suffered.

This paper describes our search for a low-cost solution to build robots with unusual shapes using compliant, passive dynamic elements for educational purposes. We give a short review on off-the-shelf robot kits and mechanical construction kits in order to identify their advantages and disadvantages. Since most of the classical mechanical construction kits do not support any interfaces to standard actuators we show some easy solutions how to overcome this constraint. We describe how to use common and cheap materials everyone can find at home or in a conventional do-it-yourself store to build unusual robots and without the need of 3D printing technology. We show some examples how to interface proprietary robot kits with other construction kits to achieve a greater construction flexibility. Further we introduce our robotic construction kit "LocoKit", which is currently under development [15]. This system is targeted towards legged robots, and promises to make it possible to build dynamically walking robots in a fast and easy way. The LocoKit is described more deeply in section V.

II. A Review on Robot Kits and Mechanical Construction Kits for Education

In the following section we list a number of robot platforms that are usually used for educational robotics and robot competitions. The list is far from complete, however, the robots mentioned are a good representation of what is usually used. This is followed by a short review on mechanical construction kits. Also here we give a broad overview of different kits using different materials and concepts how to connect the elements together.

From this short survey we select one or two example platforms and describe how to interface them with each other and how to extend them using other materials, which do not originally belong to the toolkit in order to build the robots we would like to use in class.

A. Robot Kits

Robots have been used in the last decade to introduce kids to science and technology [8],[9]. Class activities with robots range from kindergarten over secondary school to universities. A large number of robot competitions emerged such as the FIRST Lego League, Eurobot, RoboCupJunior, Botball or Robolympics, all with the aim to engage young people in these disciplines [10]. Consequently, many robot kits have been developed in research projects as well as in commercial

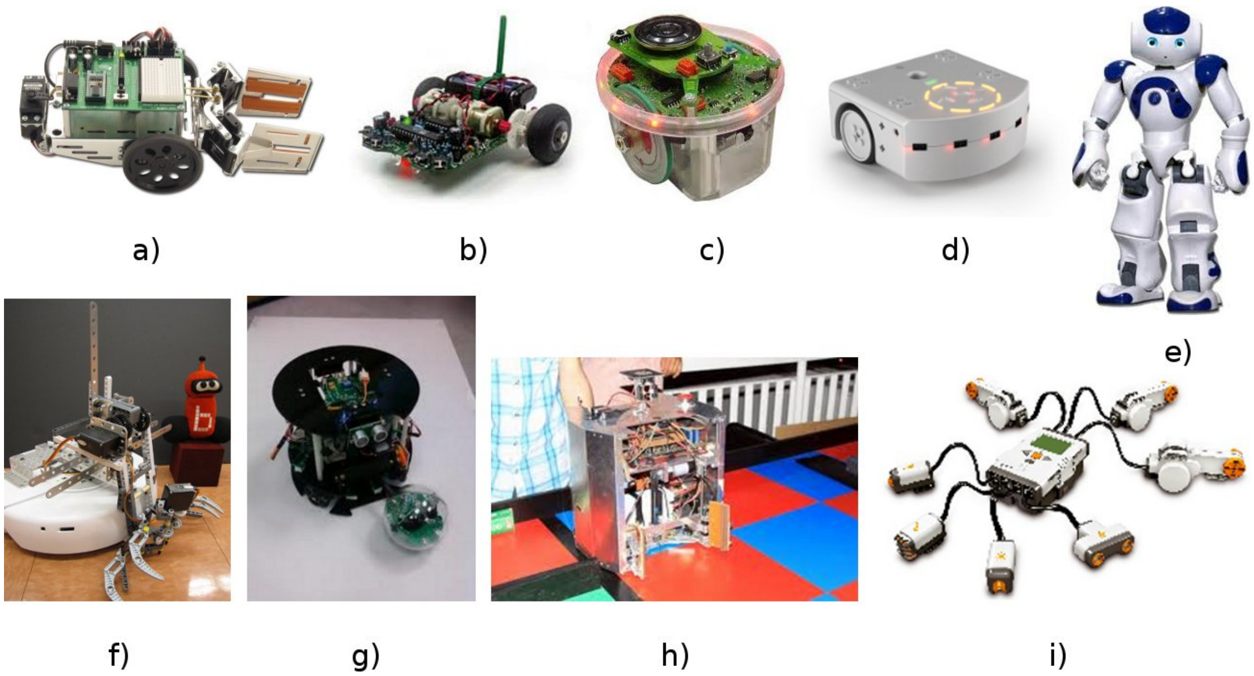


Fig. 4. A collection of robots used in education and competitions. a) boe-bot, b) Asuro, c) e-puck, d) ThymioII, e) Nao, f) Botball, g) a robot used in RoboCup, h) a robot used in Eurobot, i) LEGO NXT.

companies. A widely used robotic platform for educational robotics is the LEGO NXT[5] (Fig. 4i) [11],[12]. It provides actuators, a variety of sensors, building blocks as well as an easy-to-use graphical programming language. Additionally, the LEGO NXT platform can be programmed using high-level programming languages, such as JAVA. A low cost educational robotic platform is the Asuro[6] (Fig. 4b). By soldering all electronic components to the PCB the user has to assemble the robot from scratch. Asuro is designed to be a wheeled robot, thus the user has not much flexibility to modify the default shape. Many other educational robotic platforms use the popular Arduino[7] boards [13]. We also used a small custom made wheeled robot based on the Arduino board to teach robotics to secondary school teachers [14]. Other commercial robot platforms designed for educational purposes are E-puck[8](Fig. 4c), ThymioII[9](Fig. 4d), NAO[10](Fig. 4e).

The above list of robots used in educational robotics and robot competitions shows that the platforms are often fixed, wheeled and equipped with common sensors such as light, distance, touch etc. (Fig. 4a,b,c,d,f,g,h). The sensors and motors are usually connected to a central control unit. The user programs the controller of the robot on a PC using C/C++, Java or derived simplified programming languages and uploads the code to the robot. Besides Botball (Fig. 4f) which is a robot kit composed out of several different platforms, LEGO NXT (Fig. 4i) is the most open and flexible one regarding the shape of the robots that can be built.

[5]http://mindstorms.lego.com

[6]http://www.arexx.com/arexx.php?cmd=goto&cparam=p_asuro

[7]http://www.arduino.cc

[8]http://www.e-puck.org

[9]https://aseba.wikidot.com/en:thymio

[10]http://www.aldebaran-robotics.com

B. Mechanical Construction Kits

We use the term "mechanical construction kit" synonymously with "model construction kit". With these terms we refer to construction systems usually comprising re-usable elements such as strips, plates, angle girders, axles and gears with nuts and bolts to connect the pieces. The elements can be made out of plastic or metal, the connections can be screwed or sticked. We distinguish between "construction sets" and "construction kits". A construction set has a determined and fixed set of elements which can be assembled into one specific object (e.g. a truck) by following an assembly guide. On the contrary, a construction kit has a variety of different elements to enable the construction of any object possible within the constraints of the elements at hand and the imagination of the user.

The history of classical mechanical construction kits goes back to the beginning of the last century with Frank Hornby who invented and patented 1901 a new toy called "Mechanics Made Easy", also known as "Meccano". Since then a variety of similar products emerged such as Eitech, Märklin or Stokys, some compatible with the 0.5 inch (1.273 cm) spacing of Meccano. Basically all of the traditional manufacturers suffered lately from decreasing interest in these kind of toys and the takeover of other construction kits such as LEGO. From the traditional manufacturers that survived until today, many still do not support interfaces to standard actuators and sensors (some provide a limited selection of proprietary motors).

Table I lists a collection of mechanical construction kits from manufacturers from all over the world. A short descrip-

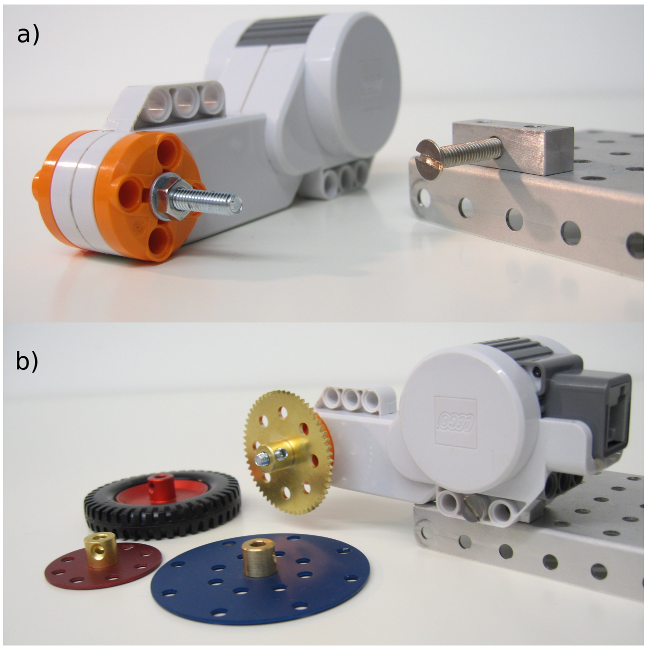


Fig. 5. a) A metric M4 screw is screwed in a LEGO motor in order to get a more stable motor shaft. A small customized block-shaped part designed to interface a LEGO motor (or sensor) with a mechanical construction kit (Stokys or Meccano). b) By means of the custom block-shaped part and the screw shaft a variety of Stokys elements can now be attached to the LEGO motor. Stokys uses standardized, metric hole sizes which increase flexibility to add other off-the-shelf components.

tion about each construction kit is given in the respective table column. Further, we list some advantages and disadvantages of each platform that will be taken into consideration for the later sections of this paper. Even though some of the platforms provide robot controllers, we focus here on the pure mechanical properties of a kit.

We took the following for us important criteria into consideration while evaluating the mechanical construction kits:

- **flexibility:** the construction of different robots should be possible, it should therefore not be a construction set.
- **compatibility**: the kit should preferably have industrial standards e.g. metric threads.
- **stability:** the assembled system should be stable, therefore preferably screwed connections. The parts should not wear out easily.
- **low-cost:** the product should have a reasonable price.
- **availability:** each single component of a kit should be individually available for purchase.

The list of mechanical construction kits in Table I shows that there is not a great variety of construction concepts. Eitech, Meccano and Stokys for instance are very similar (Eitech is compatible to Meccano's hole size whereas Stokys took over Meccano's hole spacing). This might be explained by the common period when the companies were founded. Also Mindstorms NXT and ROBO are very similar: the robot is basically built around the main controller unit. Lynxmotion differs the most, since it focuses mainly on building joints. This on the other hand constraints the possible shapes that can be realized. It can be said that generally an object is built around an initial base plate of different sizes (or around a controller unit). The components are sticked or screwed on that base plate. Basically all construction kits (except Makeblock) force the user to connect the attached components according to their fixed hole spacing grid, additionally they often provide very few varieties of angles (often 90° or 45°). None of the listed mechanical construction kits provide passive dynamic elements (except the spring in Lynxmotion) and unconventional, soft materials.

Based on the advantages and disadvantages shown in Table I, we decided to pick Stokys and LEGO as the two base construction kits for the extensions described in the following section. We took LEGO because it is widely used in educational robotics and Stokys because each part can be purchased individually and it uses metric hole sizes (this is more convenient when located in Europe and it's compatible with the LocoKit rod size). Nevertheless, the examples we show in the following sections can also be transferred to some of the other listed construction kits.

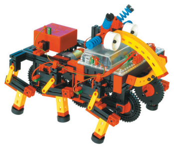
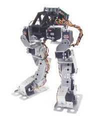
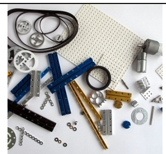
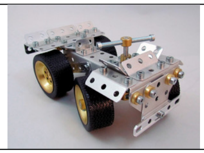
III. Interface Solutions Between Mechanical Construction Kits

There is no universal robot kit or mechanical construction kit that meets each user's particular need. Therefore, it makes more sense to combine different products to achieve more flexibility. Sometimes the LEGO NXT robotic components such as the controller and the motors are fine but the mechanical construction has to be more stable than plastic parts stuck together. Interfacing mechanical construction kits such as Meccano or Stokys could be a solution. On the other hand these traditional construction kits do not provide any interfaces to standard actuators in case the user would like to use DC motors or servo motors. The following sections show some simple solutions to these problems.

A. Solutions to Interface LEGO with Stokys

Everyone is familiar with LEGO blocks. The LEGO NXT kit provides a variety of bricks, connectors, wheels, rubber parts etc. Assemblies can be built and changed quickly and easily. However, since these parts are not screwed and the material is plastic they might not be precise enough or wear out too quickly for some applications. Fig. 5a presents an example where a metric M4 screw is screwed in a LEGO motor in order to get a more stable motor shaft. Despite the screw thread that is created within the motor due to this procedure, the original LEGO shaft can still be used (the star-shape hole remains). We had to produce a small customized part (little block mounted on a base part on the right side of Fig. 5a) in order to interface the LEGO motor with a mechanical construction kit (Stokys). By means of this custom metal part and the screw shaft a variety of Stokys components can now be attached to the LEGO motors, sensors and other LEGO components (Fig. 5b). Stokys uses standardized, metric hole dimensions which increase flexibility to add other off-the-shelf components.

TABLE I
A SELECTION OF MECHANICAL CONSTRUCTION KITS

Product	Picture	URL	Type	Advantages	Disadvantages
Lego (DK) **Mindstorms NXT**		mindstorms.lego.com	Comprehensive mechanical construction kit made out of plastic. Includes actuators, sensors, a control unit. Provides graphical and classical programming. Stick connectors.	Great flexibility, robustness of hardware and software, large variety of sensors, availability of individual parts, big community, variety of educational materials, general familiarity with LEGO blocks, 3rd-party add-ons, graphical programming and classical programming	Plastic parts wear out, sticked connections aren't stable enough for high impact applications (e.g. legged locomotion), proprietary mechanical interfaces (e.g. plugs, hole size), only 3 motor outputs and 4 sensor inputs per controller, big size and heavy weight (esp. controller).
Pitsco Education (USA) **Tetrix**		www.tetrixrobotics.com	Aluminum mechanical construction kit that includes structural material, actuators, gears, motor controllers and wheels. It provides interface solutions with LEGO Mindstorms NXT controller as well as LEGO blocks. Screwed connectors.	Great flexibility, availability of individual parts, robustness due to screwed connectors and aluminum material.	Imperial system (not metric), rather expensive, no soft or passive components.
Fischertechnik (GER) **ROBO**		www.fischertechnik.de	Plastic construction kit with actuators, sensors, and a controller. Graphical and classical programming. Sticked connectors.	Flexibility, easy assembly, a variety of sensors and unusual actuators, such as pneumatic motors	Plastic parts wear out and might not be stable enough for high impact applications, limited variety of construction parts, construction parts aren't usually sold individually, proprietary mechanical interfaces.
Lynxmotion (USA) **Lynxmotion**		www.lynxmotion.com	Mechanical construction kit made out of aluminum. Provides additionally actuators, sensors, grippers, springs, controllers, and a GUI. Screwed connectors.	Good quality material, stability, availability of individual parts, use of standard motors.	Imperial (not metric) system, rather expensive, very limited variety of components, no soft components.
Makeblock (CHN) **Makeblock**		makeblock.cc	New mechanical construction kit made out of aluminum. Compatible with industrial standards. Screwed connectors.	Stability, originality due to flexible screw positioning and adjustable components, provides interfaces to standard actuators, interfaces with Arduino, relatively cheap price.	No passive or soft components, product is still new and under development.
Eitech (GER) **Eitech construction**		www.eitech.de	Mechanical construction kit made out of steel. Provides additionally DC motors, gears, wheels, solar panels. Screwed connectors. Metric hole spacing (1 cm).	Stability, variety of elements, unconventional power supply (solar panel), cheap price, compatible hole size with Meccano and Stokys.	Relatively heavy weight (steel), no passive or soft components, no standard actuator interfaces (only to proprietary motors), hole spacing incompatible with Meccano or Stokys.
Meccano (UK) **Meccano**		www.meccano.com	Traditional construction kit made out of steel. Provides DC motors, gears and wheels. Imperial system hole spacing (1.273 cm) and hole size (4.2 mm). Screwed connectors.	Stability, variety of elements, cheap price, generally known in Europe.	Relatively heavy weight (steel), no passive or soft components, no interfaces to standard actuators, components usually not sold individually.
Stokys (CH) **Stokys**		www.stokys.ch	Mechanical construction kit made out of aluminum. Provides additionally gears, wheels, DC motors. Imperial system hole spacing (1.273 cm) but metric hole size (4 mm). Screwed connectors.	Stability, availability of individual parts, compatibility with Meccano hole spacing and hole size (only 0.2 mm difference), variety of elements, light weight (aluminum).	No passive or soft components, no interface to standard actuators, relatively expensive (aluminum has its price).

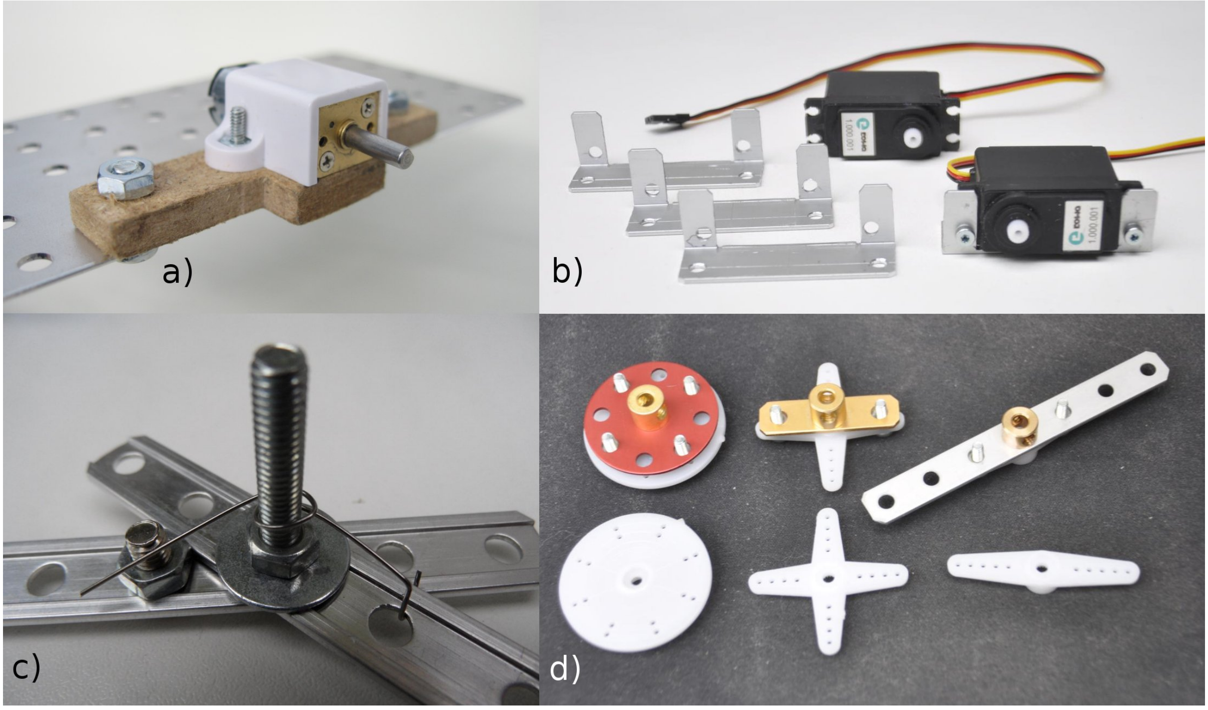


Fig. 6. A collection of different ways of creating interfaces between mechanical construction kits. a) Proprietary DC motor casing screwed onto a Stokys element by means of a custom made wooden connector part. b) A custom aluminum part designed for a servo motor to be screwed onto a Stokys or Meccano plate. c) A passive dynamic joint created with a piece of spring steel. d) Proprietary servo wheels screwed onto Stokys elements to enable a greater variety of possible servo wheel extensions.

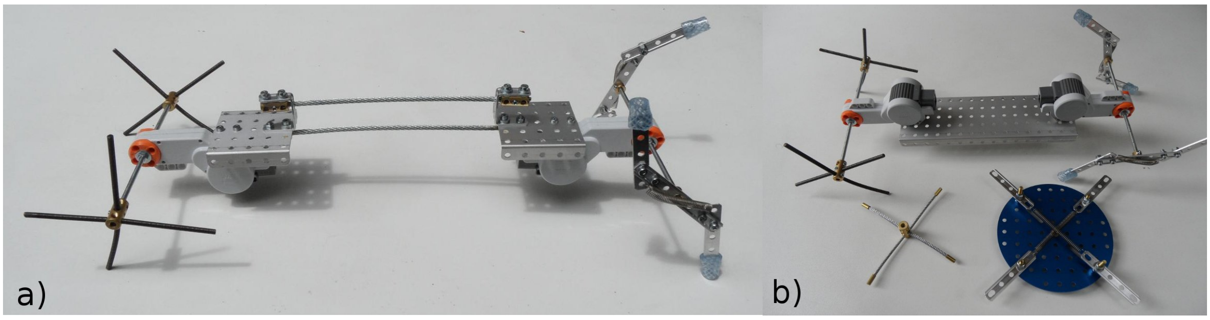


Fig. 7. Classical mechanical construction components have been extended with cheap, widely available material to create passive and flexible properties. a) A flexible spine can be created by using a piece of steel rope. b) A set of unconventional wheels made out of stings from speedometers, plastic tubes and steel ropes.

B. *Solutions to Interface Stokys with Actuators*

The casing of servo motors are not standardized and vary with each motor type. This is problematic since servo motors break easily when frequently used in a class environment. If the very same servo type is not available, often the replacement servo does not fit into the current setup. Fig. 6b shows a custom aluminum part designed for a servo motor to be screwed onto a Stokys or Meccano plate. Fig. 6a shows a proprietary DC motor casing screwed onto a Stokys element by means of a custom made wooden connector part. Fig. 6d shows proprietary servo wheels screwed onto Stokys elements to achieve a greater variety of possible servo wheel extensions.

The CAD files of all custom parts described in this paper are available on our website[11].

IV. Solutions to Extend Stokys with Passive Dynamic Materials

To build robots as in Fig. 1, 2 we need to incorporate passive dynamic materials. Structural elements that posses these kind of characteristics are usually not supported by robot kits or mechanical construction kits. Our goal was to achieve this with easy available materials, so we tried plastic tubes, spring steel, steel ropes, and strings from speedometers usually used in motorcycles. Fig. 6c demonstrates how a simple piece of spring steel wired around a joint can achieve passive dynamic properties. The stiffness can be varied easily.

The advantage of steel rope is that it is stable, flexible but

[11] http://www.embed-it.ch

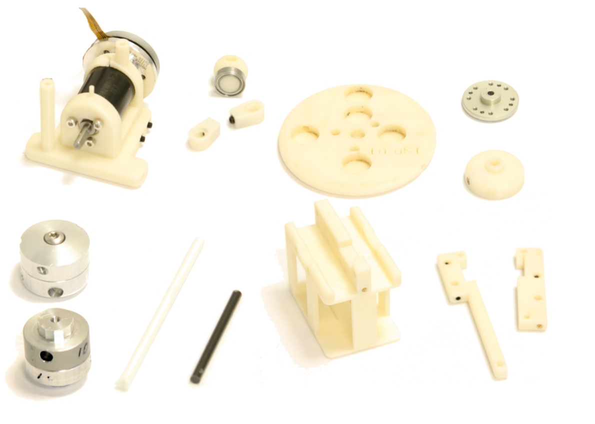


Fig. 9. A selection of the most important mechanical LocoKit parts.

not fully elastic. It suits perfectly to construct a flexible spine for walking robots, see Fig. 7a. Figure 7b shows a selection of unconventional wheels made out of strings from speedometers, plastic tubes and steel ropes. LEGO actuators are interfaced with Stokys or Meccano according to the interface description in Fig. 5.

Fig. 8 shows a Theo Jansen Strandbeest robot built with the Stokys construction kit. Even though it is a lot bigger and heavier than the 3D printed version in Fig. 3, it is nice to see that it is possible at all to build a robot like that using solely one mechanical construction kit.

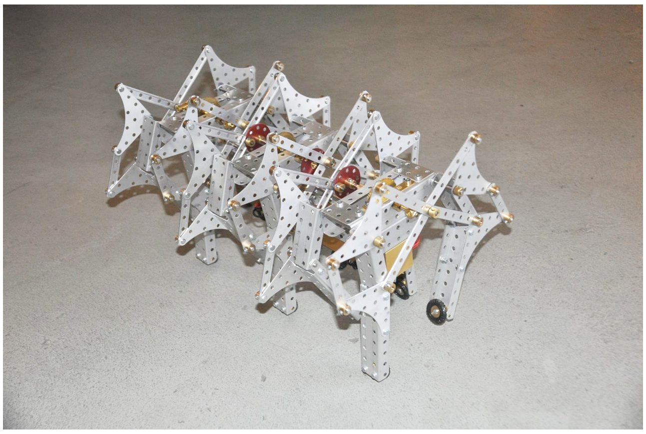


Fig. 8. An actuated version of Theo Jansen's Strandbeest built with Stokys construction kit. Image courtesy of Stokys Systeme AG.

V. New trends with the LocoKit Robotic Construction kit

The philosophy behind this system is embodiment and that the interplay between individual components of the system have to work together to form dynamic locomotion. Being a construction kit, it enables the user to make adjustments to the robot after it has been built. Opposed to other systems, LocoKit does not constrain the user to place components at fixed positions or to use determined sizes of structural elements. In the review section of this paper we saw that mechanical construction kits usually have a fixed grid size of 1 cm or more. LocoKit enables the user to adjust the position of a component within a range of a few millimeters. Hereby, the user can explore how changes of the morphology effects the performance of the system on a very fine scale. Examples of such changes could be body width, leg length, center of mass, angle of attack etc.

LocoKit distinguishes itself from the other construction kits mentioned earlier in this paper, by being the only one directly targeted to walking, running or jumping robots (Fig. 10). Also, by being designed with a focus on non-rigid elements, it gives the user the opportunity to build robots, where the body is not rigid but bendable. This feature is controversial because rigid systems are often preferred since they are easier to model and control. However, the aim of LocoKit is to be a system that supports the creating of model-free, bottom up robots with limited need for a mathematical model to describe the system beforehand.

Everything in the LocoKit system is designed such that it fits to a 4 mm rod (Fig. 9). For now, these rods are mainly composed of fiberglass or carbon fiber but could in theory be made of any material as long as it forms a 4 mm round rod. The reason for this design choice is that the user is more free to choose other materials, e.g. more soft, rigid, lighter or heavier ones. It also opens up the opportunity of making some parts of the structure stiff and other ones soft, depending on the kind of desired structure.

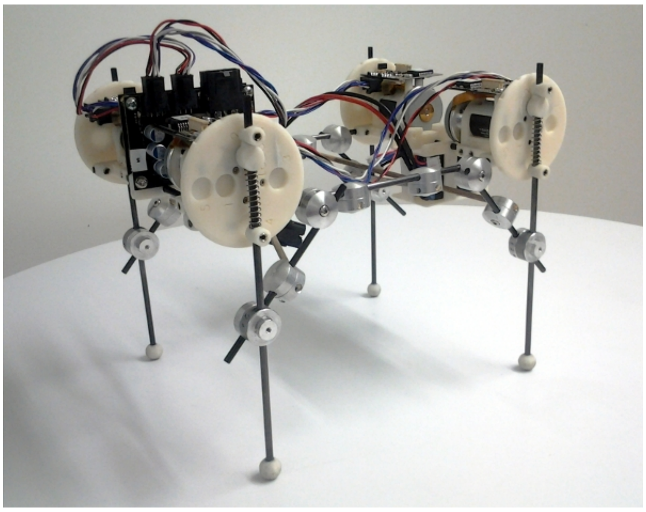


Fig. 10. A quadruped robot built with the LocoKit construction kit of Fig. 9. The used structural materials are all bendable, enabling the body to bend under its own weight. A more slip-like walking pattern is achieved due to the springs located in the upper part of the legs.

This system is still under development and therefore not yet commercially available. For more in dept information, see Larsen et al. [15].

VI. Conclusion

In this paper we described our need for unconventional robot morphologies for teaching embodied artificial intelligence and biologically inspired robotics. We described the robots we usually use in class which are custom built by means of expensive procedures such as 3D printing. Our aim is to replace the 3D printed parts using cheap, commercially available materials. After a short review on educational robot kits and mechanical construction kits we selected Stokys and LEGO as example kits. We described how common actuators can be interfaced with those proprietary toolkits by using easy custom made components. Further, we described examples on how to incorporate passive dynamic properties and compliant materials to those systems. In addition, we introduced the LocoKit, a new toolkit which is currently under development and which aims at providing those required properties for walking robots. Generally, we are pleased about the number of the toolkits available. However, we hope that in the future the manufacturers will go more towards open, standardized interfaces rather than proprietary hardware and software.

VII. Acknowledgements

This project was supported by the European FP7 project LOCOMORPH under the grant agreements No. 231688.

References

[1] Pfeifer, R., Bongard, J. *How the Body Shapes the Way We Think - A new View of Intelligence* MIT Press (2007) ISBN 978-0-262-16239-5

[2] Pfeifer, R., Lungarella, M., Iida, F. *Self-organization, embodiment, and biologically inspired robotics* Science 318, 1088-1093

[3] Pfeifer, R., Gomez, G. *Morphological computation - connecting brain, body, and environment* In B. Sendhoff, O. Sporns, E. Krner, H. Ritter, & K. Doya, K. (eds.), Creating Brain-like Intelligence: From Basic Principles to Complex Intelligent Systems (pp.66-83). Berlin: Springer.

[4] Iida, F., Gomez, G., Pfeifer, R. *Exploiting body dynamics for controlling a running quadruped robot* In proceedings of the 12th International Conference on Advanced Robotics, ICAR (2005)

[5] Rinderknecht, M., Ruesch, J., Hadorn, M. *The Lagging Legs Exploiting Body Dynamics to Steer a Quadrupedal Agent* In proceedings ot the International Conference on Morphological Computation (ICMC), Venice, Italy, March 2007

[6] Saranli, U., Buehler, M., Koditschek, D. E., *RHex: A simple and highly mobile hexapod robot* International Journal of Robotics Research, vol. 20, no. 7, pp. 616631, 2001.

[7] Assaf, D., Pfeifer, R. *EmbedIT – An Open Robotic Kit for Education* Research and Education in Robotics – EUROBOT 2011, Communications in Computer and Information Science, Springer Volume 161, pp. 29-39, (2011)

[8] Alimisis, D., Moro, M., Arlegui, J., Frangou, S., Papanikolaou, K. *Robotics & Constructivism in Education: the TERECoP project*, In Proceedings of EuroLogo 2007, Bratislava, (2007)

[9] Bredenfeld, A., Leimbach, T. *The Roberta Initiative.* In Workshop Proceedings of Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR 2010), pp. 558-567, ISBN 978-3-00-032863-3

[10] Bredenfeld, A., Hofmann, A., Steinbauer, G. *Robotics in Education Initiatives in Europe Status, Shortcomings and Open Questions.* In Workshop Proceedings of Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR 2010), pp. 568-574, ISBN 978-3-00-032863-3

[11] Kabatova, M., Pekarova, J. *Lessons learnt with LEGO Mindstorms: from beginner to teaching robotics.* AT&P Journal Plus 2, Robotics in Education, pp. 51-56, ISSN 1336-5010, (2010)

[12] Menegatti, E., Moro, M. *Educational Robotics from high-school to Master of Science.* In Workshop Proceedings of Intl. Conf. on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR 2010), pp. 639-648, ISBN 978-3-00-032863-3

[13] Balogh, R. *Acrob – an Educational Robotic Platform.* AT&P Journal Plus 2, Robotics in Education, pp. 6-9, ISSN 1336-5010, (2010)

[14] Assaf, D., Pfeifer, R. *Robotics as Part of an Informatics Degree Program for Teachers.* In Proceedings of Society for Information Technology & Teacher Education International Conference 2011 (pp. 3128-3133). Chesapeake, VA: AACE. (2011)

[15] J. Larsen, D. Brandt, K. Stoy, *LocoKit: A Construction Kit for Developing Robot Morphologies*, in Proceedings of the 12th International Conference on Adaptive Behaviour (SAB2012)

Ketchup House – A Promising Robotic Contest

Richard Balogh
Slovak University of Technology in Bratislava
Faculty of Electrical Engineering and Information Technology
Bratislava, Slovakia
richard.balogh@stuba.sk

***Abstract*—In this paper we present a new category Ketchup house, for the international robotics contest Istrobot. The main task is to manipulate ketchup cans and move them to their appropriate positions. The contest had its first run on Istrobot 2012 in Bratislava and gained a well-deserved publicity. We describe origins and rules of this new category as well as results obtained in the first year.**

***Index Terms*—engineering education, mobile robots, robotic contest, Istrobot**

I. Introduction

There is no doubt that robotic contests are great tool to trick students into learning [1]. They are excellent opportunities to reinforce the relationship which math and science have on tangible real-world applications [2]. Competitions can also emulate real life engineering and product development [3]. Large amount of various robotics contests are held all over the world, from local contests supporting the AI or robotics classes at universities to large international multi-discipline events. An overview of robotic contests can be found e.g. in [4] or in [5].

At the Slovak University of Technology in Bratislava, we organize the robotic contest Istrobot since the year 2000. More than 10 years of competitions have given us some great experiences. We started with classic Linefollower category, later the MicroMouse and MiniSumo categories were included. Since the second year, we also have the Freestyle category which attracts the biggest interest of visitors. Unfortunately, it is very difficult to evaluate various types of constructions which vary from simple Lego robots to very complex robotic systems built from scratch. This is rather an exhibition of projects than real competition. Another category – MiniSumo, gains broad interest of visitors and participants since its introduction in 2005. Unfortunately, great expectations of organisers were not met. We assumed clever constructions, focused on various strategies and tactics. Instead, robots converged to one robust construction, participants spent a lot of money and time with embellishing their precise constructions, and most important – they took it too seriously and lost the fun.

Then we started to think about the new category, which would eventually replace the MiniSumo category. Our goal is to have such contest, where cheap, simple robot with brilliant idea can win over the technologically superior and hardware overloaded but dumb robot. Our attempt is to encourage people in *thinking*, not in spending money on additional processors. We tried to identify what makes the contest attractive and challenging both for participants and for visitors:

- Challenging and clear, easy to understand task.
- Clear, well defined environment. Robotic contest should be an example of well-defined engineering problem.
- Problem solution should not require expensive and complex hardware. Participants don't want to spend the time available on fundraising.
- Contest should not require expensive and complex environment and playground. Organizers also don't want to spend the available time on fundraising.
- Robots should be eventually re-usable for other contests.
- Contest should be Lego NXT friendly (regarding dimensions, number of required sensors etc.).
- Contest should involve an opponent robot. The second robot at the playground always brings random moments. As the goal is not to build only simple automatic machines but "intelligent" robots, the way how they cope with changing conditions is a good measure of their quality.

From the beginning, it was clear that we have to include at least two robots into the competition since it is the most attractive element for spectators, and it also brings new and random elements which the robot should be able to cope with.

We have been inspired by the classical computer game *Sokoban* (warehouse keeper – see Fig. 1). It is a transport puzzle, in which the player pushes boxes around in a warehouse, trying to get them to storage locations. The game was created in 1981 by Hiroyuki Imabayashi, and published in 1982 by *Thinking Rabbit*, a Japanese software house [6]. Realistic

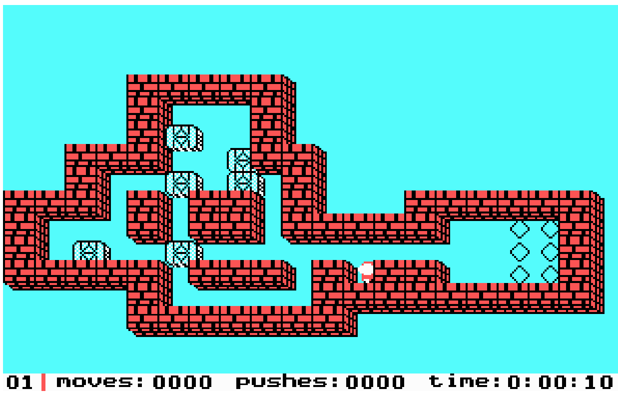


Fig. 1. Classic Sokoban game

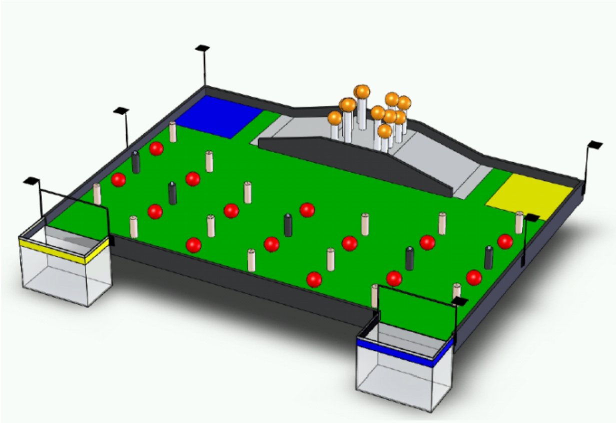


Fig. 2. Playing arena for the Eurobot 2010 contest [7].

implementation of this puzzle was used in AI course at the University in Odense during the year 2011. We analyzed the course constructions and they seem to be too complicated for amateurs; the task takes long time which is counterproductive for our type of the contest.

There are some similar contests, where the task is to collect some objects from the playground. Just to mention some, let us look at the Eurobot[1] contest in 2007 – Robot Recycling Rally. Robots collected cans, PET bottles and batteries. Their task was to sort them properly into the predefined locations. In 2010, the Eurobot contest topic was *Feed the world*. The robot which collected the most of fruits, vegetable and seeds became the winner [7] (see also a playground on Fig. 2). The matches involved two teams and they last 90 seconds. The playing elements were placed in different places on the table, either on the ground in predefined and random positions or in elevated positions. Collected elements had to be put in the containers in front of the table.

Eurobot contests are very succesfull, but we see the problem connected with this type of contest: a relatively complicated setup requiring large playfield with many additional features which make it more complicated both for organizers and for participants.

After many discussions we found a solution – competition slightly inspired by the Sokoban game, modified for two players. Navigation of the robot is simplified by the network of black lines taken from the Linefollower category. This contest is considered to be a follow-up for people already saturated with linefollowing robots, gives them an opportunity to reuse their hardware and add more complicated behaviour to their robots. The contest is also considered to replace the popular MiniSumo category. Name of the game – Ketchup House – came from the main task: to move the cans with ketchup[2] to their appropriate positions in the warehouse.

[1] http://www.eurobot.org/eng/archives.php

[2] To be precise, the can content is tomato puree, not the ketchup.

II. Ketchup House – Rules

A. Task

The task is to design and build an autonomous, microcontroller controlled mobile robot, which will move the ketchup cans into their stock. Two robots compete at the same time. The robot which faster and better fulfills its task wins.

B. Ketchup Can

The robot task is to move as much ketchup cans as possible to its home line.

Ketchup is stored in a steel tinned can with diameter 53 mm (± 1 mm) and height 74 mm (± 1 mm). The mass of the full can (with the content) is approximately 163 grams (± 5 g).

Fig. 3. Tomato puree in can. Available in regular groceries.

C. Stock

The stock is represented by the network of 5 horizontal and 5 vertical lines with the distance 30 cm (± 1cm). This dimension is sufficient also for the Lego Mindstorms robot constructions. Horizontal lines are numbered 1-5, vertical are labeled A-E. Lines are black, their width is 15 mm (± 1mm). Lines are meant as a navigational aid, it is not necessary to move along them.

There is a free area min. 30 cm around the stock from each side. Overall dimensions of the playing field is minimum 180 × 180 cm (i.e. 30 + 4x30 +30).

The base is horizontal and white. It is made of plastic, rubberized fibre, paper or similar material. When the base is not made of a single piece, then the connections shouldn't create steps larger than 1 mm. Slope changes shouldn't exceed 4 degrees.

At the start, robots are placed on intersections A3 and E3 (see Fig. 4). Vertical line A is a home line for the first robot, vertical line E is a home line for the second robot.

There are four cans in the game. At the beginning, two ketchups are at fixed positions C2 and C4. Other two cans will be placed at symmetric positions B2-D4, B3-D3 resp. B4-D2 which are chosen randomly before each run.

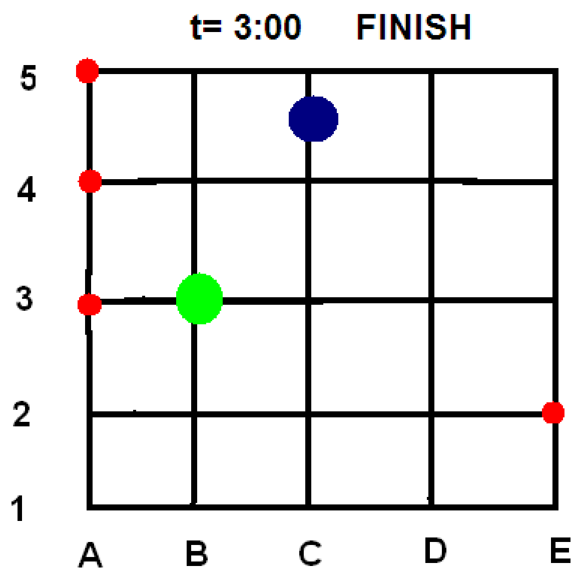


Fig. 5. Green robot wins – it has 3 cans at his home line, while the blue robot only 1. After the finish the robot can stop anywhere, not necessarily at his home line.

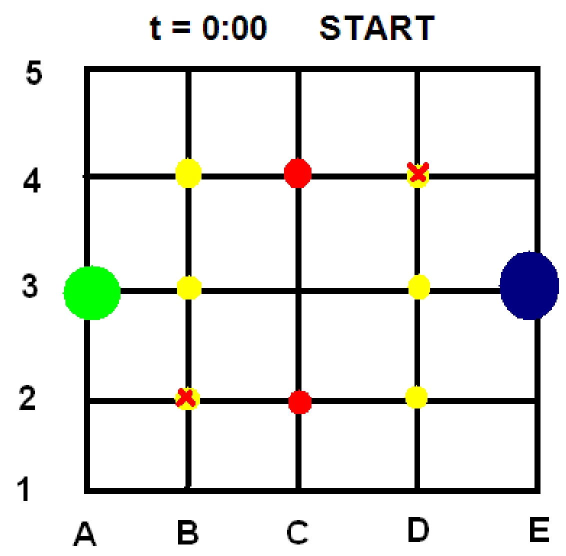


Fig. 4. Robots are at positions A3, E3. Two cans are always at C2 and C4. Other two are placed at two circles marked yellow, e.g. B2 and D4.

D. Robot – storeholder

Robot has to be autonomous. During the contest, no external influence is allowed.

The length and width of the robot have to be less than 30 cm. When the robot changes its dimensions during the contest, in any moment the dimensions can't exceed 30×30 cm. Height of the robot is not limited. Cans are not counted to the robot dimensions.

It is allowed to move also apart from lines, they are considered just as a means for navigation. During the movement, robots are not allowed to place any traces or markings. No part of the robot may stay on the base.

E. Activity of the robot

The basic task is to identify cans in the stock and to move them onto its home line. Is is allowed to move also the opponents cans. Damaging of the opponent robot is strictly forbidden.

Before the start, robots are placed at their initial positions. On the referee signal, they are activated by the team members who then immediately move back and no more interact with the robots. After the time limit, robots are immediately deactivated by their owners.

Cans may be moved using any technique (push, pull, roll,...). This is the difference comparing to the original Sokoban game, where only pushing is allowed. We considered it as a pointless limitation and we were really curious which types of movement will be really adapted. Also more than one can at the time can be moved. Robot may move in any direction, as the lines are meant just as a navigational aid.

After the time limit, the number of cans at each home line is evaluated. The can is scored when at least its small part touches the home line, not necessarily in the cross-section.

Number of cans at the home line represents score of the robot in the given lap. The contest will run in a round robin tournament. In the case of large amount of participants, the robots will be divided into the smaller groups.

Ketchups are counted after the finish. Until then, robots can steal away them from their positions.

F. Contest

Sequence of matches is determined randomly immediately before the contest. Throughout the contest, the algorithms, settings and components of the robot can be modified or configured differently for facing each opponent.

The robot must be ready within 1 minute after the call, otherwise its match is lost. Each match takes 3 minutes. If both contestants agree, the match can be stopped also sooner.

Winner of the tournament is the robot with the highest score. If during the tournament no points are scored, jury determines the winner consodering its overall success - e.g. how close the can was to the home line, whether the movement was coordinated or just random etc.

G. Results and users acceptance

Surprisingly, even the rules were published just 3 months before the competition, this category registered 12 robots and 11 of them really competed. This is not obvious for other, even mature, categories. During the contest we started with a qualification, where each robot has to show its ability to collect at least one can on the playground. Even though during the qualification more than half of robots didn't succeed, real matches were more succesfull. We split them into the two groups, based on results of the qualification, then performed round robin tournament. Six robots qualified for the finals and three of them were awarded as they gained the same amount of points – 9.

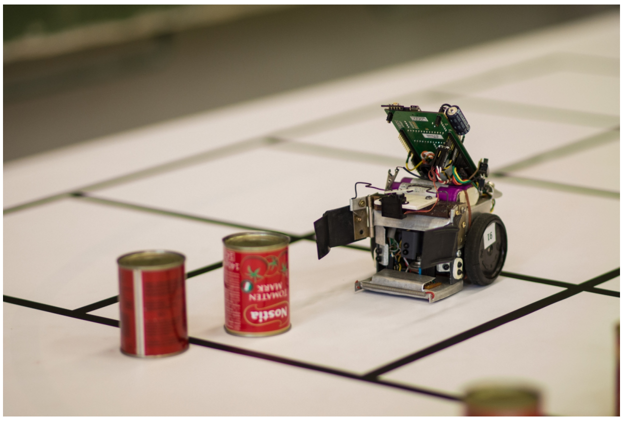


Fig. 7. Robot Missile ARM on Istrobot 2012 (author: Ján Hudec, photo: Andrej Lenčucha)

TABLE II
KETCHUP HOUSE 2012 RESULTS.

Place	Team	Veterobot	Frankie	Franta	ARMtank	PICtank	MissileARM	Score
1	Veterobot	–	2	0	2	3	2	**9**
1	Frankie	2	–	1	2	2	2	**9**
1	Franta	3	0	–	2	0	4	**9**
4	ARMtank	2	2	0	–	2	2	**8**
5	PICtank	0	1	1	1	–	2	**5**
6	MissileARM	0	0	0	1	0	–	**1**

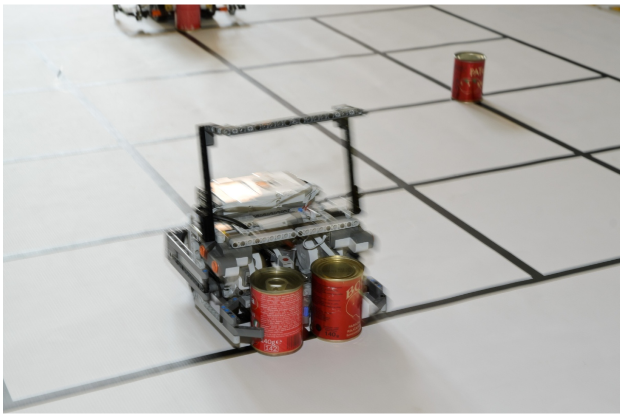


Fig. 6. Istrobot 2012 tournament (photo: Zoltán Janík)

TABLE I
LIST OF PARTICIPANTS

Team	Age	Kit?	Processor	Language	Score
Veterobot	14 – 42	Yes	NXT	NXT-G	9
ARMtank	14, 15	No	ARM	C	8
Frankie	14	Yes	NXT	NXC	6
PICtank	15, 15	No	PIC18F4550	picC	4
Franta	21, 22	Yes	ATmega328	Arduino	4
MissileARM	22	No	STM32 Arm	C	3
Omocha	32	Yes	NXT	NXC	1
Bobinator	16	No	ATmega16	C	0
Lugge	22, 27	No	STM32 Arm	C	0
Tomato LM1	13, 13	Yes	NXT	BrixCC	0
Tomato LM2	12	Yes	NXT	BrixCC	0

Only one robot was able to score full amount of 4 points (i.e. 4 cans collected). This robot – *Franta* [8][3] – was built around the Acrob [9] robot with an ATmega328 processor and one line sensor plus two additional for cross detection. For a better navigation a Hitachi HM55B compass sensor was used. For can detection, single Sharp distance sensor was used. The robot was programmed in Arduino language and environment.

We also caught some responses from visitors reflecting the motivational potential of this category:
Ketchup was great discipline and my students get motivated to learn programming... (Václav Králik)

Some others also declared an attempt to build a robot for the next year:
New category capture my attention. I assume to participate the next year... (Juraj Fojtík)

An overview of all participants with characteristics of teams (age) and their robots (kit or proprietary construction, processor and used programming language) is given in Tab. I. Last column contains number of points obtained in qualification, i.e. with no opponent robot at the playfield.

In table II, there are listed results of the final matches between six finalists. There were three teams with the same score, so we decided to award them all as the winners of the contest.

[3]see video at http://youtu.be/rqoO1gnbeUE

III. POSSIBLE DEVELOPMENT

Our new contest is also a good example of a contest which can develop over the years. It is probably too soon to change the rules after the first, pilot year. But we can see some directions in which the contest can develop in the future. First, we can increase the size of the playground and the number of cans. Also we can change the shape of the warehouse. Instead of square it might be more complicated, L-shaped or T-shaped or even very complicated shape more resembling the original Sokoban game with pre-defined final positions of the cans. More complicated shapes will focus the effort on better navigation methods and algorithms.

Another possibility to make the competition more difficult is to use coloured cans placed at predefined final positions. This will focus on different sensors and data processing.

We can also allow the ”fight” of the robots for limited amount of cans and thus the contest shift to resemble the MiniSumo contest, but this is not in the line with our ideas of development.

Another very promising possibility is to change the view of robots from competitors to co-operators. We can evaluate how robot will cooperate with each of the ”opponents” on the common goal - to collect as much cans as possible. Robot obtaining best results with all robots will be awarded as ”the best cooperating robot”. We can also consider the possibility to open a communication link between the robots to support the cooperation between randomly chosen robots.

If we would like people to focus on mechanics and construction of robots, we can introduce additional ”floors”, so cans should be manipulated in 3D and stored, for instance, to an elevated ramp.

IV. Conclusion

After the first year of this competition we consider the idea to be successful. Relatively large amount of registered (and really participating) robots gives us a great chance that the next year it will be really interesting category. We plan to include the partial tasks from this competition into the Robotics course laboratory exercises to attract students of this course to do more than in syllabus. We await also more newcomers from secondary schools hoping they will also be attracted to study at our university later.

Advantage of this contest is relatively easy and cheap playground, low requirements on robots hardware and challenging task. When used in conjunction with robotics courses, it can focus students on the problems of navigation, sensing and precise motion control. Random elements resulting from the movements of the opponent robot increase demands on more intelligence built into the robots.

We would like to encourage other organizers to include this category into their robotic contests and festivals. We would be pleased to hear about experiences from such implementations.

Acknowledgment

Publication of this paper was supported through the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of Slovak Republic with the grant VEGA VG-0690-Jur-Sk1.

References

[1] F. Wyffels, K. Bruneel, P.-J. Kindermans, M. D'Haene, P. Woestyn, P. Bertels, and B. Schrauwen, "Robot competitions trick students into learning," in *Proceedings of 2nd International Conference on Robotics in Education (RiE 2011)*, R. Stelzer and K. Jafarmadar, Eds. InnoC - Austrian Society for Innovative Computer Sciences, 2011, pp. 47–52. Available online: http://www.innoc.at/fileadmin/user_upload/_temp_/RiE/Proceedings/17.pdf

[2] Z. Dodds, L. Greenwald, A. Howard, S. Tejada, and J. Weinberg, "Components, Curriculum and Community: Robots and Robotics in Undergraduate AI Education," *AI Magazine*, vol. 27, no. 1, pp. 11–22, Spring 2006 2006. Available online: http://www.aaai.org/ojs/index.php/aimagazine/article/view/1860

[3] M. S. Raghav, S. Jain, and S. K. Saha, "Robotic Competition Based Education in Engineering (RoC-BEE)," in *Proceedings of NCMSTA'08 Conference National Conference on Mechanism Science and Technology: from Theory to Application*. National Institute of Technology, Hamirpur, November 13-14 2008. Available online: http://web.iitd.ac.in/~saha/public_html-old/ncmst08man.pdf

[4] R. Balogh, "A survey of robotic competitions. I am a Robot – Competitor." *International Journal of Advanced Robotic Systems*, vol. 2, no. 2, pp. 144–160, 2005. Available online: http://intechweb.org/volume.php?issn=1729-8806&v=2&n=2

[5] P. Petrovič, "Ten years of creative robotics contests," in *Proceedings of the 5th ISSEP Conference*, 2011. Available online: http://dai.fmph.uniba.sk/~petrovic/pub/ISSEP2011_Petrovic.pdf

[6] Wikipedia, "Sokoban — wikipedia, the free encyclopedia," 2012. Available online: http://en.wikipedia.org/w/index.php?title=Sokoban&oldid=501716416

[7] "Eurobot 2010 – Feed the world. Rules," Planete Sciences, 2012. Available online: http://www.planete-sciences.org/robot/data/file/coupe/2010/E2010_rules_and_drawing_EN.pdf

[8] I. Lacík and F. Nagy, "Acrob minirobot Franta," FMFI UK Bratislava, Tech. Rep., 2012. Available online: http://virtuallab.kar.elf.stuba.sk/robowiki/images/e/ec/Franta-arduino.pdf

[9] R. Balogh, "Acrob - an educational robotic platform," *AT&P Journal Plus*, vol. 10, no. 2, pp. 6–9, 2010, ISSN 1336-5010. Available online: http://ap.urpi.fei.stuba.sk/balogh/pdf/10ATPplusAcrob.pdf

Development of a Firefighting Robot for Educational Competitions

Taiser T. T. Barros
Carlos Tannhauser Professional Education School
SENAI
Santa Cruz do Sul, Brazil
tttbarros@yahoo.com.br

Walter Fetter Lages
Electrical Engineering Department
Federal University of Rio Grande do Sul
Porto Alegre, Brazil
fetter@ece.ufrgs.br

***Abstract*—This work presents the design and assembling details of a robot developed to take part in an educational robotic competition. A control law based on Lyapunov theory was developed and implemented on a Programmable Logic Controller to control the robot.**

I. Introduction

Every two years the Brazilian institution *Serviço Nacional de Aprendizagem Industrial* (SENAI) — National Service of Industrial Apprenticeship — promotes the Knowledge Olympiad, a Professional Education Competition, where students can show their skills in specific areas (like mechatronics). The competition lasts for four days and in its course the students need to solve problems usually seen in real industrial environments. The performance of students is rated according to technical items that come from industry needs [1].

Industrial robotic is one area of the Knowledge Olympiad and includes theoretical and practical knowledge in many fields like mechanical, electric, electronic and pneumatic systems. It follows the format of other Robotic competitions like FIRST — For Inspiration and Recognition of Science and Technology — that aims to inspire young people to interest and participate in science and technology [2] and NRC — National Robotics Challenge — that is promoting educational robotics since 1986 in a competition that actually offers twelve robotics contests [3].

In the Industrial robotic area, competition teams are composed of three students that need to develop a mobile robot able to move in a field with or without obstacles, solving a proposed problem. The Knowledge Olympiad is a competition for students of SENAI mid-level technician courses, where they can share their knowledge and learn with other students. The teams are always renewed every two years and their components need to be less twenty one years old.

The competition has two stages: regional (on each state) and national. The champions from regional steps go to the national one, and champions from national competition can enjoy an international competition: The WorldSkills, that is a competition with more than 60 years and occurs every two years joining students — from 52 countries — that compete in skills of various areas testing themselves against demanding international standards [4].

On 2012 regional competition, the proposed problem demanded the robot to be able to identify and extinguish fire focuses. The competition was divided in four different modules, where the robot needed to search for candles (used as fire focus).

In the first module, the team needs to assembly the robot. Thereafter, the assembled robot is weighted and the team needs to show that the robot is able to move autonomously for one meter on the competition field. The second module is designed to test the capacity of the robot to move on the competition field and find the points of possible fire focuses using a sound signal to indicates when they are found.

In the third module, the robot needs to find the fire focuses again, but at this time they could be activated and the robot needs to signal this condition. And finally, in the fourth module, the tasks are equal to those in third module, but at this time the robot needs to climb up and down in two slopes located randomly on the competition field. At the end of the competition modules, all the points from each team are calculated and the winner is known.

Figure 1 shows the competition field that presents different lanes for the robot to move from an initial point (P0) to the fire focuses points (F1 and F2). The field lanes differs in lengths and angles and each team can choose the best path for their robot, considering items like path difficulty and the shortest time. Figure 2 shows the actual robot performing a competition step.

The remainder of this paper is as follows: Section II treats the robot structure, presenting the mechanical structure and the control architecture. Section III proposes a control law to be implemented in the Programmable Logic Controller (PLC), and section IV presents some simulation results.

II. Design of the Robot

Many technical concepts from different areas like mechanical, electric, electronic and pneumatic systems were used to project an build the robot. This allowed students team to exercise their technical knowledge, as idealized by the Knowledge Olympiad. This section briefly describes the robot.

Figure 3 shows the robot in a exploded view and figure 4 shows its 3D view. All robot parts were designed using the

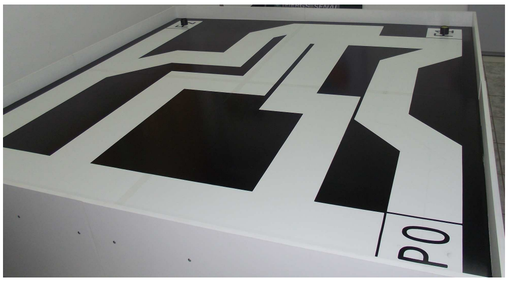


Fig. 1. Competition field.

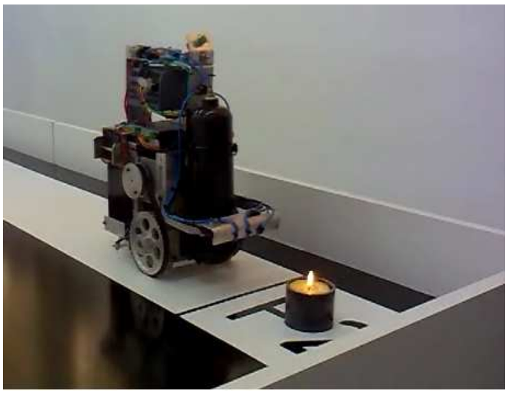


Fig. 2. Robot.

Solidworks CAD software. Basically, the robot structure can be described by referring the numbers seem on figure 3:

- Pneumatic components (1)
- Transmission components (2)
- Batteries (3)
- Flame detector sensor board (4)
- Step motors (5)
- Robot chassis (6)
- Robot controller (7)
- Drives (8)

A. Robot Mechanical Structure

1) Pneumatic components: Based on the tested methods, the best way to extinguish fire was by means of compressed air. This way, a pneumatic system was developed using a pneumatic reservoir (with pressure calibrated at 8 bar) and one pneumatic solenoid valve used to shoot air.

Every time the robot find a fire focus one air shot is released. The reservoir is sized to release at least twenty shots.

2) Transmission components: The transmission between step motors and robot wheels uses a couple of gears with 1:2 relation driven by a synchronized belt.

3) Batteries: Two sets of batteries (24V = 12V + 12V) are used to power the robot. One is connected to drives and motors, while the other one provides PLC power, thus avoiding noise problem due to current peak while starting the motors.

4) Flame detector sensor board: Two methods were tested to allow robot to detect fire focuses:

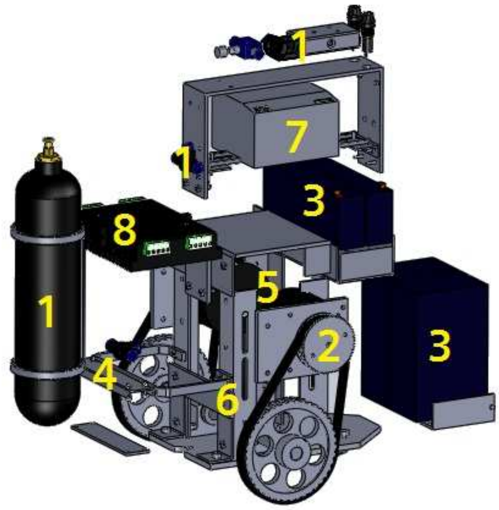


Fig. 3. Robot exploded 3D view.

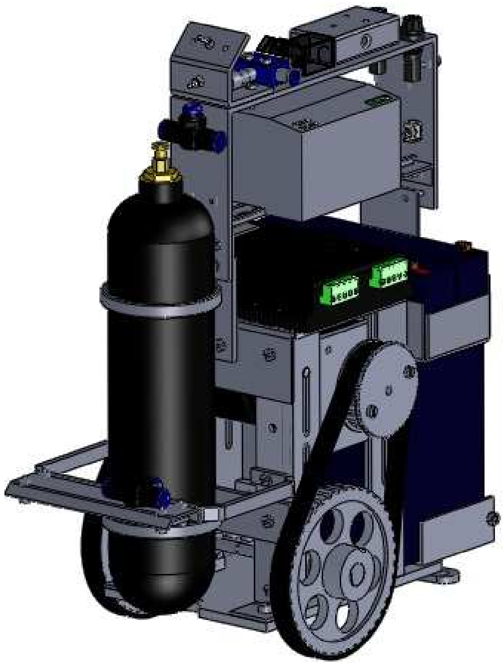


Fig. 4. Robot 3D view.

- Detecting temperature
- Infra-red Detection

The infra-red proved to be better, as its response was faster and more accurate than temperature detection. Infra-red sensor board development used basically some pairs of LED-photodetectors. Figure 5 shows the circuit board developed to integrate the sensors.

5) Step motors: The total mass allowed for the robots in competition is 25 Kg. Step motors were sized by compromising their weight against the torque needed to move the robot. In fact, the motors were oversized to avoid problems when moving the robot.

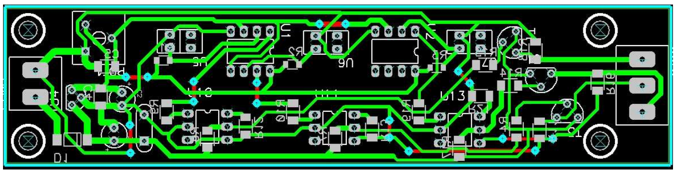


Fig. 5. Flame detector sensor board.

6) Robot chassis: The robot chassis was designed and milled by the students. Only components like belts, gears and bearings were purchased and used off-the-shelf. Figure 6 shows a piece designed to the robot chassis.

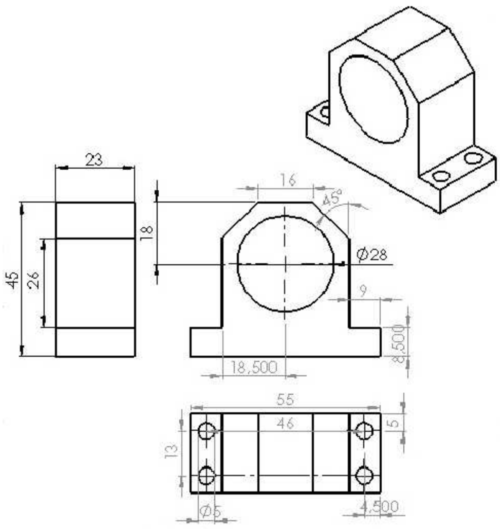


Fig. 6. A robot chassis piece.

B. Robot off-the-shelf Controller

1) PLC: To use industrial components, a PLC was chosen. A PLC is an equipment with many capabilities like network communication and complex calculation. It is possible to foresee that they will engage important place in the factory of the future [5]. The use of a PLC provided dependable hardware leaving the students free do develop the control software.

The PLC is a SIEMENS S7-1200 family CPU [6], specifically the CPU 1214C, that among other things, offers 2 PTO (Pulse Train Outputs) used to generate pulses to control the drives. The software was developed using the LADDER language. The PLC development environment is shown on figure 7.

2) Drives: The drives used in the robot actuate the step motors by using the micro step technique to increase stepping accuracy [7]. The drive model used allows up to 25600 steps per motor revolution.

III. Robot Control System

A. Robot Open Loop Guidance

The main idea used to guide the robot was based on the competition field design. On figure 1, three main points are shown: P0 - the start/end point, and F1-F2 (where the candles are placed).

For each competition module, the robot needed to start from P0, and verify if a fire focus was present at F1 or at F2 (it was possible to exist only at F1 or at F2, or moreover at F1 and at F2), returning to P0 after that. Then, the robot software was designed by following coordinate points.

One crucial point to get good results was the initial placement on the competition field, as the robot is guided by relative coordinates, the initial point always need to be the same, otherwise the robot would loose his position and do not return for P0.

This open loop guidance, served most the time during the competition, but one situation has proved that this control has particular week points like when the robot needed to rise up and go down from a ramp. While going down, the robot had a little sliding and switched its course. This way, the end point P0 was not reached.

The open loop guidance follows the idea from figure 8. The PLC calculates each point from the coordinate system, sends a PTO signal to the drives, which generate the number of pulses needed to drive the step motors. Besides, the PLC monitors the Flame Sensor Board to detect fire focuses, and if necessary actuates the pneumatic solenoid valve to extinguish flames.

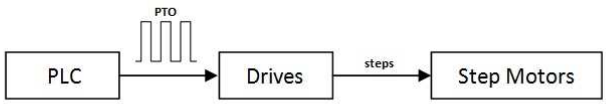


Fig. 8. Robot open loop guidance.

B. Robot Closed Loop Control

In order to improve the robot performance, a closed loop control system was developed (figure 9). To allow this new system in the robot, a pair of encoders will be used to sense the displacement of each wheel.

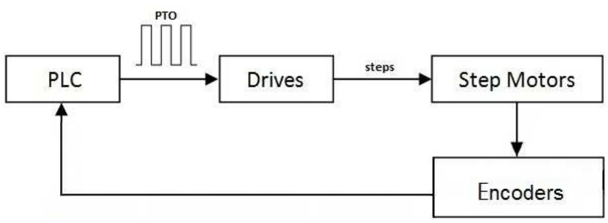


Fig. 9. Robot closed loop control.

1) Robot Mathematical Model: This work describes a differential drive wheeled mobile robot as that one depicted in figure 10. Its kinematic model [8] describes the robot position and orientation given linear and angular velocities:

$$\dot{x} = f(x,u) = \begin{bmatrix} \cos x_3 & 0 \\ \sin x_3 & 0 \\ 0 & 1 \end{bmatrix} u \qquad (1)$$

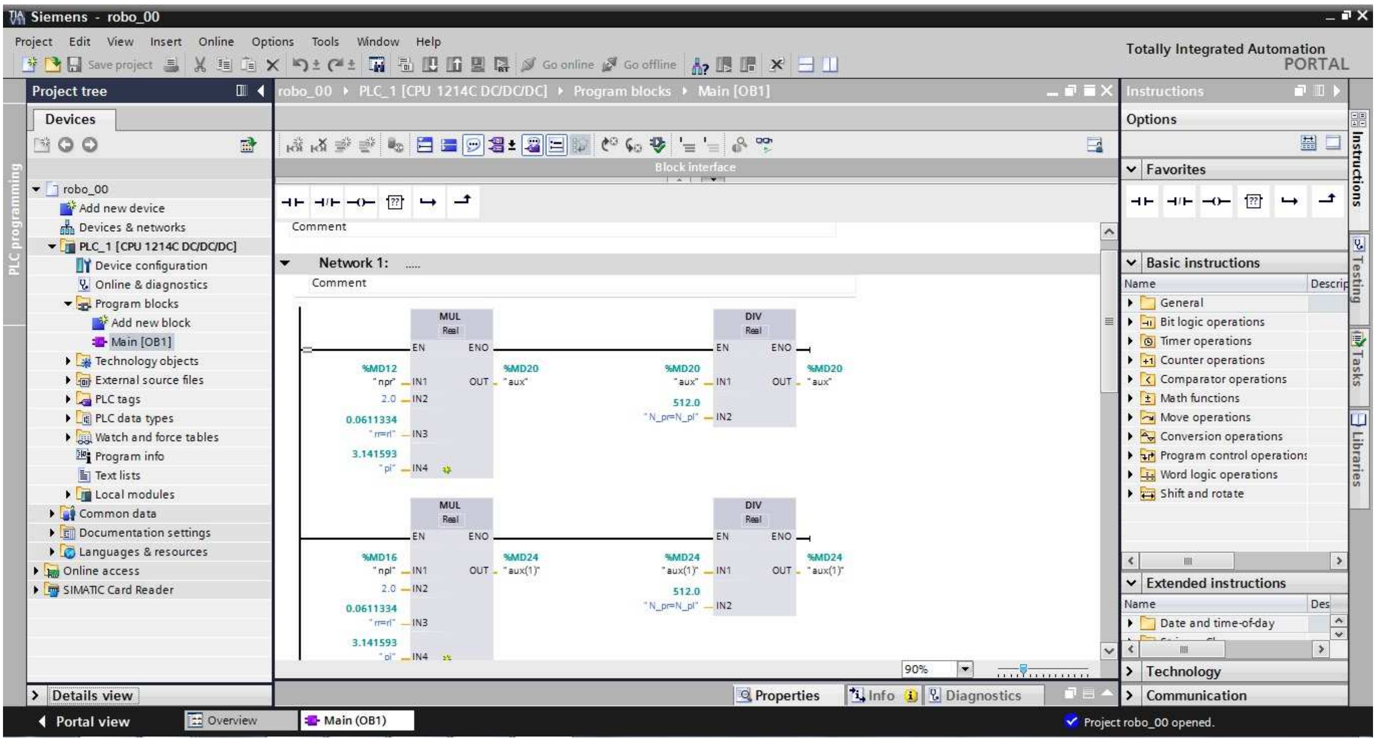


Fig. 7. PLC program development environment.

where $x = \begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix}^T$ is system state vector and $u = \begin{bmatrix} u_1 & u_2 \end{bmatrix}^T$ is the input vector. The state variables x_1 and x_2 are the plane coordinates, x_3 is the orientation angle, and the input variables u_1 and u_2 are the linear and angular speeds. Figure 10 shows the system coordinates, where X_{c_1} and X_{c_2} are the axes of the robot and X_1 and X_2 form the inertial coordinate system. Time dependency is omitted.

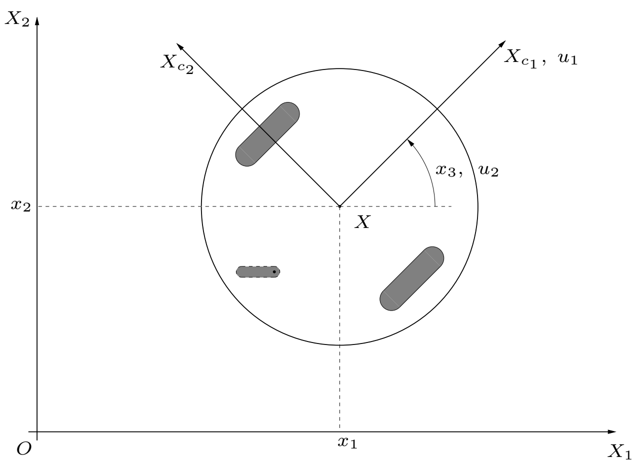


Fig. 10. Differential-drive mobile robot coordinates.

Differential-drive mobile robots are nonholonomic systems [9]. An important general statement on the control of nonholonomic systems has been made by Brockett [10], who has shown that it is not possible to asymptotically stabilize the system at an arbitrary point through a time-invariant, smooth state feedback law. In spite of it, the system is controllable [11].

Ways around Brockett's conditions for asymptotic stability are time-variant control [12], [13], [14], [15], non-smooth control [11], [16], [17] and hybrid control laws [18]. In this paper, we will obtain a set of possible input signals based on non-smooth control law which is obtained by a non-smooth coordinate transformation. A general way of designing control laws for nonholonomic systems through non-smooth coordinate transformations was presented by [11]. We have considered a mapping from the state space to the input space as presented by [8].

The mappings from the system state to the input space which are used for point stabilization are such that the state space origin is made asymptotically stable. If we represent the mapping as $g : \mathbf{X} \rightarrow \mathbf{U}$, $\mathbf{x} \in \mathbf{X}$ and $\mathbf{u} \in \mathbf{U}$, then the autonomous system

$$\dot{\mathbf{x}} = f\left(\mathbf{x}, g(\mathbf{x})\right) \tag{2}$$

where $f(\cdot, \cdot)$ is described by (1), is asymptotically stable at the origin. However, it is of interest to stabilize the robot at any point $\mathbf{x}_r$, which means any given position and orientation $\begin{bmatrix} x_{r_1} & x_{r_2} & x_{r_3} \end{bmatrix}^T$.This can be accomplished by the coordinate change $\bar{\mathbf{x}}(\mathbf{x}, \mathbf{x}_r)$, obtained by setting a new reference frame $X_{r_1} X_{r_2}$ at the reference position $\begin{bmatrix} x_{r_1} & x_{r_2} \end{bmatrix}^T$ with an angle x_{r_3}, according to figure 11. Thus, the coordinate change from $X_1 X_2$ to $X_{r_1} X_{r_2}$ consists of a translation and a rotation of angle x_{r_3}. It is readily verified that $\bar{x}_3 = x_3 - x_{r_3}$.

Therefore, the coordinate change $\bar{\mathbf{x}}(\cdot,\cdot)$ is obtained by the transformation

$$\bar{\mathbf{x}} = \begin{bmatrix} \mathbf{R}(x_{r_3}) & \mathbf{0} \\ \mathbf{0} & 1 \end{bmatrix} (\mathbf{x} - \mathbf{x}_r) \tag{3}$$

where $\mathbf{R}(x_{r_3})$ is a 2-D rotation matrix, that is,

$$\mathbf{R}(x_{r_3}) = \begin{bmatrix} \cos x_{r_3} & \sin x_{r_3} \\ -\sin x_{r_3} & \cos x_{r_3} \end{bmatrix}. \tag{4}$$

Hence, if the system $\dot{\bar{x}} = f(\bar{\mathbf{x}}, g(\bar{\mathbf{x}}))$ is stable at $\bar{\mathbf{x}} = \mathbf{0}$, then $\dot{\mathbf{x}} = f(\mathbf{x}, g(\mathbf{x}))$ is stable at $\mathbf{x} = \mathbf{0}$. Therefore, in order to stabilize the system at any arbitrary point $\mathbf{x}_r$ based on a control law g that leads the state to the origin, it suffices to use $g(\bar{\mathbf{x}})$.

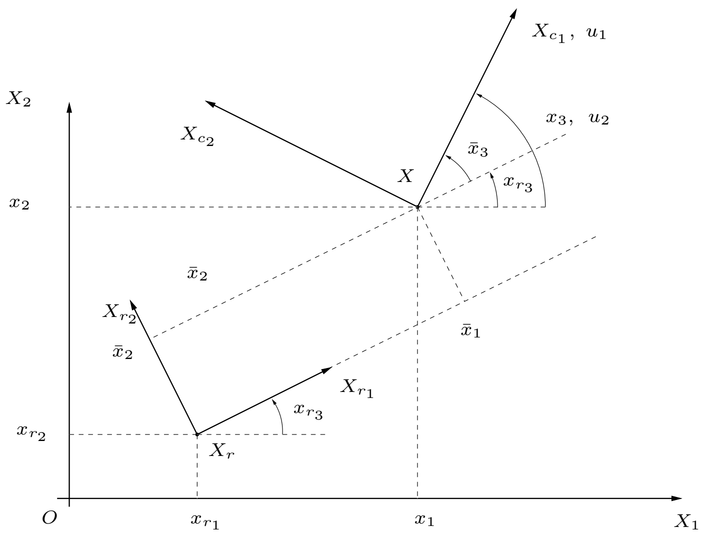


Fig. 11. Robot coordinates with respect to the reference frame.

By considering a coordinate change [8],

$$e = \sqrt{\bar{x}_1^2 + \bar{x}_2^2} \tag{5}$$

$$\psi = \operatorname{atan2}(\bar{x}_2, \bar{x}_1) \tag{6}$$

$$\alpha = \bar{x}_3 - \psi. \tag{7}$$

the system model (1) can be rewritten as

$$\begin{cases} \dot{e} = u_1 \cos\alpha \\ \dot{\psi} = u_1 \dfrac{\sin\alpha}{e} \\ \dot{\alpha} = -u_1 \dfrac{\sin\alpha}{e} + u_2. \end{cases} \tag{8}$$

Then, given a Lyapunov candidate function

$$V = \frac{1}{2}\lambda e^2 + \frac{1}{2}(\alpha^2 + h\psi^2), \tag{9}$$

it can be shown that the input signal $\mathbf{u}(k)$

$$u_1 = -\gamma_1 e \cos\alpha \tag{10}$$

$$u_2 = -\gamma_2\alpha - \gamma_1 \cos\alpha \frac{\sin\alpha}{\alpha}(\alpha - h\psi), \tag{11}$$

with h, γ_1, $\gamma_2 > 0$, makes (8) asymptotically stable [8]. We note that even though the model (8) is discontinuous at the origin, due to e in the denominator, the closed loop system is not. The term in the denominator is canceled in closed loop because (10) contains e as a factor.

Since u_1 and u_2 were calculated according to (10) and (11) the angular speed of right wheel (ω_r) and left wheel (ω_l) can be obtained by:

$$\omega_r = \frac{u_1 + u_2\frac{b}{2}}{r_r} \tag{12}$$

$$\omega_l = \frac{u_1 - u_2\frac{b}{2}}{r_l} \tag{13}$$

where b is the distance between wheels and r_r, r_l are the right and left wheel radii. Once the angular speed of each wheel is known, the number of control pulses that need to be sent to the drives to actuate the right (n_r) and left (n_l) wheels can be computed by:

$$n_r = \frac{\omega_r}{2\pi} N_r T \tag{14}$$

$$n_l = \frac{\omega_l}{2\pi} N_l T \tag{15}$$

where N_r, N_l are the number of pulses to generate one complete motor revolution and T is the sampling period.

The robot position can be estimated based on following odometry expressions:

$$x_c[k+1] = x_c[k] + \Delta D[k] \cos\left(\theta_c[k] + \frac{\Delta\theta[k]}{2}\right) \tag{16}$$

$$y_c[k+1] = y_c[k] + \Delta D[k] \sin\left(\theta_c[k] + \frac{\Delta\theta[k]}{2}\right) \tag{17}$$

$$\theta_c[k+1] = \theta_c[k] + \Delta\theta[k] \tag{18}$$

where ΔD is the robot linear displacement and $\Delta\theta$ is the robot angular displacement given by:

$$\Delta D[k] = \frac{\left(\frac{n_{pr}}{N_{pr}} 2\pi r_r + \frac{n_{pl}}{N_{pl}} 2\pi r_l\right)}{2} \tag{19}$$

$$\Delta\theta[k] = \frac{\left(\frac{n_{pr}}{N_{pr}} 2\pi r_r - \frac{n_{pl}}{N_{pl}} 2\pi r_l\right)}{b} \tag{20}$$

where n_{pr}, n_{pl} are the number of pulses read from encoders coupled to each wheel, and N_{pr}, N_{pl} the number of encoder pulses per revolution.

IV. Simulation Results

Two simulations were made using MATLAB to verify robot mathematical model behavior:

- Point Stabilization
- Path tracking

A. Point Stabilization

On this simulation it is possible to verify the robot behavior when moving from point $[0, 0, 0]^T$ to the reference point $[2, 2, \pi]^T$. Figure 12 shows the robot displacement on x axis, figure 13 on y axis, figure 14 the robot angle behavior while this displacement and figure 15 the robot displacement in Cartesian space, where it is possible to observe that the reference point was reached. The continuous line represents the system output simulated and points represent the estimated robot position.

Robot linear and angular speeds are depicted on figure 16 and figure 17 shows the simulated encoder reading pulses of right and left wheels.

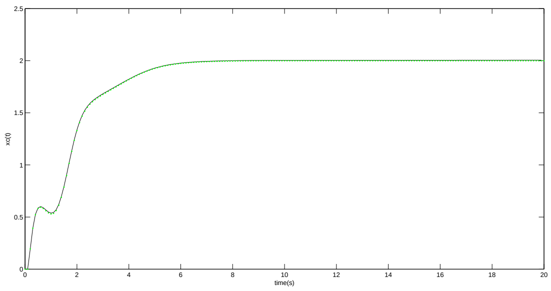


Fig. 12. $x_c \times time$ (line) and $x_c estimated \times time$ (dots).

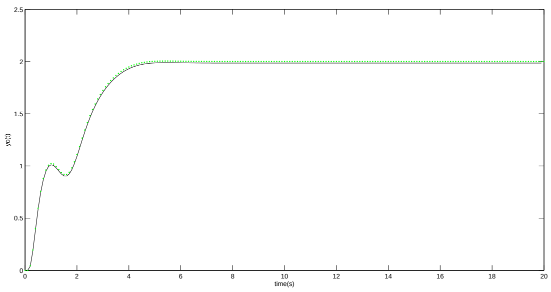


Fig. 13. $y_c \times time$ (line) and $y_c estimated \times time$ (dots).

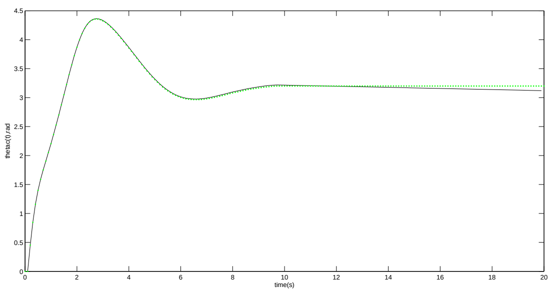


Fig. 14. $\theta_c \times time$ (line) and $\theta_c estimated \times time$ (dots).

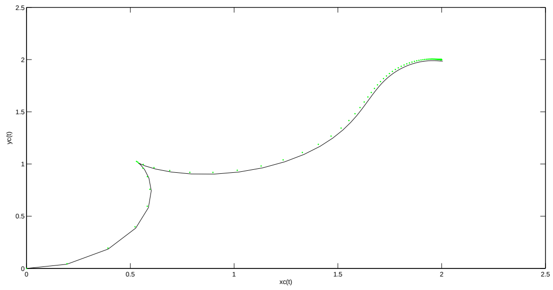


Fig. 15. Robot trajectory $x_c \times y_c$ (line) and estimated trajectory (dots).

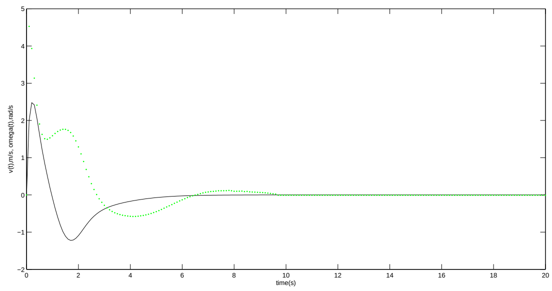


Fig. 16. Robot linear (u_1) - (line) and angular (u_2) - (dots) speeds.

B. Path tracking

To verify the behavior of robot control when moving between several points a path tracking simulation was released. On this simulation result three main curves are observed: the system output (robot real position - continuous line), the estimated robot position (dashed line) and generated control reference (circles). Figure 18 shows the robot displacement on x axis and figure 19 on y axis.

The robot angle behavior indicates that the orientation of the robot turned $2\pi rad$ and turned back to initial orientation as shown on figure 20. It is possible to observe that difference between curves related with angle behavior is less than path related. On figure 21 the robot displacement in Cartesian space is shown, where it is possible to observe that the estimated

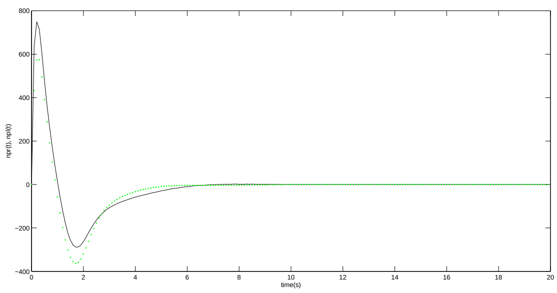


Fig. 17. Encoders reading simulation: right wheel (line) and left wheel (dots).

position try to follow the control reference, otherwise it drifts from the real robot position. This fact is a characteristic of the odometry, being that better results on practical situations can be achieved by means of calibration.

Figure 22 demonstrates linear and angular speeds and figure 23 the encoder readings from right and left wheels. The control signals generated by means of control law is shown on figure 24.

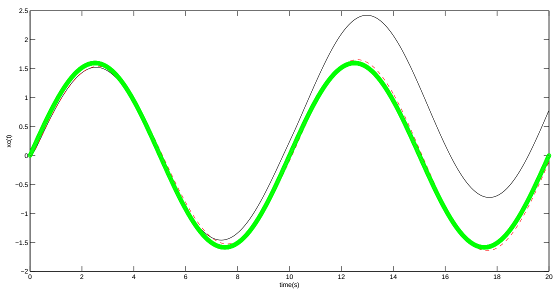


Fig. 18. $x_c \times time$ (line) and x_c estimated $\times$ time (dashed line) and control reference (circles).

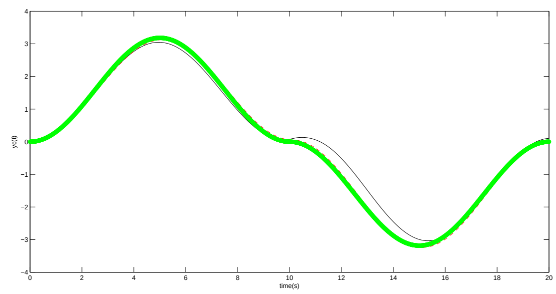


Fig. 19. $y_c \times time$ (line) and $y_c estimated \times time$ (dashed line) and control reference (circles).

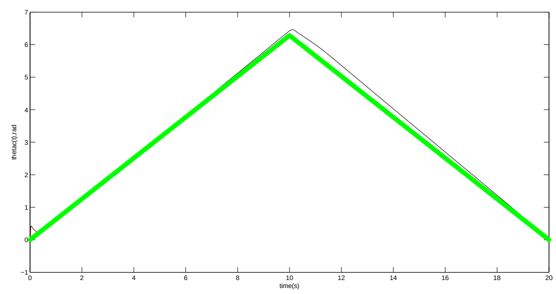


Fig. 20. Robot angle θ_c (line) and estimated angle (dashed line) and control reference (circles).

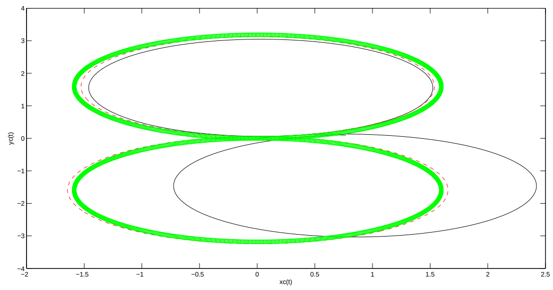


Fig. 21. Robot path $x_c \times y_c$ (line) and estimated robot path (dashed line) and control reference (circles).

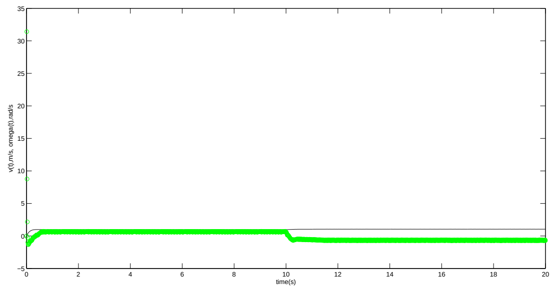


Fig. 22. Path speeds u_1 (line) and u_2 (circles).

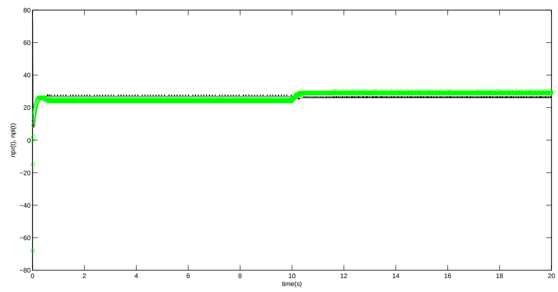


Fig. 23. Encoders reading path simulation: right wheel (line) and left wheel (circles).

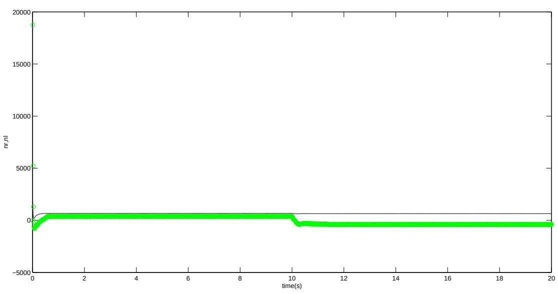


Fig. 24. Control signals: right wheel (line) and left wheel (circles).

V. Conclusion

This work showed the results of a robotic competition from Brazilian Institution SENAI. The robot development allowed the students team to get in touch with a lot of technical knowledge from different areas like mechanical, electric, electronic and pneumatics. Besides, the team could live different situations related with the competition, like psychological stress, teamwork and pro activity.

On the competition first step an open loop guidance was developed. In order to improve the control performance a closed loop one is being developed to get better robot results on the second step of the competition. Simulation results has shown that the robot will converge to a desired point when following the control generated by control equations. Programming it on PLC allows the team to use a lot of advanced features of it.

The proposed control law was validated by means of mathematical model simulation. Future work can be developed by implementing the control law in the PLC and verifying practical results.

Acknowledgment

Authors would like to thank Fundação de Apoio à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) and Serviço Nacional de Aprendizagem Industrial (SENAI) for the financial support.

References

[1] "Olimpíada do conhecimento," Serviço Nacional de Aprendizagem Industrial, 2012, <http://www.senaiolimpiadas.com.br>.

[2] "For inspiration and recognition of science and technology," FIRST, 2012, <http://www.usfirst.org/>.

[3] "National robotics challenge," NRC, 2012, <http://www.nationalroboticschallenge.org/joomla/>.

[4] "Worldskills international webpage," WorldSkills International, 2012, <http://www.worldskills.org/>.

[5] L. A. Bryan and E. A. Bryan, *Programmable Controllers, Theory and Implementation*, 2nd ed. USA: Industrial Text, 1997, pp. 8–10.

[6] *S7-1200 Programmable controller - System Manual*, Siemens, 2012, <http://support.automation.siemens.com/BR/view/en/36932465>.

[7] *AN822 - Stepper Motor Microstepping with PIC18C452*, Microchip, 2012, <http://ww1.microchip.com/downloads/en/appnotes/00822a.pdf>.

[8] W. F. Lages and E. M. Hemerly, "Smooth time-invariant control of wheeled mobile robots," in *Proceedings of The XIII International Conference on Systems Science*. Wrocław, Poland: Technical University of Wrocław, 1998.

[9] G. Campion, G. Bastin, and B. D'Andréa-Novel, "Structural properties and classification of kinematic and dynamical models of wheeled mobile robots," *IEEE Transactions on Robotics and Automation*, vol. 12, no. 1, pp. 47–62, Feb 1996.

[10] R. W. Brockett, *New Directions in Applied Mathematics*. New York: Springer-Verlag, 1982.

[11] A. Astolfi, "On the stabilization of nonholonomic systems," in *Proceedings of the 33rd IEEE American Conference on Decision and Control*. Lake Buena Vista, FL: Piscataway, NJ, IEEE Press, Dez. 1994, pp. 3481–3486.

[12] J. B. Pomet, B. Thuilot, G. Bastin, and G. Campion, "A hybrid strategy for the feedback stabilization of nonholonomic mobile robots," in *Proceedings of the IEEE International Conference on Robotics and Automation*. Nice, France: IEEE Press, Mai. 1992, pp. 129–134.

[13] A. R. Teel, R. M. Murray, and G. C. Walsh, "Non-holonomic control systems: from steering to stabilization with sinusoids," *International Journal of Control*, vol. 62, no. 4, pp. 849–870, 1995.

[14] J. Godhavn and O. Egeland, "A lyapunov approach to exponential stabilization of nonholonomic systems in power form," *IEEE Transactions on Automatic Control*, vol. 42, no. 7, pp. 1028–1032, Jul. 1997.

[15] F. Rehman, M. Rafiq, and Q. Raza, "Time-varying stabilizing feedback control for a sub-class of nonholonomic systems," *European Journal of Scientific Research*, vol. 53, no. 3, pp. 346–358, May. 2011.

[16] O. J. Sørdalen, "Feedback control of nonholonomic mobile robots," Thesis (Dr. ing.), The Norwegian Institute of Technology, Trondheim, Norway, 1993.

[17] C. Canudas de Wit and O. J. Sørdalen, "Exponential stabilization of mobile robots with nonholonomic constraints," *IEEE Transactions on Automatic Control*, vol. 37, no. 11, pp. 1791–1797, Nov 1992.

[18] P. Lucibello and G. Oriolo, "Robust stabilization via iterative state steering with an application to chained-form systems," *Automatica*, vol. 37, no. 1, pp. 71–79, Jan. 2001.

Exploring Creativity and Sociability with an Accessible Educational Robotic Kit

Silvia S. C. Botelho, Lilian G. Braz and Ricardo N. Rodrigues
Center for Computational Science
Federal University of Rio Grande
Rio Grande, RS, Brazil
http://www.silviacb.c3.furg.br

***Abstract*—This paper presents a pedagogical proposal for Robotic in Education. The approach explores the creative aspects and social consequences of the collective project of robotic devices. A set of steps that compose the proposed methodology was applied to Brazilian schools. A robotic kit available is also presented, allowing its implementation even in schools with low budget.**

I. Introduction

New technologies have a big impact in the way modern societies live. For example, the way people communicate is everyday more centered around the internet. Online services like instant messaging, social networks, video streaming, etc have not only allowed for a reinvention of traditional ways of communication but have also created totally new ways of socializing. In a similar way, the education of children in schools has been directly influenced by new technologies. For example, online searches have substituted the traditional encyclopedia researches; projectors and smart boards have taken the place of blackboards; educational video-games have been used to stimulate creativity and curiosity, etc. The use of these technological tools in schools can improve the quality of education and help to prepare students to a technological society.

Another technology that has been used in education is robotics. Robotics is the science that studies the creation and programming of machines that perceive and interact with its environment. It is a naturally interdisciplinary field, involving concepts from mathematics, physics, mechanics, electronics, informatics, engineering and psychology. The use of Robotics in Education (RiE) allows students to learn a broad range of concepts through the construction and/or manipulation of robots. It has been successfully applied in several schools worldwide, being used from small kids education [16], [7] to graduate level classes [14]. Kids, in special, tend to show a big interest in robots, making it an excellent motivational tool for low grades education.

RiE has a great potential to improve education, but there are some open issues that still need to be addressed. In this paper we focus on two main issues: first, as new technologies bring new benefits to our society, it raises an issue of democratic and equal access to these technologies. High costs can make the implementation of RiE in some schools inviable, specially in poor countries, where economical resources for education may be scarce. As education is one of the main factors that can change this reality, it is important to adapt educational technologies to be as accessible as possible, so they can become viable to a broad range of schools. However, most implementations of RiE make use of educational robotic kits developed by private companies, which can be too expensive for some schools, limiting their access to this technology.

The second main issue with RiE is that traditional pedagogical methodologies may not be appropriate to maximize the benefits of RiE. Schools and educators may have to reformulate their existing pedagogical methodologies or create new ones that can explore the full potential of RiE. This change represents a big challenge for educators since it is still not clear which practices are effective to its implementation, managing and evaluation.

In this paper, we present two main contributions to the field of Robotics in Education that are directly related to the issues described above. First, we present an open source robotics kit that can be constructed from simple objects and scrap material, making it accessible to a broad range of schools. Next, we propose a new RiE pedagogical methodology that focus on students socialization and creativity through the design and construction of robotic structures.

The rest of the paper is organized as follows: in section II we present an introduction to the field of RiE and analyze the main concepts that are important to our work like accessibility, pedagogical methodologies and design in RiE; in section III we propose the construction of an open-source accessible robotic kit that can substitute private companies robotic kits; in section IV we describe a detailed pedagogical method for RiE; in section V we report and analyze some workshops that have been conducted to evaluate the proposed robotic kit and methodology; finally in section VI we present our final analysis, conclusions and future works.

II. Robotics in Education

Robotics in Education (RiE) has been proposed since the 80s and has been successfully implemented by several schools worldwide. The work of Papert [11], with his pioneer LEGO/LOGO project, is considered a precursor of several works involving RiE. It is strongly based on the constructivist educational theory, which support that most learning is achieved when ideas and thoughts are materialized in the construction of something concrete.

Most pedagogical methodologies for RiE make use of standardized robotics kits, which consists of sets of hardware pieces and tools. Some robotics kits, as well as their pedagogical methodologies (when available), are summarized bellow:

- **GoGo Board**[15] Library of open source electronic devices. Can have multiple use. Students can construct their own projects or start with available projects. Different programming languages are supported. Does not provide a specific pedagogical methodology.
- **Topobo**[12] Robotic toy consisting of building blocks where some components have kinetic memory, which can record a sequence of movements from an initial hand-moved example. This simplify robots programming, removing the need for a computer-based programming interface and allowing for a slow transition between static building blocks to moving robots. Several teaching methodologies are possible: free play, robotic puppeteering, collaborative group construction, problem guided project, etc.
- **LEGO**[2], [13] Educational assembly kit composed of static and moving parts. Several versions are commercially available. For example the NXT 9797 kit is composed by 431 pieces like blocks, beams, axels, wheels, gears and pulleys. The electronic components are composed by sensors, motors and the NXT programmable microcontroller, which support three motors and up to four sensors. The programming is done trough a sequence of icons in a visual programming interface, called Mindstorm. Several teaching projects are suggested in the LegoZoom magazine following a specific pedagogical methodology.
- **VEX**[4] Provides software, hardware and classroom resources bundles for construction of advanced robotics systems. Provides standard curriculums with focus on science and engineering learning. Strongly support robotics competitions between students as a motivational tool.

The acquisition cost of these kits is one of the main factors that restrict the implementation of RiE in some schools. With exception to the GoGo Board, all kits above are from private companies. [5] presents a comparison between some private kits, including a cost estimation. In order to make RiE more accessible, some researchers have proposed the development of cheap open source robotic tools. For example, Miranda [9] proposes a low value robotic kit called RoboFacil and a visual programming interface, called ProgrameFacil. In the same line, Gonçalves [6] proposes a low cost robot reusing electronic scrap, what reduces costs and gives support to an environmental education.

Many robotic kits, including the ones proposed by Miranda and Gonçalves, tend to have a bias toward technical education, focusing on the science and engineering aspects of robotics. According to O'Malley [10], children show interest to these aspects only if they are already motivated by science and engineering activities. We believe that independently of the robotic kit, the pedagogical methodology should explore the kit at its maximum, supporting the key aspects of learning without focusing only on technical aspects. However, very few robotics kits provide a suggestion for a pedagogical methodology that can guide educators on how to explore it efficiently.

One of the most popular robotics kits is Lego, and is accompanied by a suggested pedagogical methodology. Due to its popularity and relative maturity we adopt this methodology as a baseline to evaluate our proposed methodology. The Lego pedagogical methodology starts with the presentation by the professor of a theme/problem to be solved by students in groups. The projects show a specific intention that vary in each activity. Each student within a group assume a specific functions among the following: presenter, organizer, constructor or programmer. The projects themes are suggested in a periodic magazine, which contains thematic introduction to the problem, a step-by-step assembly/programming guide and suggestion for further questioning and project extension. A teacher's version of this magazine also includes further details and classroom strategies suggestions, such as debates, interviews, internet researches, etc.

Note that the main educational focus in the Lego methodology is in the proposed theme/problem. In other words, all activities revolve around the main theme; the robotic kit is mainly used as a tool for teaching the concepts related to the theme. The focus is not in the technical aspects of robotics, which (for the intended purpose) is the ideal situation. However, the design process of the robotic devices is also hidden (since a step-by-step solution to the problem is given), so all the creative thinking and deep reasoning involving the design of a robotic device is not worked with this methodology.

According to Lopes [8], design is a fundamental part of RiE. New concepts are not learned by simply copying a project that is already constructed and does not require creative thinking [8]. By giving students a practical activity that merely reproduce something that has already been built and tested, reducing their action to assembly and testing of a pre-defined prototype, the RiE looses its reflection, investigation and transformation characteristics. Lopes proposes that, given a theme/problem, students creativity be explored trough an initial drawing of what is intended to be constructed, indicating the parts and explaining its functionalities. However, Lopes does not provide a detailed methodology, with explicit practices and procedures, only recommendations, which are used as foundations for our proposed pedagogical methodology.

III. Accessible Robotic Kit

We emphasize that low buying-power should not impede schools from implementing technological education projects. So to make RiE more accessible, we describe in this section the construction of a robotic kit using scrap material and low cost components. The kit is divided in three main parts: the building blocks, which are the components used in robot assembly; the electronic hardware board, which is used to

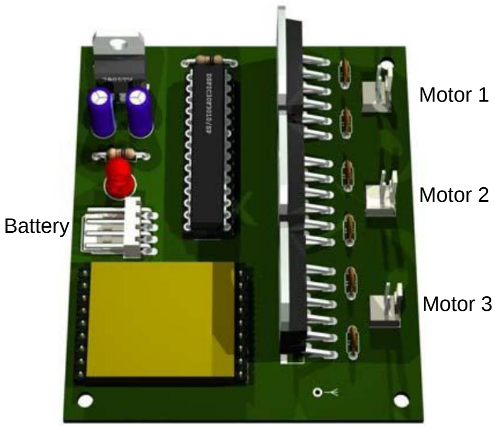


Fig. 2. Electronic board used to control the robot.

Fig. 3. Programming interface used to program the robot.

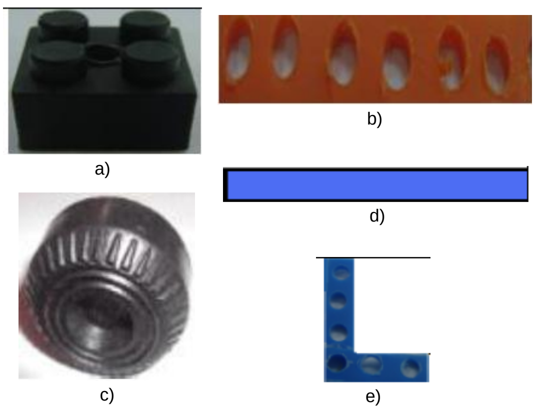


Fig. 1. Basic blocks that compose our robotic kit.

control the robot; and the programming interface, which is used to program the robot.

A. Building Blocks

Figure 1 depicts the main building blocks in our kit. Other components can be freely introduced into the kit as needed, however we identify these components as the basic structures necessary to most projects. In order of appearance we have: a) block, which can be purchased in toy stores, used in basic structures assembly; b) beam, made from wood sticks (ice-cream sticks, wood scrap) with carved holes, allows for connection between parts; c) tires, can be purchased in toy stores or adapted from bottles cap, buttons, etc; d) axel, made from wood sticks, allows for transmission of forces between engines and gears; e) angled beam, made from pieces of wood, used in projects that require angular change.

We suggest the components be available in different sizes and that a color scheme be adopted to represent components of different sizes. Beside these building blocks, the kit also includes tape, small electric engines, rubber bands and other tools (scissors, glue, etc).

B. Hardware

We have developed an electronic board to control up to three motors. The hardware design is open source and is available for download at http://www.nautec.c3.furg.br/SABERLANDIA. The board stores a sequence of actions programmed by the user and then reproduce these actions at a latter time without the need of a computer. The upload of instructions (program) into the board controller is done through serial port and the power alimentation tension is 110V or 220V. Figure 2 depicts the electronic board.

C. Programming Interface

Figure 3 shows the open source programming interface we have developed. Using the graphical user interface buttons, students can create a sequence of commands (movements) that will be sent to the robot. The interface is intuitive, simple and does not require the knowledge of any programming language, allowing students to focus only on the development of logical and algorithmic thinking. The program and its Java source code can be downloaded from http://www.nautec.c3.furg.br/SABERLANDIA.

IV. A Detailed Pedagogical Methodology for RiE

In this section, we describe a new pedagogical methodology that explores students creativity and socialization skills by focusing on robotics design. Similarly to the Lego methodology, our proposal follows a constructivist approach, where students learn by implementing a concrete project. However, in our proposal, neither the project solution nor the steps necessary for its implementation are well defined in the beginning, as we argue that these steps contain key aspects to stimulate creativity and logical thinking.

The project starts from a main theme, which can be suggested by the professor or students. This theme should allow for the construction of some robotic device to solve a proposed problem. The pedagogical methodology consists of five main steps:

First Step - Virtual Sketch. The objective of this step is to stimulate the curiosity, interests and doubts related with the main theme. Students should individually draw a first proposal with their ideas about the solution to the problem. After this, students gather in groups and share their individual ideas. Each group should discuss, exchanging and improving their ideas, and then present a final collective proposal, which can be a refinement of some student proposal or a novel proposal. Note that this step has a strong social component, where each student should defend their ideas and listen to others.

Second Step - Functional Sketch. The virtual sketch proposed by the students usually lack details and do not include mechanical (engines, gears) nor logical components. Therefore, in this step the groups are asked to refine their proposals, thinking and expressing the needs and the operating characteristics of the virtual sketch.

Third Step - Concrete Sketch. First, the available technological resources (educational kits, alternative material, scrap, etc) are presented to the students. The groups should identify the main components that will be used in the construction of their projects, taking into consideration the available resources. Using this information, students may modify or/and adapt the functional sketch, creating a concrete sketch, so it can be built in practice. This step is based on the construction of knowledge through a concrete idea, as defended by Papert [11]: "Better learning will not come from finding better ways for the teacher to instruct, but from giving the learner better opportunities to construct."

Fourth Step - Prototype construction. The groups should collectively implement their solutions as drawn in the concrete sketch, working out creative solutions to eventual problems that may appear. The constructivist learning methodology is directly applied in this step, where children can finally put in practice the ideas they have been working. This follows Papert's idea, that states that learning is improved if students can construct something concrete, like for example, a scale model, a software, something that can be seen and analyzed.

Fifth Step - Presentation. We suggest the groups prepare a final report showing the final robotic system as well as the project evolution process, pointing out strengths and weaknesses in the project.

V. Evaluation

We present a set of four workshops developed to evaluate the proposed educational kit and methodology. The workshops main themes were: trash compactor, tower, claw and mascot. As mentioned before, we use the Lego methodology together with the LEGO-MindStorms robotic kit as a baseline for comparisons. The workshops qualitative analysis presented here is based on a large collection of data consisting of on site observations, pictures, video recording and students reports. A total of 60 projects were analyzed. All parts involved in these workshops (students, student's legal responsible, teachers and school) have been properly informed on the research scope and have signed the appropriate release forms.

A. Workshop 1 - Trash Compactor

In this workshop, we follow the project from Legozoom magazine, year 6, volume 4, where the main objective was to build a trash compactor. The class named fifth grade "A", composed of 24 students (8 boys and 16 girls), has been oriented following the suggestion in the magazine. Meanwhile, the class named fifth grade "B", composed of 27 students (14 boys and 13 girls) has been oriented following our proposed methodology. In this workshop, both classes have used the Lego/Mindstorm robotic kit so only the pedagogical methodologies will be compared.

Analyzing the behavior and results of class "A", which followed the Lego pedagogical methodology, we observe the following:

- The students within a group have worked collaboratively, helping each other in several tasks. This observation is in agreement with Bonals' affirmation [3]: "students can learn more and better if they are allowed to face the learning processes together, specially when they can reach a specific objective and work as a team".
- All eight groups have successfully constructed the robot as suggested in the magazine. However, only one group have extended the project to solve the challenge proposed in the magazine (this challenge would require students to change the project and create a new solution without having access to a step-by-step guide). Moreover, seven groups have reported to successfully completed the project, ignoring the suggested challenge. This situation relates to [1], where the students follow the manual in a mechanical way, without attention to the underlying concepts, making the extrapolation of these concepts difficult.
- All teams where very conservative in their programming approach, strictly following the suggestions given by the teacher (as indicated in the LegoZoom magazine) without risking a different approach. Once again, we observe that when students are given a "straight line" to the solution they tend to focus on this path without thinking alternative solutions. The steps trough this line become their target and not the search for the best path.

On the other hand, analyzing the behavior and results of class "B", which followed the proposed methodology, we observe the following:

- The same level of collaboratively work as in class "A" has been observed.
- There has been a big variation in the project solutions. For example, figure 4 and 5 show all the phases of two distinct groups. In the first group, the idea was to have two rotating gears that would compress the trash. On the other group, the idea was to have a weight based compressor. Other ideas included a hammer like smasher and a jaw like compressor.
- Most groups had difficulties in making the electric motors work as intended, so many demonstrated their projects by manually moving gears or parts. When some students were questioned why they had difficulties, once they had been in contact with the Lego kit for 3 years, they

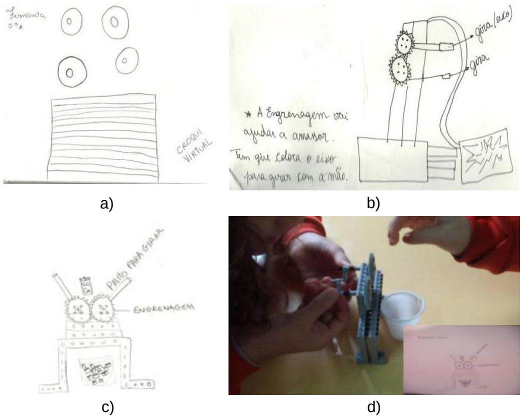


Fig. 4. Group 1 project. a) Virtual sketch; b)Functional sketch; c)Concrete sketch; d)Prototype.

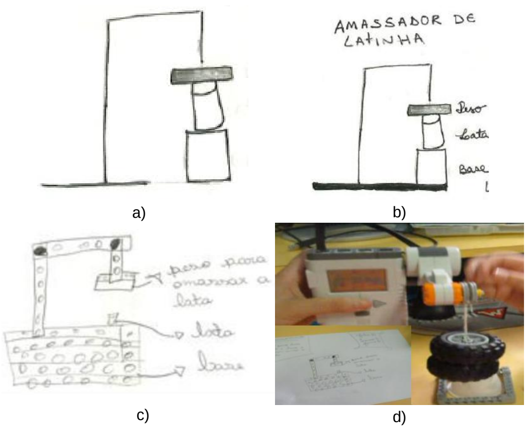


Fig. 5. Group 2 project. a) Virtual sketch; b)Functional sketch; c)Concrete sketch; d)Prototype.

answered: "it was hard to construct without the assembly manual. We do not know how to use the pieces". From a constructivist point of view, a "mistake" is seen as a opportunity for learning, so educators should make clear to students that this is acceptable, avoiding unnecessary frustration.

B. Workshop 2 - Tower

In this workshop, we follow the project theme from Legozoom magazine, year 9, volume 3, where the objective was to build a tower. The class named eight grade "A", composed of 27 students (14 boys and 13 girls) followed the magazine suggestion. Meanwhile, class named eight grade "B", composed of 27 students (14 boys and 13 girls) followed our proposed methodology. We observe that while class "A" had to build a tower as described in the magazine (with the challenge to make it higher), class "B" had no restrictions to which form or functionalities the tower should have and students were motivated to create novel towers. Both classes were lectured with a introductory presentation on the subject showing examples of towers (e.g. Eiffel tower) and describing their functional utility and symbolic value as sign of a new era. Class "B" could use the Lego kit as well as our proposed accessible kit.

Analyzing the results of both classes, we observe some similarities with the first workshop:

- All groups have worked collaboratively.
- All groups in class "A" have strictly followed the guide and most have not completed the challenge. After teacher insistence, most groups presented a solution that consisted on stacking up more pieces on top of the tower, without taking into consideration any significant structural change.
- The proposed towers in class "B" where vastly distinct, containing creative and interesting ideas. Some examples of towers are: a tower with a energy consumption indicator on top, a spinning tower, a finger like tower with an spinning basketball on a top.
- Overall, students found the accessible kit easier to use than the Lego kit. However, some had difficulty in coupling structural parts with the hot glue, mainly because pieces do not dock so perfectly as in the Lego kit.

Even following the guide, students from class "A" have reported that it was challenging to construct the tower. We also observed that the Lego activity required a great level of organization, discipline and concentration, which can be perceived as a positive aspect of Lego methodology.

C. Workshop 3 - Arm with claw

This workshop was an adaptation of a project proposed in Legozoom magazine, year 9, volume 2. The objective was to construct a robotic arm that could pick an object and move it to the other side. Class named seventh grade "A" (30 students, 20 boys and 10 girls) used the Lego methodology, while class named seventh grade "B" (25 students, 12 boys and 13 girls) followed our methodology.

This workshop was atypical as none group (in both classes) were able to successfully complete the task. The main difficulty was programming the movements that would allow the claw to grab the object, move to the other side and open it to release the object. However, we have observed that all groups were motivated in solving this problem.

D. Workshop 4 - Mascot

Students were asked to create a mascot to represent the school. No restriction on the form or movements were imposed. In this workshop, only our proposed methodology was evaluated. The groups could choose between using the Lego kit or the accessible kit.

Overall, students gave the accessible kit a positive evaluation. They seemed to have no troubles in creating and sending commands to the electronic board. Once again, some students had difficulties in managing the hot glue. Some examples of what was said: "The electronic board is just like the NXT, it sends and receives instructions", "the programming was different, but it was easy", "we had difficulties in using the hot glue, but after we got it, it was cool".

VI. Conclusion

We have presented a new methodology for using robotics in education (RiE) along with an accessible robotics kit. The key aspect of our methodology is that it allows students to freely create robots in groups without following a strict step by step guide. We argue that this is an important aspect to engage students, strength creativity and improve social skills. Several workshops where carried out and lead to a positive evaluation on our method.

The proposed accessible robotics kit was also positively accepted by students as being as good as a commercial kit (Lego). Students reported that the kit was simple to use, including the programming environment composed by the computer interface and electronic board. The only complain was related with the use of hot glue to connect the pieces (in commercial kits parts usually snap together). This suggest a possible improvement that will be left for future works.

References

[1] D. P. Ausubel. *Educational psychology: a cognitive view*. Holt, Rinehart and Winston: New York, 1968.

[2] Dave Baum. *Definitive Guide to Lego Mindstorms*. APress L. P., 2nd edition, 2003.

[3] Joan Bonals. *El Trabajo en pequeños grupos en el aula*. Barcelona, España : Graó, 2000.

[4] VEX Education. Retrieved on november 16, 2011, from http://www.vexrobotics.com/education.

[5] D.U. Ekong. Resources for using robotics to inspire interest in engineering. In *Southeastcon, 2009. SOUTHEASTCON '09. IEEE*, pages 273 –277, march 2009.

[6] P. C. Gonçalves. Protótipo de um robô móvel de baixo custo para uso educacional. Available on http://pt.wikilingue.com/es/Lego_Mindstorms, Retrieved on February 18, 2009.

[7] Frank Klassner. A case study of LEGO Mindstorms^{TM} suitability for artificial intelligence and robotics courses at the college level. *SIGCSE Bull.*, 34:8–12, February 2002.

[8] D. Q. Lopes. *A exploração de modelos e os níveis de abstração nas construções criativas com robótica educacional.* PhD thesis, Universidade Federal do Rio Grande do Sul- URGS, Porto Alegre, 2008.

[9] G. L. Miranda. Limites e possibilidades das tic na educação. In *Revista de Ciências da Educação*, number 3, pages p. 41–50, Lisboa, May 2007.

[10] C. O'Malley and D. Stanton Fraser. Literature review in learning with tangible technologies. Discussion Paper 0-9548594-2-1, NESTA, 2004. Report 12.

[11] Seymour Papert. *The Children's Machine: Rethinking School In The Age Of The Computer*. Basic Books, New York, 1993.

[12] Hayes Solos Raffle, Amanda J. Parkes, and Hiroshi Ishii. Topobo: a constructive assembly system with kinetic memory. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, CHI '04, pages 647–654, New York, NY, USA, 2004. ACM.

[13] M. Resnick and S. Ocko. LEGO/Logo: Learning Through and About Design. In I. Harel and S. Papert, editors, *Constructionism*, pages 141–150. Ablex, Norwood, NJ, 1991.

[14] R. Rocha. Utilização da robótica pedagógica no processo de ensino-aprendizagem de programação de computadores. Master's thesis, Centro Federal de Educação Tecn. De Minas Gerais, 2006.

[15] Arnan Sipitakiat, Paulo Blikstein, and David P. Cavallo. Gogo board: augmenting programmable bricks for economically challenged audiences. In *Proceedings of the 6th international conference on Learning sciences*, ICLS '04, pages 481–488. International Society of the Learning Sciences, 2004.

[16] S. Zilli. A robótica educacional no ensino fundamental: Perpectivas e práticas. Master's thesis, Universidade Federal de Santa Catarina, 2004.

Teaching C/C++ Programming with Lego Mindstorms

David T. Butterworth
University of Queensland, Australia
d.butterworth@uq.edu.au

***Abstract*—Computer programming is a skill required in many professions, not just computer science. Lego Mindstorms NXT can be incorporated into a programming course to add hands-on interactivity that will better engage a broader range of students. Chosing the most suitable programming language is difficult, and this paper summarizes some experiences in teaching students using RoboLab and NXT-G for Mindstorms NXT. The text-based language RobotC is recommended for beginner and intermediate level courses, and various code examples are provided to assist teachers in building lesson plans. It is suggested that advanced programming should be taught in C++, and an example of using the NXT++ library to control a robot arm is presented. Teaching all levels of programming, using robotics, is more enticing and stimulating for students, and teachers can justify the purchase of expensive robot hardware by employing it in multiple areas of the school curriculum.**

I. Introduction

Lego is a popular tool for science and technology education, in particular the Technic and Mindstorms products [1]. The Mindstorms series began with the RCX, and the current NXT and NXT 2.0 kits (Fig. 1) have become a defacto standard for teaching beginner-level robotics to students [2][3].

It may be suggested that Lego Mindstorms is a robotics construction kit and thus only useful for schools that provide a specific robotics curriculum. It is true that the majority of Mindstorms projects are based around some type of mechatronic vehicle or device, but it is now widely accepted that robotics activities are an effective way to teach important core skills [4][5]. Furthermore, the flexibility of the Lego system and range of available parts means that its application in school activities is limited only by the creativity of teachers and students [6].

At present, the majority of students first encounter Lego Mindstorms during the secondary 6-12 education phase, once the average student has reached an appropriate level of development. However students relative competency with technology is always increasing, so just like primary K-6 level students are now familiar with the internet and may own a high-powered mobile phone, the young students of tomorrow will arrive at school having assembled and programmed their own robots at home.

This technology creep places a tremendous strain on teachers to update their own knowledge and lesson plans, and a tight budget means that a class-set of equipment cannot be updated at the same pace as technology change. If the purchasing responsibility is passed on to parents, such as with compulsory laptop policies, this reinforces the belief that technology education is only for those that can afford it. One alternative is that groups of students can share expensive technology resources by visiting a capstone school or education center. Another alternative is to make equipment purchases more cost-effective by utilising them to a greater extent in the curriculum.

Traditionally, technology resources like Lego Mindstorms will be utilized in a specific part of the school curriculum, such as a weekly science class or semester-long robotics program. The benefit of high-quality kits like Lego Mindstorms is their versatility and expandability, as opposed to the broad range of inferior robotics construction kits that can now be found in toy stores. Therefore curricula can be designed using Lego Mindstorms to more effectively engage students across a broader range of subject areas than simply robotics, including general mathematics and science classes.

Technology skills like programming should no longer be thought of as part of the information technology curriculum. The ability to write a computer program to solve a problem, or to streamline a processing task, is a skill required by tomorrow's young professionals in all lines of work. For this

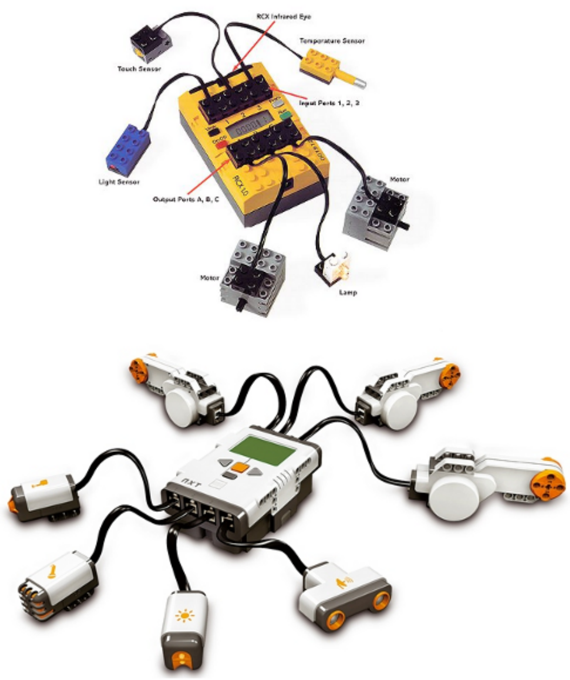


Fig. 1. Lego Mindstorms RCX (top) and NXT (bottom)

reason, many people struggle to learn computer programming on-the-job, after leaving school, rather than through formal education.

It can be difficult to make the subject of programming interesting to students, and typical complaints are that ”it is boring” or they ”are not good at it”. Therefore, by combining a programming language like C++ with Lego Mindstorms, the subject can become more engaging to a broader range of students, and the school gains extra utilization of an expensive resource. A systematic literature review of the effectiveness of robots as tools for teaching progamming can be found in [7].

II. Teaching experiences

The University of Queensland, Australia, conducts an outreach program [8] for secondary school students, teaching basic robotics and ICT (Information & Communications Technology) skills, and also holiday workshops for teachers who need to conduct their own classes. Robotics is taught using Lego Mindstorms in two 4-hour sessions, covering introductory topics and basic concepts in Artificial Intelligence.

The purpose of these sessions is to excite students about computer science and engineering, through the use of robotics, and potentially continue their studies at a university-level. In a typical session of 20 students, from a mix of schools, there will be 1 or 2 students who have never used Lego before. If we are to consider Lego the defacto standard for engineering education at the secondary and university levels, then these students have already been left behind. The majority of students have used Lego before, so they possess the skills necessary to read construction plans, spatially orientate the pieces, and efficiently construct a Lego model. As many as 30% of students have already had some exposure to the Robocup robotics competition [9], and it is these students who have skills that will be advantageous at the university-level.

Sessions were originally conducted using the Lego Mindstorms RCX brick. These units have an excellent lifespan, however some wiring cables and general Lego pieces require occasional replacement. However, many students reported that they were already familiar with the newer NXT brick and its programming system, and so because of this technology creep, a new class set of Mindstorms NXT was purchased. At present, Lego Mindstorms is not widely used at the primary school level, so the RCX brick is a good choice for younger students. Secondary schools might consider donating old RCX sets to the junior students, or they may be used for multi-brick Lego projects like the Robocup Dance competition.

The graphical programming software Lego RoboLab v2.9 was used to program both the RCX, and the newer NXT brick, which is actually supplied with different software. RoboLab is a simple and efficient way for students to start learning programming and hard-working students will design a program that fills an entire screen, indicating they are ready for a more advanced assignment. The NXT-G software supplied with Mindstorms NXT does offer some additional programming functionality, however its more cluttered appearance makes it harder to use for students or teachers who are new to programming. Unfortunately the RoboLab software environment now looks quite dated, and many students are using NXT-G at their own school, so the session materials were recently re-written to reflect this.

More experienced students can also program the Mindstorms NXT using a text-based programming language, such as RobotC, which is covered in section IV. Teaching text-based programming is beyond the scope of an 8-hour introductory session, however many students are using RobotC in the robotics curriculum at their secondary school. The University of Queensland also hosts the Robocup Junior competition for the State of Queensland, and it is worth noting that the leading teams in the Robocup Rescue and Robocup Soccer categories are using RobotC to program their robots.

III. Chosing a programming language

It is possible to program the Mindstorms NXT using all the typical programming languages. Table I shows some of the language implementations that are available.

Some of these languages can be used to write a program that runs on the actual NXT brick, which requires firstly downloading a new operating system called firmware to the NXT. Other languages can be used to write a program for your desktop PC that remotely controls the NXT. The first option is most suited to building an autonomous mobile robot, however remote control is sometimes used where more computer processing power is required. A PC-based program is more suited to a robot arm or experiment that sits on the desk, and may communicate via USB cable or wireless Bluetooth methods.

Deciding which programming languages should be taught is a topic of much debate, and is best discussed in consultation with industry professionals and university staff. The basic skills of programming are transferrable and can be taught with any language, however it is the author’s opinion that students will have an advantage if they finish secondary school with some exposure to Visual Basic, C and C++. Visual Basic can be used to automate tasks in the Microsoft Office application suite, so this will benefit students who go on to work in areas of business or management. The C language can be used to write programs for a massive range of platforms, including Lego Mindstorms for secondary students, or embedded Microprocessors for engineering students. Experience with programming in C++ will be mostly beneficial to potential computer science or engineering students, who will have an excellent head-start if they have experience with this language.

The use of Lego Mindstorms for teaching C programming is discussed in [10] and the C implementation RobotC has been compared with other languages in [11][12]. Delman et al. discuss using a variant of C++ for programming RCX and NXT robots in [13] and [14].

When chosing a language to program the Mindstorms NXT, it is important to realize that many of the language implementations are not complete. This means, for example, that if you program the NXT using a variant of the C language called NXC (Not eXactly C) [15], that the complete range of

TABLE I
LIST OF SOME TYPICAL PROGRAMMING LANGUAGES FOR THE MINDSTORMS NXT

Language	**Implementation**	**On-board program**	**Remote control**
C	RobotC	√	
C	NXC	√	
C/C++	nxtOSEK	√	
C++	NXT++		√
C++	Ander's C++ Library		√
C++	NXTface		√
C++	Lestat		√
C#	MSRDS		√
.NET	Mindsqualls		√
Python	NXT-Python		√
Java	leJOS	√	
Matlab	RWTH NXT Toolbox		√

C commands is not available. Therefore teachers should chose a language that has a large user support base, which is a good indicator of high-quality software. The author recommends a C implementation called RobotC [16], and using C++ with the NXT++ library [17].

IV. ROBOTC

RobotC is a subset of the C programming language, and includes a program editor and debugging environment. A trial 30-day license is available free of charge, or a classroom license will cost USD$199 per year. There are other C language variants available with no licensing costs, including NXC (Not eXactly C) mentioned in Section III, so teachers may be tempted to employ these. However, from experience, the author would strongly recommend the use of RobotC due to the large number of resources and online support that is available, and the high-level of functionality available.

The level of support for RobotC surpasses that currently available for other C language variants for the NXT and the license cost is well justified. As one example, it was decided to use the NXC language for an undergraduate Computer Science course with NXT Mindstorms. While the software is free, the lack of support means you can be on your own if problems arise, and some fundamental programming features are not permitted, including floating point arithmetic and static variables. It is possible to install a user-created firmware update to add support for floating point arithmetic, however it does not annex significant other functionality.

It can be intimidating for teachers to incorporate RobotC into the curriculum if they are not personally trained in computer programming. It is best to firstly cover the fundamental elements of a computer program, and the RobotC documentation can help in this regard. A lesson plan can be constructed around specific problem solving tasks, and teachers can use the online resources for assistance in developing their own solution to the problem. There are usually multiple programming approaches to solve a problem, but if students are struggling the teacher can then provide assistance with reference to their own previously solved solution.

This paper provides some examples of RobotC code for solving typical programming problems, to be considered advanced-level for secondary students. The source code is available online [18] and teachers may use it to build their own solutions.

- State Machine template, for sequential problem solving.
- Drive forward in a straight line, using feedback from wheel sensors.
- Gradual start for motors, using non-linear speed profile.
- Testing the NXT 2.0 RGB color sensor.
- RGB color sensor as a light sensor (line follower and pre-processor definitions example).

V. C++ AND NXT++

C++ is a powerful object-orientated programming language but, in fact, RobotC is more than sufficient for directly programming the Mindstorms NXT. However if the goal is to teach C++ programming, which typically involves students creating purely screen-based GUI applications, then the NXT could be incorporated to add a level of physical interaction to the task. Examples include writing a stock control program linked to a robotic arm, or agitation and testing of samples in a scientific experiment.

The C++ program is written on a desktop PC, using a development environment like Microsoft Visual C++. The Mindstorms NXT is connected to the PC via USB cable, or paired using wireless Bluetooth. The NXT is controlled using an API (Application Programming Interface) in the NXT++ library, a free open-source C++ interface that communicates with the NXT using the Lego Fantom DLL (Dynamically Linked Library).

The NXT++ library was written in 2007, but development work has ceased in recent years. The result is that some advanced Lego NXT functionality is not well documented or been fully incorporated yet. However NXT++ does contain enough functionality to add a more physical dimension to a C++ project, and being open-source means that advanced C++ programmers can make any additions they require.

This paper introduces an update to the NXT++ library, culminating in the release of a new version: NXT++ 0.7 [19]. Most useful is the support for multiple NXT Bricks via USB, in addition to Bluetooth. New features added in v0.7 are:

- List all available NXT Devices connected via USB and Bluetooth, including device name and MAC address.
- Open connection to specific NXT Device, using device name or MAC address. Supports multiple simultaneous connections via USB and/or Bluetooth.
- Retrieve device name of NXT brick.
- Set new NXT device name.
- Retrieving NXT firmware version (fixed).

```
// gradual_motor_start_non_linear_ramp.c
// RobotC for Mindstorms NXT
//
// Gradual start of motors using non-linear speed ramp
// [David Butterworth, 2012]
//
// This program demonstrates how to gradually start a
// pair of NXT motors, drive at a steady speed,
// then gradually slow down again.
//
// This is useful for vehicles or robots, where
// suddenly applying maximum speed can cause the
// robot to "jerk", which may affect wheel encoder
// readings.
//
// The motor output speed is calculated using a
// non-linear (bell shaped) speed profile.
//
//    outputSpeed = finalSpeed
//        *( 0.5 - 0.5*cos( (1/stepsForRamp)*PI*step ) );
//
// finalSpeed = The desired output speed (amplitude).
// stepsForRamp = How fast to increase the motor speed.
//      You should experiment with this value, because it
//      depends on the loop execution time of your program.
// step = The ramp iterator.
//
// The outputSpeed will increase from 0 to finalSpeed, in
// stepsForRamp number of steps.
// However we can't calculate (1/stepsForRamp)*PI on the
// fly in RobotC, the equation output is zero, so we
// calculate a rampConstant during program compilation
// using a pre-processor definition.

// stepsForRamp
#define STEPS_FOR_RAMP 70 // 70 steps is good for demo.
                          // 25 is quite fast.
                         // 1 is minimum value, so you can
                        // see how much jerk the robot has.

#define MOTOR_PORT_LEFT  motorC
#define MOTOR_PORT_RIGHT motorA

//-----------------------------------------------------//

// Calculate the rampConstant during program compilation
#define RAMP_CONSTANT (PI/STEPS_FOR_RAMP)
// e.g.  (1/200)*PI = 0.015708

// Declare vars
int finalSpeed = 0;
float outputSpeed = 0;
int step = 0;

// Main
task main()
{
    // Set maximum final speed for motors
    finalSpeed = 70;

    // Loop forever
    while (true)
    {
        // Initial state is state1
        static int state = 1;

        switch (state)
        {
            case 1: // State 1
                // Ramp-up Motor Speed
                nxtDisplayString(3, "Faster...");
```

Fig. 2. Excerpt from author's code examples for RobotC [18]

An example of a C++ programming project from a University Computer Science course is presented in Fig. 3: A 4-DOF (Degree of Freedom) robot arm using Mindstorms NXT. The design utilized 5 NXT motors, thereby requiring 2 NXT Bricks. The NXT Bricks were connected to a laptop PC via USB and controlled with a C++ program and the NXT++ Library. A USB web camera was used with the OpenCV Computer Vision Library to implement a color-based Blob-tracking algorithm. The result was an advanced C++ programming project that incorporated existing Mindstorms NXT resources and more fully engaged the students involved, while they learnt a broader range of skills.

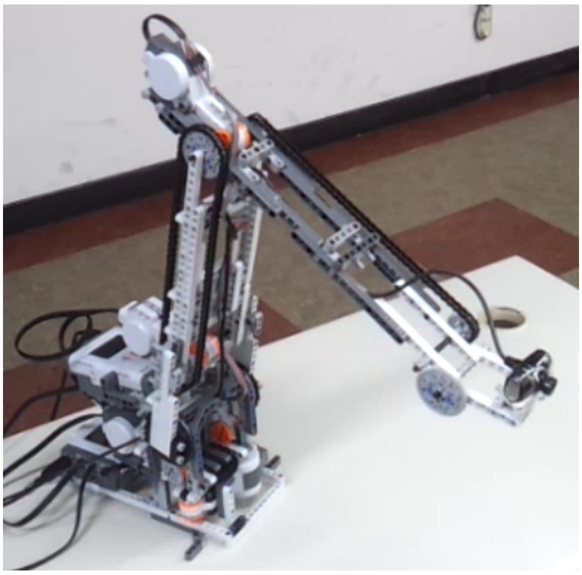


Fig. 3. 4-DOF Robot Arm using 2 Mindstorms NXT Bricks

VI. Conclusion

RobotC and Lego Mindstorms are highly recommended for teaching beginner-level programming. This implementation of the C language lacks many of the complexities that confuse students new to programming, while retaining enough of the C language syntax to be powerful enough for more advanced projects. It forms a good bridge towards teaching ANSI C to university-level students, and is more than sufficient for any Lego robotics challenge. Teachers should be wary of utilizing alternative, low-cost C language variants that lack functionality and support resources. Code examples in RobotC have been provided to assist teachers with lesson planning.

It is recommended that future engineering and science students should possess a competency in programming with C++. However, regardless of the language, the typical programming coursework can alienate students for whom programming is a tool, rather than an interest in its own right. Using additional resources like Lego Mindstorms can make programming coursework more engaging to students, and the NXT++ library is presented as an effective way of connecting C++ with a hands-on problem. This paper presented a new version of NXT++, incorporating support for multiple NXT bricks.

Using OOP (Object-Oriented Programming) languages like C++ will not provide any additional benefit beyond using RobotC, when creating a Lego robotics project. Furthermore, an advanced understanding of robotics or OOP will require specific study in these areas. However, Lego Mindstorms is one tool that can be used to initially engage a broader range of students in studying advanced programming, for whom the semantics of C++ might otherwise be considered dull and boring.

Unfortunately for teachers, the fast pace of technology change makes it difficult to decide which software, technology or specific skills should be addressed in the classroom. It can be said that knowledge in any programming language is sufficient for students to bootstrap an understanding of other languages. However, if we can observe a trend and recognize the technology skills of most importance, we can provide students with a competitive edge for their future. If today's students are learning with tablet PCs and building robots, how will you engage the next generation of young learners?

REFERENCES

[1] (2012, Jun.) LEGO Mindstorms. [Online]. Available: http://mindstorms.lego.com

[2] F. Klassner and S. D. Anderson, "LEGO Mindstorms: not just for K-12 anymore," *IEEE Robot. Autom. Mag.*, vol. 10, no. 2, pp. 12–18, Jun. 2003.

[3] T. Karp, R. Gale, L. A. Lowe, V. Medina, and E. Beutlich, "Generation NXT: Building Young Engineers with LEGOs," *IEEE Trans. Educ.*, vol. 53, no. 1, pp. 80–87, Feb. 2010.

[4] A. B. Williams, "The qualitative impact of using LEGO MINDSTORMS robots to teach computer engineering," *IEEE Trans. Educ.*, vol. 46, no. 1, Feb. 2003.

[5] Z. S. Roth, "The role of robotics in freshmen engineering curricula," in *Proc. 5th Biannual World Automation Congress*, vol. 14, Jun. 2002, pp. 389–394.

[6] S. Galvan, D. Botturi, A. Castellani, and P. Fiorini, "Innovative robotics teaching using LEGO sets," in *Proc. IEEE International Conference on Robotics and Automation (ICRA'06)*, May 2006, pp. 721–726.

[7] L. Major, T. Kyriacou, and O. P. Brereton, "Systematic literature review: Teaching novices programming using robots," in *Proc. 15th Annual Conference on Evaluation & Assessment in Software Engineering (EASE'11)*, Apr. 2011, pp. 21–30.

[8] (2012, Jun.) Robotics Workshops at Univ. of Qld. [Online]. Available: http://www.uq.edu.au/ict/robotics-workshops

[9] (2012, Jun.) Robocup Junior Australia. [Online]. Available: http://www.robocupjunior.org.au

[10] S. H. Kim and J. W. Jeon, "Educating C Language using LEGO Mindstorms Robotic Invention System 2.0," in *Proc. IEEE International Conference on Robotics and Automation (ICRA'06)*, May 2006, pp. 715–720.

[11] D. Swan, "Programming Solutions for the LEGO Mindstorms NXT: Which approach is best for you?" *Robot Magazine*, 2007. [Online]. Available: http://find.botmag.com/100701

[12] S. L. Salcedo and A. M. O. Idrobo, "New tools and methodologies for programming languages learning using the scribbler robot and Alice," in *Proc. Frontiers in Education Conference (FIE'11)*, Oct. 2011, pp. 1–6.

[13] A. Delman, L. Goetz, Y. Langsam, and T. Raphan, "Development of a System for Teaching CC++ Using Robots and Open Source Software in a CS1 Course," in *Proc. International Conference on Frontiers in Education: Computer Science & Computer Engineering (FECS'09)*, Jul. 2009, pp. 141–146.

[14] A. Delman, A. Ishak, L. Goetz, M. Kunin, Y. Langsam, and T. Raphan, "Development of a system for teaching CS1 in CC++ with Lego NXT Robots," in *Proc. International Conference on Frontiers in Education: Computer Science & Computer Engineering (FECS'09)*, Jul. 2010, pp. 396–400.

[15] (2012, Jun.) NXC (Not eXactly C). [Online]. Available: http://bricxcc.sourceforge.net/nxc

[16] (2012, Jun.) RobotC. [Online]. Available: http://www.robotc.net

[17] (2012, Jun.) NXT++ (original web site). [Online]. Available: http://nxtpp.clustur.com/

[18] D. Butterworth. (2012, Jun.) RobotC example programs. [Online]. Available: http://david.butterworth.org.au/rie2012

[19] (2012, Jun.) NXT++ 0.7 (new version). [Online]. Available: http://david.butterworth.org.au/rie2012

Design of a Flexible and Project Based Postgraduate Module on Applied Computational Intelligence: A Case Study

Jenny Carter
Centre for Computational Intelligence
Faculty of Technology
De Montfort University
The Gateway
Leicester LE1 9BH
Great Britain
jennyc@dmu.ac.uk

Samad Ahmadi
Centre for Computational Intelligence
Faculty of Technology
De Montfort University
The Gateway
Leicester LE1 9BH
Great Britain
sahmadi@dmu.ac.uk

***Abstract*—The MSc Intelligent Systems (IS) and the MSc Intelligent Systems and Robotics (ISR) programmes at De Montfort University are Masters level courses that are delivered both on-site and by distance learning. The courses have been running successfully on-site for 8 years and are now in the fifth year with a distance learning mode. The Applied Computational Intelligence module gives students the chance to apply knowledge gained in other modules on an application area of their choice. A substantial number of these involve robotics work though not all. Over the years there have many excellent pieces of work submitted by students for this module and number have gone on to be published. This paper presents the background to the module, ideas for flexible design of such modules, some examples of the students' assignment work and a discussion of the perceived value of the module.**

***Index Terms*—Case studies, post-graduate, project based learning, distance learning, flexible design.**

I. Introduction

The MSc Intelligent Systems (IS) and the MSc Intelligent Systems and Robotics (ISR) programmes at De Montfort University are Masters level courses that are delivered both on-site and by distance learning. The courses are delivered mainly by the members of the Centre for Computational Intelligence (CCI) at De Montfort University. Their development enabled us to capitalise on the research taking place within the CCI and therefore on the strengths of the staff delivering the modules.

Each MSc consists of 8 taught modules and an independent project which is equivalent to 4 modules. Each module is worth 15 credits (7.5 ECTS). The MSc ISR includes two mobile robots modules whilst MSc IS replaces one of these with a Data Mining module as an alternative application area for those less interested in pursuing mobile robotics work. A Research Methods module is delivered in semester 1 to ensure that students are equipped with the necessary skills to carry out literature searches, write project proposals and so on; and a module titled 'Applied Computational Intelligence (CI)' enables students to pursue an appropriate area of their own interest in greater depth. An overview of the course content is shown in figure 1. In this paper we discuss the approach taken in design of the Applied CI module to create a flexible, dynamic and project based module.

The remainder of the paper is structured as follows: Section 2 gives some background information about the module, its learning outcomes and how they are assessed; Section 3 describes some of the work submitted by students for assessment in this module with particular focus on those that are robotics based; Section 4 provides some discussions and Section 5 draws conclusions from this work.

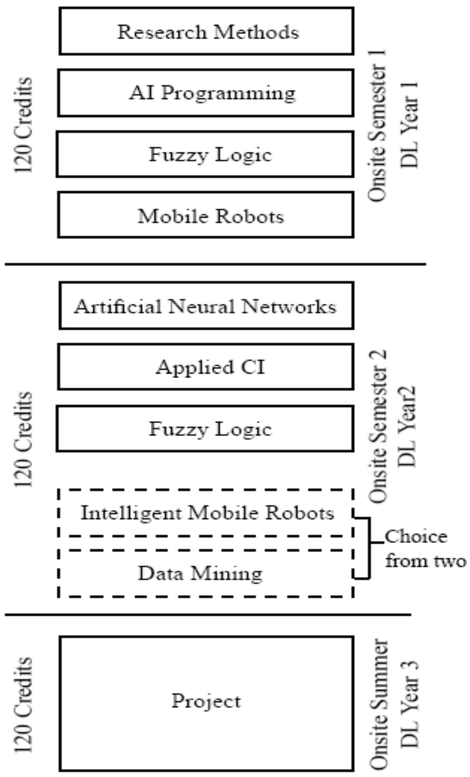


Figure 1. The course structure

II. The Applied Computational Intelligence Module

This section gives an overview of the content of the Applied CI module. There are two tutors associated with the module. The module aims to introduce new application areas of CI while bringing together the ideas and techniques covered in the other modules thus giving the students the opportunity to begin to develop their special interests. The learning outcomes (LOs) have been devised with this in mind and are as follows:

- LO1 - Apply AI techniques to given practical problems
- LO2 - Recognise the multi-disciplinary nature of AI and its potential application areas.
- LO3 - Critically appraise relevant literature in order to formulate a plan for their own practical/experimental work
- LO4 - Synthesise a solution to a problem (planned in LO3) and evaluate the solution.

In order to achieve these LOs the modules is organised into a series of lectures, lab sessions, tutorials and seminars. Also to achieve flexibility in bringing new application areas the module is designed as a set of different blocks of lectures each focusing on one application area and some gest lectures. This enables us to include new and exciting application areas based on our new interests without major changes to the structure of the module. Examples of such blocks are knowledge based systems, AI for video games, music and AI, web log mining and philosophy of AI.

This module is delivered both to on-site students and to distance learning students.The basic teaching strategy is to provide students with presentations, research papers and reading associated with fundamental issues and enable learning through reading, discussions (using the e-learning facilities &/or seminars), practical implementations and/or experimental work. Students are also given application papers to support the fundamental topics in the syllabus and have access to current research material much of which results from the work of the CCI. Each year there are guest speakers.

To accommodate the distance learning students some of the sessions are pre-recorded using video, some are in the form of presentations with added sound using Articulate Presenter, and there are various electronic resources including e-books that are available with multi-user licenses from the univeristy library.

The assignment is divided up into 3 components though 2 of these relate to the same activity. Initial laboratory work on some new topics as assessed as a portfolio of lab exercises and this is worth 20% of the module mark. The remainder is for the main project style piece of work. Assessment of this is divided up as 20% of the module mark for a conference style presentation and 60% for a report detailing the project work carried out. An extract from the assignment is given in below:

*"**Select an area of study** based on your interests and possible directions for your MSc project in consultation with your tutors (some example areas of applications are provided in Appendix 1). Write a short 'terms of reference' (TOR) document. This should be approved by one of the tutors before you begin work on this project."*

***Carry out investigative work** into the chosen area, this should include the following activities:*

- *critical review of associated literature*
- *Either a practical implementation to illustrate some feature of the application area **or** appropriate experimental work to support the investigation.*

So this part could take the form of practical work if for example you base your study in the area of Robotics or Expert Systems etc. or it may be experimental (something with music or data classification etc. might require this);

***Prepare a presentation** +/- demo that facilitates discussion of your subject area. This should last no longer than 20 minutes and should include 5 minutes for questions. For distance students we will arrange a time that fits with your work schedules and will use Skype (unless you want to come in to do it here in Leicester). "*

The students are required to submit the report in the form of a conference paper using one of the IEEE templates found in [1]. One advantage of doing this is that those that do work that is of publishable quality and are interested to do so can prepare the document for publication with the minimum of additional time. Tutors provide feedback for those cases to make the report into a publishable paper. In section 3 we consider some examples of the students' work.

III. Examples of Projects from Past Students

This section looks at examples of work submitted by students on this module in the past. We will briefly mention some of the non-robotics focused examples but will give greater emphasis to those that do feature applications in the area of robotics.

Projects chosen by students cover a wide range and many of them then take the work further for their main MSc project. Some have then continued with the work to PhD level. A number of students have completed good project work in the application area of AI and computer games, notably, Martin Rhodes [2, 3] and Matthias Brandstetter [10, 11] developed their work further for the MSc project and subsequently for a PhD in a related area. The subject of [2] and [3] was on using evolutionary computation to the optimisation of simulated free kick situations in Football and the resulting project won the BCS machine intelligence prize in 2008. In [10] a novel genetic programming was proposed to solve Ms. Pacman competition problem and in [11] a new approach and interface for learning from user experience in games was developed. William Lawrence [4], 5] developed a Mathematics teaching game using neural network.

Over the years quite a few students have used this assignment to develop entris for the Robot Challenge that takes place annually in Vienna [6]. Three of these are described below.

A. Autonomous robotics helicopter

Ben Passow started working on an autonomously controlled robotics heicopter for his assignment in this module (Fig. 2). He developed this for his Masters project and further work led to him being awarded a PhD. The helicopter has featured at the robot challenge on more than one occasion where he won prizes. He also won the BCS machine intelligence prize at the SGAI conference in Cambridge. The focus of this work was the development of a fuzzy inferencing system to control the heading of a small indoor helicopter and a section from the abstract is given here: “The work addresses the problem of system identification when implementing a Takagi-Sugeno-Kang type fuzzy logic controller. Instead of identifying the system formally beforehand, the fuzzy controllers consequent parameters are learned using a Neuro-Fuzzy Inference System with data collected from an existing, previously implemented proportional controller. The controllers are implemented on an embedded microcontroller driven system attached to the helicopter” [6, p1]

Figure 2. Autonomous robotic helicopter

B. Puck collect robot challenge entry

Another student, now also doing a PhD with us developed a robot for entry to the ‘puck collect’ stream. This is where the robot has to be able to wander around at the same time as an opponent and collect coloured pucks (the colour is either blue or red and is allocated at the beginning of the match). Pucks of the correct colour then have to be deposited on a ‘home’ square of the same colour. See Fig 3.

David Croft’s robot, Puckman, (fig. 4) used a vision system that meant it was possible to use only a small mouth for puck collection and the design was such that it aimed to collect only the correct colour of puck. A camera was mounted on the front of the robot as part of the vision system. If a puck of the wrong colour was collected a secondary system took over to identify and reject it. The edge detection technique implemented here was a FIRE operator with a Mamdani fuzzy inferencing system. David was able to apply this to a colour vision system by processing each RGB colour channel as separate grey scale and then combining them again. This was an excellent design and although the reasons were usually down to some other lesser fault rather than a problem with the idea and implementation of the vision system.

C. Sumo robot challenge entry

A current full time student of the course developed an entry for the sumo stream of the competition (Fig. 5).

For this development the student used the Lego NXT programmable brick. The computational design included the use of a colour sensor and a vision system (an ultrasound sensor). The vision sensor enabled the robot to find its opponent and then the use of the engineering features, namely the weapon, would set in. Again this was a good design with good ideas.

Figure 3. The puck collect entry [8]

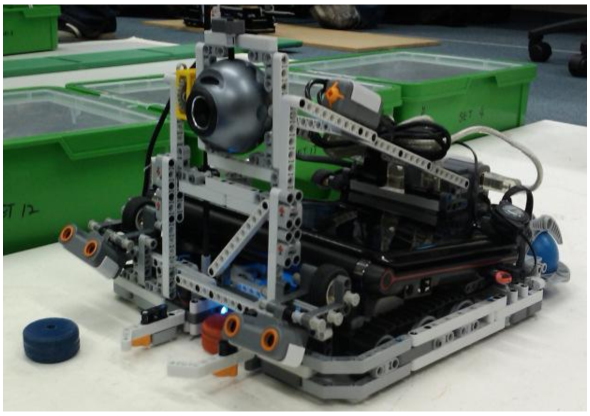


Figure 4. The puck collect entry [8]

Our students have entered sumo robots to the competition in the past as well and two won second and third prizes on different occasions.

Other projects that were robotics based but not specifically for the robot challenge includes that of Ed Laurence who did a project titled: ‘Application of Adaptive Neural Networks for Hover Control of an Autonomous Helicopter’. The helicopter used was a single rotor and the student investigated two approaches to configuring the network, namely Feedforward

Neural Networks *(*FFNN*)* and Elman's Recurrent Neural Networks *(*ERNN). The student achieved the highest possible mark for this work and it was truly outstanding.

Another example from a student this year who is a distance learner is that of Pamela Hardaker whose project is titled 'Using EMG signals for real time control of a microprocessor controlled prosthetic limb'. She carried out experiments in the use of an Electromyographic sensor to determine whether a person is standing, walking or running. She captured the output of the sensor in a variety of ways in order to find out which features could be observed to change as the person changed the type of movement. She then trained an Artificial Neural Network so that it could recognise each state and hence give a real time signal to a prosthetic leg.

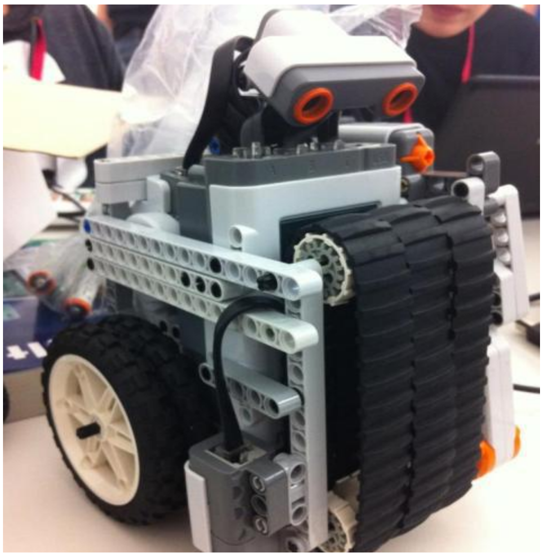


Figure 5. The sumo entry

In this section we have presented some illustrative examples of the work of students on the Applied CI module. The next section provides a discussion about the kind of work that results from the students studying on this module and we believe it to be an example of good practice.

IV. Discussion

The examples given illustrate the breadth of projects undertaken by our students but also show the depth that they are able to reach in their choice of application area by being given the freedom to choose and work in a project based way. Telling them that they can build on this work for their main project and providing them with examples of how past students have done this gives them a better understanding of how to go about planning and carrying out the assessed work for the module. Although the original design of the module was not centred on a specific learning style we believe that the module is an example of project based learning as defined in [9].

The presentations sessions are always the best part of the module. The topics that the students present are quite diverse which adds to the interest level and usually they are very enthusiastic and there are lots of clever ideas. The students in the audience usually join in asking questions as well which adds to the conference feel. If the students do then publish their work later they will have already had a chance to practise presenting in front of other people.

The distance students can come in to the conference sessions and present on-site if they wish and some choose to do this. Most distance students present by Skype to the two tutors and this works well. It is unfortunate that they miss out on the group presentations though and we hope to find ways around this. One approach that goes some way to at least sharing content is giving all students the facility to upload their presentations with sound if possible to a wiki on Blackboard so that other students can listen in their own time. So far only a few students have ever taken up this opportunity to upload their presentations in this way as it is voluntary but we may make it a compulsory part of the module in future so that everyone can see everyone else's presentation if they wish to.

We have found it very advantageous to have the written reports submitted using one of the IEEE conference templates. It is a good way of getting a sensibly formatted piece of work and it is easy to limit the length (e.g. by specifying 4-6 pages) without thinking about word counts. The students also seem to be happy doing this as they see how their work might look if it was to be published, as they do not have to make decisions about formatting and it gives them practise for the future.

Quite a few students have continued with the work that they started in this module for their MSc projects and for their PhD. One student in this year's cohort wrote a very detailed plan of work that was divided into work packets – the first being for this module, the second for his project and the third for a PhD which he has already applied for (and been accepted on) even though he still has his project to complete. This could be viewed as anecdotal evidence to suggest the approach taken in the module may encourage students to stay with us.

V. Conclusions

In this paper we have described the Applied Computational Intelligent module on the MSc Intelligent Systems (IS) and the MSc IS & Robotics courses at De Montfort University as an example of a project base module and a good example for flexible design. We have given example of projects undertaken by students with a particular emphasis on those that have a robotics focus. We believe that the approach taken encourages the students to undertake challenging projects that are of interest to them and as a result we see some excellent and innovative work, some of which has been published and some that has been developed further leading to MSc projects and in some cases PhDs.

Acknowledgments

We would like to acknowledge the students who allowed us to describe their work in this paper. They are: David Croft, William Lawrence, Pamela Hardaker, Ben Passow, Mike Cogle, Martin Rhodes, Edward Laurence and Matthias Brandstetter.

REFERENCES

[1] Institute of Electrical and Electronics Engineers (IEEE) home, June 2012. http://www.ieee.org/conferences_events/conferences/publishing/templates.html

[2] Rhodes, Coupland, 2008, An Evolutionary Approach to Simulated Football Free Kick Optimisation, in proceedings of SGAI 2008, Cambridge, UK.

[3] Rhodes, Coupland, 2007, An Evolutionary Approach to the Optimisation of Sport Simulations: Direct Free Kicks in Football, In proceedings of UKCI 2007, Imperial College, London, UK.

[4] Lawrence, Carter, Ahmadi, 2010, A GCSE Maths Tutoring Game using Neural Networks, In proceedings of IEEE Games Innovation Conference.

[5] Lawrence, 2009, A research proposal for a GCSE maths tutoring game using neural networks, In proceedings of International IEEE Consumer Electronics Society's Games Innovations Conference, ICE-GIC 2009 UK.

[6] Robot Challenge home, June 2012. http://www.robotchallenge.org/

[7] Passow, Coupland, Gongora, 2007, Embedded Helicopter Heading Control using an Adaptive Network-Based Fuzzy Inference System, UKCI 2007.

[8] Croft, Coupland, 2010, The Application of Colour FIRE to Robot VisionThe Application of Colour FIRE to Robot Vision, UKCI 2010.

[9] Grant, 2002, Getting a grip on project-based learning: theory, cases and recommendation, Meridian, Information & Communication Technologies Journal.

[10] M. Brandstetter and S. Ahmadi (2012). Reactive Control of Ms. Pac Man using Information Retrieval based on Genetic Programming, IEEE Conference on Computational Intelligence for Games, Granada, Spain.

[11] M. Brandstetter and S. Ahmadi (2012). Learning from User Experience in Games, the International Games Innovation Conference 2012, Rochester, New York.

Using Educational Robots as Tools of Cultural Expression: A Report on Projects with Indigenous Communities

Dave Catlin
Valiant Technology Ltd.
3 Grange Mills, Weir Road,
Balham, London SW12 0NE, England
dave@valiant-technology.com

James L. Smith
Office of Superintendent of Public Instruction,
Olympia, WA, USA
podsmith@gmail.com

Kenton Morrison
Evergreen Elementary School
Fort Lewis, WA. USA
espidon02@msn.com

***Abstract*—This paper reports on the use of educational robots with indigenous people. It shows how effective educational robots are at providing tools of self expression and act as a bridge between the modern world and the traditions of Native peoples. The original work first took place with Maoris in New Zealand. A similar, independent project, run by the Native American Squaxin People of Puget Sound, a Sovereign Nation in Washington State, embraced the understandings developed in New Zealand. Following a description of the project, we will evaluate the educational effectiveness of the project using the ERA[1] Principles as an evaluative framework[1]. We will also discuss the value of ERA as a helpful tool for understanding educational robotics.**

I. Introduction

In the late 1990s, the New Zealand government implemented a project aimed at enhancing and protecting the status of the Maori language and culture within the New Zealand society. This was part of an ongoing reassertion and rebirth of an indigenous heritage, which had been under pressure for years. The problem facing the Maori nation was their children were being seduced by the dominant Eurocentric culture and were loosing touch with their roots. An educational robotic project was a small successful part of an initiative aimed at countering this trend. The robot used was the Roamer supplied by Valiant Technology.

Similar problems are faced by indigenous peoples all over the world. There are striking parallels between the experience of the Maori and Native Americans. The Squaxin Island Peoples of Puget Sound in Seattle, Washington State also used Roamer in a summer project run at their tribal centre.

This paper describes these two situations and reports the role played by the Roamer and its practical effect on the wider aims of the community. We then analyse the Squaxin project using the ERA Principles as an evaluative framework. We will then argue that the results simultaneously contribute to the verification of the value of educational robots and the value of the ERA Principles.

[1]Educational Robotic Applications.

II. Research Methods

The original Maori work is taken from Valiant Technology's unpublished historical archives. The Native American Project took the form of an unstructured case study. Observers were both participatory and non-participatory.

III. A Brief History of Maori Culture

In order to thrive the first Westerners arriving in New Zealand had to learn Te Reo (Maori language). As early as 1814 missionaries were developing a written form of Te Reo. Maoris enthusiastically adopted reading and writing their language. Throughout the 19th century the Maori and Pakeha (European New Zealanders) mixed and Te Reo was common parlance even for government officials, missionaries and other prominent people.

By 1860 English had become dominant. Te Reo was confined to Maori communities largely rural and isolated from the Pakeha majority. Some parents encouraged their children to learn English and even to turn away from other aspects of their customs. Maoris questioned the relevance Te Reo in the Europeanised world.

This process of assimilation gradually led to suppression of the Maori language and culture. Sir James Henare remembered being punished for speaking Te Reo on the school grounds. More and more Maoris learned English in order to get jobs. Before World War II only 25% of Maoris lived in cities. The lure of work enticed a migration from the country and 20 years later 60% of the Maori population lived in the cities. By 1980 less than 20% of the Maori population were considered native speakers. In the 1970s reaction to this decline started. Maori leaders recognised how language was integral to their cultural heritage. Various initiatives precipitated a gradual change until Te Reo became an official language of New Zealand in 1987 [2].

Despite this the attractions of modern life mesmerised Maori youngsters and engaging them in their inheritance was not straightforward. In the late 90s a national programme was launched aimed at encouraging Maori and non Maori children to understand Maori culture, lore, language and traditional practices.

IV. Roamer Maori Project

As part of an initiative instigated by Massey University Education dept. co-operating with staff and student teachers at Palmerston North Teachers College, John Mellsop, the New Zealand Roamer expert, was asked to provide some workshop units that focussed on training teachers (Maori and non Maori) and student teachers in effective methods using Roamer as the motivation tool for children to take self initiated interest in learning.

John and others produced a number of interactive activities based around several ancient Maori Myths and Legends bringing the fabricated characters alive using Roamer to provide appropriate (but simple) movement whilst the story was read, narrated or adlibbed by students or the tutors (Fig 1).

Fig. 1. Selection of Maori Activities

In one version of the legend of Hinemoa and Tutaneki, Hinemoa, a Maori Princess, had to swim across the lake (Rotorua) in order to secretly meet with her lover Tutaneki who lived on Mokoia, an island in the middle of the lake. This swim involved exposure to tuna (eels), Taniwha (dragons), Rapu (water weed), rats, suspicious family (iwi) and other obstacles. Fig 2 shows Roamer characters and images of the Taniwha created by Maori students as part of the enactment of the story.

A large floor map of the lake and island was drawn. Various characters and obstacles were placed on this.

The students depending on age group had a variety of objectives to consider which involved not only language but solution design, planning, mathematics and environment issues.

V. The Native American Experience

In many ways the Native American experience parallels the Maori story. It seems fewer European immigrants "went native", but certainly there came a point where the agenda focussed on assimilation. Many tribal customs were banned and what seem to be outrageous acts of cultural vandalism went on long after the Second World War when the US Congress pursued a policy of termination. This process aimed to assimilate Native Americans by terminating the separate Nation rights of the various tribes. This only stopped in 1970 [3].

Fig. 2. Roamer characters created by Maori students.

It was in the 1970s that the Native Americans started reasserting their cultural identity. By 2010, when the Roamer Squaxin Project took place, the process of revival was commonplace.

VI. Background to the Squaxin Project

The Squaxin are a small tribe, part of the Salish peoples, who form a cultural, ethnographic and linguistic sub group within Native American society.

The traditional home of the Squaxin is a small isle in the marine waterway complex (Figs 3 and 4) known as Puget Sound in the Seattle area of Washington State, USA. The thickly wooded Cascade Mountains isolated the coastal tribes of the North Western seaboard, and consequently the canoe became a major method of travel.

Fig. 3. View across the waterways of Puget Sound. Because of their connection to the sea the Squaxin were also known as the People of the water.

For centuries Squaxin used the canoe to journey to potlatch gatherings up and down the Pacific coast line. The potlatch was a festival of giving - effectively a redistribution of wealth. It involved feasting, dancing and singing. Much of this was spiritual and sacred. A single potlatch could last for weeks [4].

Fig. 4. The Squaxin tribal homeland.

The potlatch was beyond the comprehension of European American (and Canadian) people. In particular it was beyond the pale for Christian zealots aiming to "civilise the natives". Its banning and the opening of land routes saw the end of the canoe journeys.

In 1989, as part of the reassertion process the Salish Tribes restarted the canoe ceremony (Fig 5). It has now become an annual event.

Fig. 5. The traditional canoe journeys went as far south as San Francisco and north into British Colombia.

VII. Squaxin Roamer Project

Tribal Elder and the Squaxin Education Director approved this project. It was organised by James Smith from the Superintendents Office in Olympia with the support of Dave Catlin from Valiant Technology.

The event was held at the tribal centre and as it was a summer school project, attendance was not compulsory. Kenton Morrison, a local elementary school teacher and experienced Roamer user, trained students from the Gen Yes Program[2] to run the project.

As with Maoris youngsters, Squaxin students live in a world where their culture is marginalised. We will show later that this is not just a result of suppression, but a natural consequence of what is called the Circuit of Culture. The aim of this project was to engage the students in STEM rich activities linked to the traditions of the tribe. Just as with the Maoris we suggested a number of Roamer activities based on the traditional stories of the Squaxin peoples[3] [4]:

1) The Salmon Run (Fig 6)
2) The Origins of Animals
3) Hunting Activity
4) Gathering Berries

The essence of these activities would be familiar to Roamer users in New Zealand, British and American classrooms: that is, familiar in terms of what the students do and the STEM[5] content they engage in. What is different is the contextual aspects - and we will see that this is significant.

The original plan was to use the stories to familiarise the students with the Roamer. Then they would use the robot to explore:

1) The Canoe Journey
2) The Potlatch
3) Tribal Dance

Fig. 6. The students created a Salmon costume for Roamer and programmed the robot to "swim" up the river avoiding obstacles like the bear, rocks and fishermen.

The idea was for students to film these events. A bureaucratic miscommunication lost a week of the programme and the Tribal Centre was closed for two further weeks as a mark of respect for the death of two Tribal Elders. Consequently, the students only engaged with the Salmon Run activity and while a lot of the film work was done, it was never completed. Nevertheless, participants considered the project a successful excercise.

A. *Kenton Morrison's Project Report*

Students were highly motivated to work with the robots. We used some simple lessons to teach the students to program the robots. We taught them how to storyboard a story and create backgrounds and props for Roamer. This led students to an interest in their tribal art.

[2]http://genyes.org/

[3]tribehttp://squaxinislandmuseum.org/

[4]All these activities are freely available in the Roamer Activity Library: https://activity-library.roamer-robot.com/

[5]Science, Technology, Engineering and Mathematics

While working with this concept, community members began to take interest. They were able to share the importance of the tribes canoe journey. The original idea now evolved into Roamers re-enacting parts of the trip.

Students began researching the route of the journey and the tribal traditions and celebrations that occurred when the canoe arrived at each stopping point. To make this successful, we enlisted the assistance of community members that had made the canoe journey. Community members taught tribal art, music, and dance. They also provided information on the journey itself.

Students now started learning tribal dances, songs, drumming, and tribal art as they studied tribal celebrations. Students decorated the Roamers with hand-made tribal blankets and programmed them to perform tribal dances (Fig 7).

Fig. 7. Students have dressed Roamer up with the blankets they made and are ready to start the drumming and dance session.

The event cumulated in a morning activity where all students gathered to share their learning. One group had created a giant floor map of the route of the Canoe Journey. Students would program Roamers, that had been decorated to resemble canoes, to travel from point to point in the journey and discuss what happened at each point (Fig 8).

Fig. 8. The Roamer canoe enacting the Canoe journey while the story is narrated by the students.

In the end, the head of the summer school, who had been sceptical at the start, stated that he had never seen a summer where students took such an interest in their culture. Roamer became the catalyst for students to find and study areas of culture that interested them.

B. Comments from Sally Brownfield

Squaxin Education Director Sally Brownfield made the following comments about the project:

"Tribal youth experienced a deeper understanding of their language".

"Adults saw it as curriculum; this transformed and they started to see it as culture".

"I was also pleased that the students wanted to learn more about indigenous math and science used in the navigation process of the Canoe Journey. The moon, stars, and land masses created a natural navigation laboratory".

C. Comments from James Smith

James Smith from the Olympia Superintendent's office commented:

"Instructors were pleased that students wanted to learn more about their culture through the use of Roamer reproducing the Canoe Journey".

"Would they have got into this without Roamer? Yes. But they got into it quicker than they would have normally. They saw it initially as school work but recognised how school connected with culture. Recreating the journey on the floor with Roamer brought it to life for them".

VIII. Basis of Analysis

Beyond the scope of this paper our wider objective is to show how educational robots can enhance a student's learning experience in many different learning scenarios. These can be formal learning situations, where we must demonstrate to teachers that robots can support their efforts in delivering curriculum and raising the test scores. They can also be less formal objectives - like those of the Squaxin project. Political and public pressures in some education systems demand the use education methods supported by "scientific research"[6]. Such restraints apply to the tool (robots) and the application (robotic activity). So while we can analyse the activities presented in this paper we can also ask, how these findings contribute to a more general verification of educational robotics.

The ERA Principles provide a tool we can use to examine the value and effectiveness of educational robotics in a consistent way [1]. They provide a framework for designers and educators creating robots and robotic activities. They were created by Dave Catlin and Mike Blamires based on an amalgam of educational theory, the practical needs of teachers and students and the technical insights of robotics and AI. Above all they were influenced by Dave Catlin's 30 years of unpublished experience with educational robots in thousands of schools and in 30 countries on 5 different continents.

The e-Robot Project is a longitudinal research programme aimed at gathering evidence to substantiate ERA [5]. While we use ERA as a benchmark for evaluating activities, we also

[6]See the e-Robot project reference for citations relating to this claim.

use the results of that analysis in e-Robot to verify and refine ERA [7].

In general e-Robot does not aim to compare whether using robots to deliver a particular aspect of education works better than a non-robotic approach. We are working on the premise that teachers need to be able to choose methods from a range ways of engaging students in appropriate education experiences. We recognise that whats suitable for a specific teacher and group of students in a particular time and situation varies. Sometimes it will be fitting to use robots and other times it would be inappropriate. Our wider aim is to gather evidence that validates the use of robots.

We present our analysis with a formal definition and a brief explanation of a relevant ERA Principle. This is followed by comments on its significance to these projects.

IX. Analysis

A. ERA Principle: Pedagogy Principle

The science of learning underpins a wide range of methods available for using with appropriately designed educational robots to create effective learning scenarios.

This principle identifies 28 different characteristics of educational robotic activities. These traits can be thought of as the 'atoms' that combine in different ways to make educational robotic activities valuable experiences. The following analysis takes a characteristic and explains its embodiment within a specific Squaxin activity to demonstrates the value of the activity.

1) Activity: Salmon Run

Pedagogical Principle: Focussed Task
A focussed task helps the student develop a narrow skill.

In The Salmon Run to make Roamer travel along the river students have to move the robot specific distances, turn specific angles and to do this series of actions in a specific order. In doing this students get to practice estimation skills for distance and angle. Students did get the angles and distances wrong. However, they were able to refine their solutions while simultaneously honing their basic skills. This type of self correcting process is a positive learning mechanism.

Pedagogical Principle: Engagement
An aspect of the activity that clearly engages the students interest and creates a positive learning environment.

Students found it entertaining when they estimated the angle incorrectly and made the salmon swim into the mouth of the bear instead of around it. This kind of mishap endowed the activity with a spirit of enjoyment and consequently created a positive learning environment.

[7]We cannot represent the arguments supporting ERA and e-Robot in this short paper and the reader is referred to the original papers available online at http://www.valiant-technology.com/uk/pages/archives.php#researchpapers

2) Activity: Tribal Dance

Pedagogical Principle: Experience
Robot activities can provide students with experiences that provide the opportunity for implicit learning which contributes to a student's prior learning repertoire.

The dance activity involves mathematical ideas of sequence, pattern, symmetry, translations and rotations. The students involved in this activity were too young to have formally met these concepts in school. The Experience Principle claims that prior knowledge is a well established Science of Learning tenet. Moreover, much of students' prior knowledge is subconscious. It is gained through established psychological processes relating to implicit learning. We do not claim that student engagement in the Dance Activity proved or contributed to a proof of these claims. That needs to be established in a more specialised research project. If we accept the principle as a conjecture, we can claim that the mechanisms for developing appropriate experience is evident.

Pedagogical Principle: Exploration
This is using a robot to explore a situation and consciously discover the knowledge embedded in a Microworld or the environment.

Some of the students involved in the dance activity did start to recognise formal ideas and consciously use them to develop their dance. For example the notion of a pattern of movement translated to a different location. We note that this did not involve the development of formal mathematical language, though students did invent words to discuss their endeavours.

Pedagogical Principle: Modelling
Students use a robot to model an idea. This frequently takes the form of a program representing a mathematical idea.

The process of watching the dance, interpreting that as movement of the robot, then producing a program to perform that movement is an example of the students' engagement in the modelling process.

Pedagogical Principle: Creativity
Robot activities can provide the opportunity for creative thinking exhibited through the development of novel solutions to problems, imaginative use of knowledge and concepts or the development of something with artistic merit.

In this activity students could simply model what they saw. Some did that. Others showed creativity and embellished the dance movements of the robot.

Pedagogical Principle: Catalyst
This is an aspect of educational robot activities that causes students to engage in a series of tasks that do not directly involve the robot.

The Dance Activity encouraged students to engage with tasks like weaving and exploring patterns in the design of blankets. It also provided a context for learning traditional music.

3) Activity: Canoe Journey

Pedagogical Principle: Research
Students research topics and gather information necessary to successfully complete an educational robot activity.

Students had to find out about the canoe journey and apply that to the activity. Their research involved them seeking advice from more knowledgeable people (Elders) and studying publically available information.

Pedagogical Principle: Presentation
Students use a robot to present what they have learned.

Students presented what they had learned about the canoe journey using the Roamer.

B. ERA Principle: Personalisation

Educational robots personalise the learning experience to suit the individual needs of students across a range of subjects.

Both these projects are macro examples of this principle. The Maori activity of programming the Roamer to avoid the obstacles as it swam to the island, involves the development of the same mathematical skills as the Salmon Run activity. The cultural settings personalised the activities at a group level. On this level personalisation was a vital part of both projects. It was, as reported by all those involved, successful in connecting students to their culture and through their culture to elements of school curriculum. For example:

1) Reading and writing skills were engaged in presenting the canoe journey
2) Programming skills were involved in all the activities
3) The activities involved mathematical skills of measurement, estimation, pattern, sequence, symmetry, translations and rotations as well as the opportunity to practice basic arithmetical skills to solve practical problems
4) Making skills were inovled to create props and the robot characters
5) Aspects of the geography curriculum was covered in the creation of maps
6) Music skills were involved in dance activity

C. ERA Principle: Equity

Educational robots support principles of equity of age, gender, ability, race, ethnicity, culture, social class, life style and political status.

Although it was not the main focus of these projects, it was clear that curriculum was involved. Writers Gay [6] and Bouillion, L.M., Gomez [7] show the importance on the cultural situating and contextualisation of activities on the issue of curriculum Equity. Catlin and Robertson [8] explore how the Circuit of Culture relates to Equity and educational robots. They would cite the observed performance of the students in the activities, showed the ability of Roamer to adapt to the cultural and ethnic situation and reduce the cultural curriculum barriers often facing minority groups. In this context this project provides evidence supporting the Equity Principle.

Cultural expert Professor Stuart Hall points out: *Culture.... is not so much a set of things, novels and paintings or TV programmes and comics, as a process, a set of practices* [9]. This certainly attests to the significance and power of active participation in the canoe journey. He explains that shared meanings do not mean that every member of a culture has the same opinion on a topic and that culture is not simply a cognitive process: it is also about feelings, attachments and emotions. The Circuit of Culture (Fig 9) illustrates how culture creates meaning. It demonstrates the dynamism of cultures, how they self perpetuate and how they mutate in a complex process. The Squaxin canoe journey is an iconic cultural

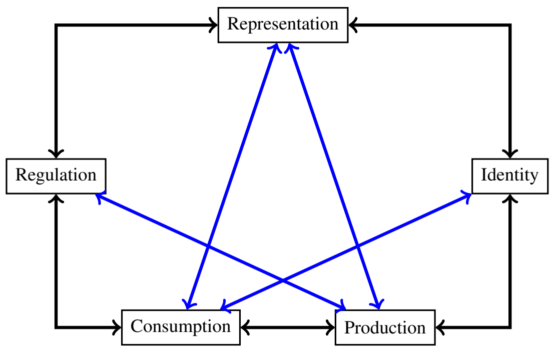


Fig. 9. The Circuit of Culture depicts the relationships between the different elements of culture.

representation - a practice of the community. The community **regulates** how, formally or informally, the modern canoe journey is organised and conducted. Of course a community **consumes** its culture, it watches the canoe journey, listens to the drum beats and hears its songs. Obviously it also **produces**; members beat the drums, sing the songs and paddle the canoes. People who participate in these various processes **identify** with them, They become members of the community.

Subgroups exist within the Squaxin community: Elders, women, men, children. The Squaxin are not isolated. They are also American. There lies the heart of the cultural problem. Squaxin youth are subjected to the mainstream American Circuit of Culture, which because of sheer number of producers, consumers and representational forms tends to drown out their participation in the Squaxin traditions. The suppression years made the situation worse, but the American Circuit of Culture predicts the inevitable distraction of Squaxin youngsters from their tribal traditions. This type diversion concerned both Maori and Squaxin Elders.

D. ERA Principle: Engagement

Through engagement Educational Robots can foster affirmative emotional states and social relationships that promote the creation of positive learning attitudes and environments, which improves the quality and depth of a student's learning experience.

This principle also plays a crucial role and interacts with Equity in a potent way. Clearly the students become involved in the projects. What initially appeared to many to be simple curriculum explorations, transformed into cultural events because of the students' engagement as active learners. Instead of passively listening and watching (**consuming**) the culture, they became **producers**. Students sought information and advice of the Elders and applied that knowledge to a modern technology. Effectively they **produced** new forms of culturally endowed **representations** for the **consumption** of their community and the reinforcement of their **identity**.

E. ERA Principle: Sustainable Learning

Educational Robots can enhance learning in the longer term through the development of meta-cognition, life skills and learner self-knowledge.

Typically educational robotic activities involve scenarios that present students with opportunities to develop life skills.

Cognitive Development	
Managing	Research
Emotional Development	
Relating	Communication Cooperation
Caring	Sharing Empathy
Social Development	
Giving	Group Contributions
Working	Presentation Teamwork
Personal Development	
	Motivation

Fig. 10. Sustainable Learning opportunities identified in the Squaxin Project

Fig 10 represents admirable human traits as classified by the ERA Sustainable Learning Principle and are evident in these projects. While it is impossible to measure whether the students actually developed these skills, we can report they were involved in situations where they had the opportunity to engage in them through practice.

X. Conclusion

The two projects indicated the possibilities of using educational robots as a bridge between students, the traditional culture and the modern, often dominant culture, that they experience on a day to day basis. They provided the students with the opportunity to become active learners and participants in a Circle of Culture involving their native traditions. Participation in the canoe journey is an act of cultural production. But participation is restricted to adults. Roamer allowed the students to become producers and not simply passive consumers of culture. By embracing robotics it modified the regulatory aspects of the culture. That which is seen as culturally acceptable now included a modern technology. It was clear from the responses of the Maori and Squaxin Elders that they considered the work as a help to strengthen their children's cultural identity.

The Squaxin project provided evidence of the potential for educational robotics to connect students to the curriculum via their cultural environment. It is believed the Maori project also provided this evidence, though it was not specifically noted at the time. What was evident in the Maori project is that non-Maoris also connected to the indigenous culture of New Zealand in a positive way.

We also feel that the ERA Principles provided a useful tool for evaluating the project. The process of using ERA also demonstrated the effectives of the principles.

Acknowledgment

The authors would like to thank John Mellsop for the supply of information relating to the Maori experience and Sally Brownfield and the other Tribal Elders of the Squaxin Peoples. We would also like to extend our appreciation to the teachers at Massey University and Palmerston Teacher Training College. A special thanks to the GenY students for the help with the Squaxin Project.

References

[1] Catlin, D. and Blamires, M. (2010) The Principles of Educational Robotic Applications (ERA): A framework for understanding and developing educational robots and their activities. Proceedings of Constructionism 2010, Paris

[2] 'History of the Maori language - Te Wiki o Te Reo Maori': Decline and Revival url: http://www.nzhistory.net.nz/culture/tereo-introduction (Ministry for Culture and Heritage), accessed 21-Feb-2012

[3] Fixico, D.L. (1990) Termination and Relocation: Federal Indian Policy, 1945-1960. University of New Mexico Press

[4] Beck, M. and Oliver, M. (1993) Potlatch: Native Ceremony and Myth on the Northwest Coast. Alaska Northwest Books

[5] Catlin, D. and Blamires, M. (2010). The e-Robot Project: A Longitudinal On-Line Research Collaboration to Investigate ERA Principles. TRTWR 2010 Conference, Darmstadt, Germany, part of SIMPAR 2010.

[6] Gay, G. (2000) Culturally Responsive Teaching: Theory, Research and Practice. Teachers College Press.

[7] Bouillion, L.M., Gomez, L.M. (2001) The Case for Cultural Entailments and Genres of Attachement in the Design of Educational Technologie p 331 to 349 in Smart Machines in Education Edited by Forbius, K.D. and Feltovich, P.J. MIT Press.

[8] Catlin, D. and Roberson S. (2012) Using Educational Robots to Enhance the Performance of Minority Students, TRTWR 2012 Conference, Riva La Garda Italy.

[9] Du Gay, P; Hall, S; Janes, L; Mackay, H; and Negus, K.(1997) Doing Cultural Studies. The Story of the Sony Walkman. Sage Publications in association with the Open University.

[10] Hall, S. Editor (1997) Representation: Cultural Representations and Signifying Practices. Sage Publications in association with the Open University.

Robots Facilitate Team Building at Adults' Learning Groups for Cultural Studies

Nikolaos Fachantidis[1], Alexandridou Paraskevi[2], Dimitra Tosiou[3]
Educational Dept., University of Western Macedonia
Florina, Greece
[1]nfaxanti@uowm.gr
[2]alexandridou@gmail.com
[3]toula220@hotmail.com

***Abstract*—This paper examines if robotic activities can offer a proper context for adults' team-building and also proper learning environment. Effective team-building seems to be an important factor for adults' learning communities, but also for organisations' operation.**

Socially assistive robotics (SAR) related researches show that human-robot social interaction rather than physical contact, is the success key of many tasks from rehabilitation therapies to cognitive activities.

In our project, adults who met each other for first time, participated in robotics hands-on tasks in cultural studies. Tasks involved construction, but also social interaction with humanoid robots. Project implementation and data analysis showed that participants considered that robot involvement had a positive impact in both major goals: participants' team development and cultural aspect learning. Questionnaire analysis showed that the combination of such a technology with cultural activities can offer a context not only suitable for learning, but also for team-building. Social interaction with robots motivated participants to achieve progress in learning and to communicate/collaborate as a team.

***Index Terms*—Cultural studies, Educational Robotics, Team Building, Socially Assistive Robots, Interactive Robots, Learning Environment, Traditional Dance, Edutainment.**

I. INTRODUCTION

The last decades governments around the world have declare the need for more effective training for adults and have linked this objective specifically to the needs of the labour market. European Union member countries, agree that lifelong learning is one of the most important characteristics of social and working life not only in the future, but also in our days. Employees and professionals, of all skill levels, have to improve their technical and business skills and enhance them in order to be aware of the continuous technological changes and new job requirements [4]. The dramatic growth of the adult-student population and also the need to promote lifelong learning, stresses for proper organized educational methods, based on adulthood characteristics.

In the field of adult education, there is a long discussion about adulthood definition. According to Rogers [16], it is rather difficult to define an adult and identify those characteristics inherent within the cultural construct of adulthood. He suggests that the basic characteristics of adulthood include far-sightedness, self-control, established and acceptable values, security, experience and autonomy. Jarvis [7] adds that the concept of adulthood refers to those individuals who are considered as adults within their society.

Adults have different study approach from kids, with high ability of learning and also acquiring knowledge and skills. According to Courau [2], there are specific principles related to adults' learn, skills and attitudes acquisition. The first principle suggests that adults learn when they are familiar with the training material. With respect to the second principle, training should be related to adults' every day life, goals and needs with meaningful instructions. The trainer should inform them analytically for the educational goals and also their progress. Adults learn better if they can self-direct their training and also participate actively. They have accumulated a wealth of information and experience, which can function as a rich resource for learning. Major principle related to adult education is motivation to learn. Adult learners are primary motivated to internal factors, such as self-esteem, quality of life and job satisfaction. They need to feel that they belong to a learning group, with warm relations. The members of the group should accept and support each other and work cooperatively.

II. TEAM BUILDING FOR ADULTS LEARNING

A. *Theories and schemes*

According to Courau [2], group activities facilitate adult learners to fulfil the most of the above mentioned principles. Team building also works as an organizational strategy to engage employees and improve productivity [11]. Researches [8], [13] show that team building has a positive moderate effect across cognitive, affective, process, and performance outcomes. Future work places may require people to rely on team members for rewards, recognition, and training traditionally provided by the company. Strong teams may hinge on developing career paths and designing career development events that are deployed through team-based experiences [1].

In team building, the adults form small groups (3-5 persons) and a project is assigned to them, which they have to accomplish in a certain period. The adults, as members of a team, have the opportunity to work together in order to solve a problem, or to work in parallel the different tasks of the same project. Because of the small group, they feel comfortable to express their opinion, to their teammates. In this way, team working, benefits the development of friendly and close relations between members and also increases participants' self-directed learning ability Courau [2]. The intensive and authentic communication between team members, supports reflecting thinking, increases motivation to learn and secures active and critical participation in a social context [20].

According to Maslow's Hierarchy of Needs (1954), each member in the team seeks for safety (including freedom from anxiety and stress), the need for belongingness, friendship and love and also seeks to feel competent, confident and self-assured. These can be obtained easier, if the team starts its life cycle working on an achievable activity with edutainment characteristics. The original research about team-development model [18] describes four stages in the development of a team-forming, storming, norming and performing. The act of passing through the team-development process is the process of converting a loose group into an effective team. In the first stage (forming) the members are still unsure of each other and looking for the trainer's help. In the second stage (storming) members challenge the views of others and express their own, finding areas of disagreement. In the third stage members agree on the principles of cooperation and work together. In the forth stage, as the team reaches the end of their cooperation, either the members make one concerted effort to finish the project, or they are breaking up as they regret the end of the project. Later researches modelled team's life cycle in a more detailed approach [18], assigning key factors to the four stages.

The first two stages are considered crucial, since the team members try to adapt and relate to each other and also to find their role in the team. For this reason special effort is given by educators and consultants, but also by companies that sell infrastructure for team building. Lego Foundation has developed a special product range: Lego Serious Play, for facilitating the first two stages of team building: "It is a language, communication tool, problem solving methodology, based on the belief that everyone can contribute to the discussion, the decisions, and the outcome." [11]. The product (kit and instructions) propose three steps: Constructing, Giving meaning and Making the story.

B. *Implementing Robots to facilitate the team building stages*

The Human-Robot Interaction (HRI) for socially assistive robotics applications (SAR) is a relatively new established research area at the intersection of a number of fields, including robotics, medicine, psychology, cognitive sciences and sociology [21]. New applications for robots in health and education are being developed for broad population of users. In SAR applications the robot's goal is to create close and effective interaction with a human user for the purpose of giving assistance and achieving measurable progress in convalescence, rehabilitation, learning, etc [6].

Lego's Serious Play effort, which is based mainly on Constructionism theory [16] and Social Constructive theory, take advantages of the diversity of Lego's bricks and the unlimited creations that can be constructed. In the other hand virtual teams can be supported with special designed systems [7] or through computer games [3]. Robotics can offer both the construction and software capabilities in order to support diverse activities during team building. They also offer the opportunity to design and construct creations/mechanisms that have close relation with the team goals and the whole effort (adults training or employee management).

In this work we present robotic constructions that facilitate team building at adults learning groups for cultural studies.

Fig. 1 Lego's Serious Play kit

Fig. 2 Lego's Serious Play for Adults Team Building

III. PROJECT "LEARN TRADITIONAL DANCE WITH ROBOTS"

During the 27th of June to 8th of July 2011, the Intensive Program "People and Space in the Borderland of Western Macedonia: Tracing historical, social and intercultural features" took place at the Educational Department of University of West. Macedonia in Florina. 25 postgraduate and undergraduate students from Holland, Cyprus and Greece participated. They followed daily courses, related to culture aspects of the area (history, architecture, sociology, etc.).

From the previous year, it has been cleared that team building activities would have been a proper start of the program, since students were unacquainted and faced problems initially in communication and cooperation. Because of the intensive character of the program, team building activities should have not been distractive or irrelevant to the courses' academic goal. On the other hand the initial courses were theoretical, with no opportunity for interactive activities.

To face those issues we came up with a schedule to implement robots in order to facilitate the team-building with activities relevant to the courses. We chose to design a cultural project on traditional dance and costumes. The topic was included in the program curriculum. So the purposes of the project were:

1) getting to know the culture of Florina (knowledge acquire) and

2) interaction, communication, familiarity and acquaintance between learners through activities with robotic constructions (team building).

The 25 participants were divided to 6 teams (1 group of 5 individuals, 5 groups of 4 individuals), in order to have small groups, according to previous researches. The teams were mixed to prevent aggregation of expatriates and possible acquaintance, which would compromise the second purpose of the survey.

Fig. 3 The common robotic platform used in the project

C. Robot architecture

According to Feil-Seifer and Mataric [5] socially assistive robots (SAR) must engage the user effectively, without need for user extensive training and has to be implemented with proper physical embodiment. Because of the lack of time we decided not to start from scratch, but to give the participants a common robotic platform as a base (fig.1, fig. 2). The robots were required to dance and so they were designed and constructed in order to move on the floor (towards both axes X & Y) and also to face in every direction (upper body torso rotation Rz). In order to synchronise its movement (dance steps) with the music a microphone was used, along with an ultrasonic sensor for collision avoidance. The dimensions of the robot were decided so it could be able to perform the “Zaramo” dance on a table, but also to be big enough in order to give to the participants the ability to dress it.

D. Team building activities

The educational process was divided into five phases. Each team was given a short questionnaire so each group would have to evaluate the other teams, at the end of each one of the five phases.

Phase 1: introductory or informative. Participants were informed about the general purposes of the scheduled bonding activities and the stages of these activities. Moreover they discussed the possibility of connecting robot activities with cultural goals (eg dance, theatre, social aspects, etc.).

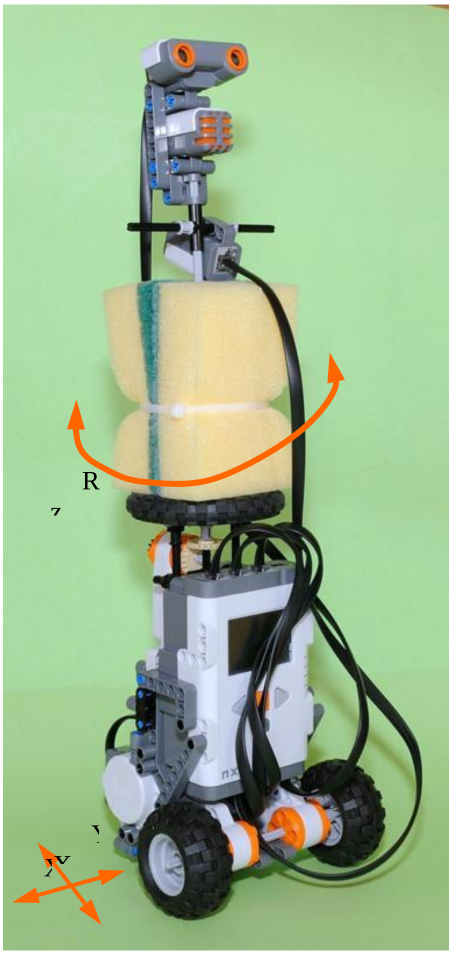


Fig. 4 The common robotic platform movements

In order to familiarize with cultural and traditional aspects of the city of Florina, participants were introduced with real authentic traditional costumes and watched videos about the local dance "Zaramo." The ensuing debate focused on the traditional clothing (colors, decorative items) and analysis of the steps of "Zaramo."

Phase 2: best costume contest. The content of this activity was the creation and decoration of traditional costumes, using a special pattern, which would help them to create a garment for the robot dancer. The teams worked at different work corners. Each group could obtain useful materials (corrugated paper in various colours, paper napkins in various colours and with various designs, ribbons, sea shells, markers, pencils, scissors, glue) for the decoration of its costume, from the special corner that was available for this purpose. After completing the costume, two sponges were placed on the robotic construction, which would facilitate the placement of the costume on the robot.

Fig. 5 Robot costume construction

In the end, each group evaluated the other teams' costume. The evaluation criteria were the quality of the fabric (quality textile) and decoration of the clothing of the robot (art).

Fig. 6 Robot costume completion

Phase 3: contest about the synchronization of the robot motion with the repeating patterns of music and dance. In this phase, each team had to synchronize the movement of its robot according to the repeating patterns of dance - music. All robots "knew" how to dance Zaramo. The robots were programmed to start dancing "Zaramo" by the clapping of hands, to make the six steps of the dance, and then stop. So, every time a member - representative of the group was performing in the class, he was clapping his hands as many times as necessary in order to give rhythm to the robot mimicking the traditional ways, based on the music and patterns of Zaramo according to the video that was being played. At the same time, the other groups were rating the robot's motion control of contestant group.

In the end, all the robots were placed in the traditional circular shape, to dance Zaramo all together with the synchronized hand-clapping of all groups.

Fig. 7 Robot dancing completion

Phase 4: dance contest between groups. The goal of this activity was the transition of knowledge (dance learning) from the robot to the individual. The participants in order to learn Zaramo placed on the floor the 6 steps (in the form of footprints) of Zaramo, which had been designed on A4 papers. The practice was followed by a dance contest between the groups. Each team had to dance in a circle and was rated by the other groups, with evaluation criteria: 1) the rhythm, ie whether the sequence of steps combined with the music (slow or fast) 2) the steps, ie the movements of the legs were correct, based on the six dance movements and 3) the cycle, namely whether the team maintained the shape of the cycle during the dance.

Phase 5: The end of the team building activities. At the end, all participants were given an individual questionnaire that aimed to evaluate the educational process and to reflect on this new educational experience.

This questionnaire lasted 10 to 15 minutes and included the following open-ended questions:

- What did you like on this activity?
- In what topics/points did you work together?
- In what topics/points did you disagree with other members of the team?
- What game elements did you recognize in this activity?
- Have you seen something similar (fun with robots)? If you have seen, write the similarities or the differences.
- What did you learn doing this activity?
- Was this activity important? Why or why not?

Fig. 8 Dance contest between groups

Students rated their participation in the three competitions. In each competition, the groups evaluated one another. The rating (from 1 to 10) was carried out, on paper, based on specific evaluation criteria for each competition. The scores of the teams were announced at the end of the educational procedure. Table 1 shows the pooled results of six teams, for each of the three contests (best costume contest, contest motion control robot, dance competition between groups), that the groups attended.

TABLE I
THE FINAL RANKINGS OF THE TEAMS IN THE 3 CONTESTS

Teams			1	2	3	4	5	6
Robot	dress	Quality textile	43	38	35	39	38	34
		Art	43	38	35	38	39	35
	Motion control		36	37	36	37	37	39
Human	rhythm		41	42	35	33	38	41
	Steps		41	40	35	31	38	40
	Circle		41	45	38	35	42	42
	Results		245	240	214	213	232	231

IV. Project Evaluation – Data Analysis

For the assessment of the activities and results of the educational process, we used 2 tools: an instructor log (with data from observation and cam recorder) that was maintained all the way by a second observer and a questionnaire completed at the end of the program by the participants. In this way we had the capability to analyse data from [14]

the physical context
the human context
the interactive context
the project context

E. Observation data analysis

Based on instructor and observer log and also on the cam recorder we can evaluate the process of the team building according to the four team developing stages (Tuckman 1965). In the authentic costume and dance observation the participants were still hesitant and wandering about the nature of the project and how they would be able to combine the traditional costume and dance with robots. In the second stage, (after the first 20 minutes), they had already got to know each other and start the storming period. They tried to find their role in the team, but in a pleasant way, since the costume design and construction was fun, creative and triggered their imagination regarding the dressing of the robot. They carefully dressed up the robot and had fun while taking photos. In the third stage the participants got excited once thy learned from the instructor that they would be the ones synchronizing the robots' dance with their clapping and are eager to see how that would work out. The teams seemed to be in balance and unity, once they choose their representative without much ado. In the next activity, but at the same team-building stage, all participants tried their best in order to learn and carryout the Zaramo dance. They even hold hands and started dancing in circles which is considered a big step since such effort would have been fruitless at the beginning of the project. At the last stage of the team life cycle, they filled out the questioner, and they seemed happy that they learned the Zaramo without being heavily concerned of their grades.

F. Questionnaire data analysis

For the analysis of the open ended questionnaire we followed the quality discourse analysis.

Almost half of the participants (11/25) claimed that they liked the costume design/construction and the Zaramo dance. Another big group (10/25) liked the cooperation/collaboration between the team members and the team-building spirit. Few of them claim that they liked activity freedom (3/25) and creativity (2/25).

The majority of the participants (17/25) stated that they worked together in order to make the costume and to dance and the rest of them (8/25) stated that they cooperate in every phase of the project.

Almost half of the participants (11/25) claimed that there wasn't any disagreement point at their team and a same amount of participants (11/25) claimed that they had minor disagreements in the costume design activity, which is excused for the stage of storming.

Participants recognized many different game elements in the activities, like (10/25) synchronize robot dance and/or dressing robot, (9/25) cooperation with teammates, (6/25) contests and also (3/25) the general fun feeling.

The majority of the participants claimed that it was their first time participating in such activities and they considered them very innovative. Few of them (6/25) stated that they had similar experience with robot toys, Lego bricks and video-games such as Guitar Hero [21].

Half of the participants (13/25) claimed that through the activities they learned to dance Zaramo and design traditional costumes. Almost the same amount of participants (11/25) stated that they learned to cooperate within a team, few of them (5/25) learned robotics or just had fun (2/25).

In the total evaluation of the project some of them (10/25) stated that it was important since they learned close cooperation with in a teamwork. Other participants (9/25) answered in a similar way, claiming that they learned how to interact and have a close contact as team members. Few of them (6/25) considered the project important since they enjoied learning and (5/25) learned cultural aspects of Florina.

V. CONCLUSIONS

In the particular project we were interested in examining if robotic activities can offer a proper learning environment for cultural aspects and also proper context for team building for adults. From the project implementation and data analysis we saw that the project had a positive impact in both major goals: participants' team development and cultural learning.

We can consider robot exploitation as an important factor of the success. Robots served as dynamic tools. We took advantage of their construction and architecture, specially designed and adapted to our project needs (anthropomorphism, dimensions, etc,). Also the intelligence and interaction that robots brought to the activities captured the participants' attention. Questionnaire analysis showed that the combination of such a technology with cultural activities can offer a context not only suitable for learning, but also for team building. Social interaction with robots motivated participants to achieve progress in learning and to communicate/collaborate as a team.

Concerning the specific principles for adult learning and the project design and implementation, data analysis shows that participants got interested in this kind of knowledge (Zaramo dance, costume) and also got skills and attitudes (cooperation with in teamwork). In the rest of the duration of the program, participants continued to show their cooperative attitude.

Concerning the Maslow's Hierarchy of Needs and team life cycle, observations and questionnaire analysis show that participants involved in team building stages of forming, storming, norming and performing in a efficient way. They got their role in the team, by following a self-directed and actively participated learning path.

Through participants' responses we can see that robot costume design and guidance was the most communicational and co-operational part of the project, while Zaramo dancing was the most self expressive part, but their combination offers the context for adults team-building and cultural learning results.

VI. ACKNOWLEDGMENT

The authors would like to thank the project participants and faculty for their cooperation.

REFERENCES

[1] Cianni M. and Wnuck D., Individual Growth and Team Enhancement: Moving toward a New Model of Career Development, The Academy of Management Executive (1993-2005) Vol. 11, No. 1 (Feb., 1997), pp. 105-115

[2] Courau, S. Les outils d' excellence du formateur (The basic tools of adult trainer), 2000, Athens: Metaihmio

[3] Ellis J., Luther K., Bessiere K., Kellogg W., Games for virtual team building, DIS '08 Proceedings of the 7th ACM conference on Designing interactive systems Pages 295-304, 2008

[4] European Commission, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and The Committee of the Regions : Commission's Action Plan for Skills and Mobility Com(2002) 72. Brussels

[5] Feil-Seifer D. and Mataric M. J., "Defining Socially Assistive Robotics," Proc. of the 2005 IEEE, 9th Int. Conf. on Rehabilitation Robotics, pp. 465-468, June 28 - July 1, 2005, Chicago, IL, USA

[6] Huang W., Weib K., Watsonc R., Tanb B., Supporting virtualteam-building with a GSS: an empirical investigation, Decision Support Systems, Vol. 34, Issue 4, March 2003, Pages 359–367

[7] Jarvis P. Adult Education and the State: Towards a Politics of Adult Education, Routledge, 1993

[8] Klein C., DiazGranados D., Salas E., Le H., Burke S., Lyons R., Goodwin G., Does Team Building Work?, Small Group Research April 2009 vol. 40 no. 2 181-222

[9] Kafai, Y. B., Resnick, M., Constructionism in Practice: Designing, Thinking, and Learning in A Digital World, Eds. Lawrence Erlbaum, Mahwah, NJ, 1996.

[10] Lego Serious Play (http://www.seriousplay.com)

[11] Mackin D., The team building toolkit. New York: AMACOM 2007

[12] Maslow A.H., Motivation and Personality. Harper and Row, New York. (1954)

[13] Merriam S. and Leahy B., Learning Transfer: A Review of the Research in Adult Education and Training. PAACE Journal of Lifelong Learning, Vol. 14, 2005, 1-24

[14] Morrison, K. R. B., Planning and Accomplishing School-centred Evaluation. Norfolk: Peter Francis Publishers 1993

[15] Papert, S., Situating Construction. In I. Harel and S. Papert (Eds.), Constructionism. Norwood, NJ: Ablex Publishing. 1991

[16] Rogers A., Teaching Adults, Buckingham: Open University Press

[17] Sheard A.G., Kakabadse, A.P., (2002) "From loose groups to effective teams: The nine key factors of the team landscape", Journal of Management Development, Vol. 21 Iss: 2, pp.133 – 151, 2002

[18] Tuckman, B.W., "Development sequences in small groups", Psychology Bulletin, Vol. 63 No.6, pp.384-99. 1965

[19] Tapus A. and Mataric M. J., "Towards Socially Assistive Robotics," invited contribution, Int. Journal of the Robotics Society of Japan (JRSJ), 24(5), pp. 576-578,July 2006.

[20] Zukas M. and Malcolm J., Pedagogies for Lifelong Learning: Building Bridges or Building Walls? In Harrison, R et al. (eds) Supporting Lifelong Learning: Vol One Perspectives on Learning. London: RoutledgeFalmer and the Open University Press. 2002

[21] Guitar Hero, www.activision.com, retrieved 2 April 2012

Evaluating the Long-Term Impact of RoboCupJunior: A First Investigation

Martin Kandlhofer*, Gerald Steinbauer*, Petra Sundström† and Astrid Weiss†
*Institute for Software Technology
Graz University of Technology, Austria
[mkandlho, steinbauer]@ist.tugraz.at
†ICT&S Centre
University of Salzburg, Austria
[petra.sundstroem, astrid.weiss]@sbg.ac.at

***Abstract*—This paper presents the concept and first empirical results of our endeavor to conduct a long-term qualitative and quantitative evaluation on the impact of the RoboCupJunior (RCJ) initiative. RCJ uses robots as technical tool to educate, motivate and inspire pupils and undergraduate students up to the age of 19. Our evaluation concept is based on three pillars (individual role models and careers, monitoring people on their way through RCJ, best practice examples by mentors). As a first step of our evaluation we have conducted nine semi-structured qualitative interviews with former RCJ participants. The main goal was to get the stories of their 'RCJ careers' and to find out if their participation in RCJ have had any effect on their future development. Especially we wanted to find out if and how RCJ has raised their interest in technology in general or a technical career in particular. Within the scope of this first attempt we take it as a fact that RCJ improves technical, management and social skills and instead we try to figure out why students seem to get 'hooked' on this activity. The motivational factors we have identified so far are *the social experience*, *the engaged community* and *feelings of success*, which should be considered as value concepts for teaching 'interactive technology skills' in general.**

***Index Terms*—RoboCupJunior, educational robotics, qualitative interviews**

I. Introduction

In general, we are currently facing an increasing disinterest from young people, and girls especially, in science and technology studies. Less students decide to go into technical studies at university level. As a consequence many countries are already confronted with the problem of not having enough researchers and engineers [7]. In order to work on this challenge there are cross-cultural activities such as RoboCupJunior (RCJ) that encourage pupils and students up to the age of 19 to get involved in science and technology by the means of a project-oriented educational robotics approach. Even if there is a clear subjective impression that such initiatives are useful and effective there are only a few studies investigating the long-term effects in qualitative and quantitative terms. In this paper we present a concept and first empirical results of a planned series of studies for a systematic evaluation of the Austrian RCJ initiative in specific. The evaluation concept is designed as a long-term endeavor (5-7 years) and rests on three pillars: (1) individual role models and careers, (2) monitoring people on their way through the initiative and (3) best practice examples on integration by teachers and mentors.

In a first study we aimed at the extraction of role models and later careers of former participants. Semi-structured qualitative interviews formed the basis of that evaluation. In a first proof-of-concept we conducted nine interviews. The aim was to identify the motivational factors that 'hooked' participants and to investigate their 'RCJ careers'. Almost all interviewees were enthusiastically talking about their RCJ activities. Many of them competed for years, continued in science and engineering studies and are still interested in RCJ (e.g. being referee at competitions, promoting RCJ at schools). Many former team members are still friends and now work together at university. Even if none of the teams reached top placements at the competitions they are still proud of their achievements. For instance one of the students presented her soccer robot at the interview (see figure 1).

In the following, we first provide some background information on RCJ and the current situation in Austria. Then we describe the method used, the participants, and finally our findings and conclusions.

II. Background

RCJ is part of the international scientific initiative RoboCup [24] that fosters research in advanced Robotics and Artificial Intelligence. The vision of RoboCup is that by 2050 a team of fully autonomous humanoid soccer robots will defeat the human world champions. In order to address children and young students as well, RCJ was established in 1998 within the scope of the RoboCup world championship 1998 in Paris. In 2000 the first international RCJ competition took place in Melbourne. Twenty-five teams from different schools in Australia, USA and Germany participated [20]. At the RoboCup 2011 in Istanbul there were about 1000 junior participants from 30 different countries forming 250 teams [4]. Every year the international RCJ competition takes place in a different city all over the world.

The project-based international RCJ initiative has a strong focus on education [19]. Pupils and undergraduate students up to the age of 19 are encouraged to get involved in science

Authors listed in alphabetical order.

and engineering. The goal is to improve technical and social skills, to foster teamwork and creativity, as well as to promote international contacts and knowledge exchange.

RCJ, the competition, comprises of three disciplines: (1) Rescue, (2) Soccer and (3) Dance. The task in RCJ Rescue is to construct and program an autonomous robot to find its' way through a rescue arena. Here the challenge is to follow a black line on the floor, to avoid debris, to deal with gaps and a ramp and finally to detect and rescue the victim. The arena is composed of different rooms, each room increases the level of difficulty. In RCJ Soccer four robots, usually one striker and one goalkeeper per team, play soccer. Detecting the ball, identifying opponent players and teammates, as well as locating the goals are some of the challenging issues to deal with. Robots are only limited in size and weight so students can work out different innovative solutions. Finally RCJ Dance is a discipline that focuses on the combination of technical skills and creativity. The goal is to prepare a short on-stage performance of robots and humans. Important evaluation criteria are choreography, costumes, and decoration, as well as technical aspects of robot construction and programming.

Except for some minor adaptations each discipline remains the same from one tournament to the next. The idea behind it is to give students the chance to improve their robots at each competition and to make progress visible [7]. Students are allowed to use standard robotic kits such as the Lego Mindstorms NXT as well as self-designed robots. Figure 1 shows an example of a self-designed soccer-robot. Figure 2 shows the excitement of junior participants at the RoboCup 2009.

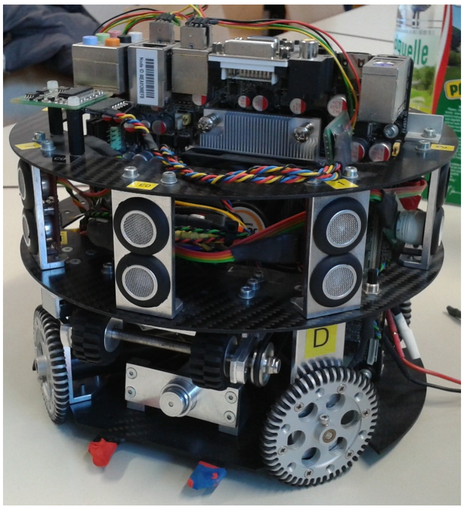


Fig. 1. A RoboCupJunior soccer robot.

In Austria RCJ was introduced in 2007. Various activities and events were organized in order to promote the initiative and to establish the first RCJ regional centers in Austria. Due to a rapidly increasing number of schools interested in participating in RCJ further regional centers were build up in order to establish a nationwide network. By now the Austrian RCJ network consists of eight regional centers, distributed among almost all Austrian provinces. A regional center offers standardized service packages to encourage schools, students and teachers to participate in RCJ. These include presentation at schools, introduction courses for pupils, training courses for teachers, renting robotics kits to schools, open-lab-days, as well as special events such as science weeks for students or robotics workshops. Presentation at schools usually serve as a first introduction for teachers and students to RCJ. Interested school classes can attend an introduction course, which lasts for about three hours. The courses have a strong focus on hands-on experiences. Using Lego Mindstorms NXT robotics kits attendees are introduced to the principles of robotics and programming. In addition training courses provide teachers with a basic knowledge and tools to integrate RCJ into their classes. Advanced courses and workshops deal with different programming languages, advanced hardware or special topics around RCJ. During the so-called open-lab-days teams can visit a regional center and use the available facilities (i.e. rescue arenas, soccer fields, robotics hardware) in order to prepare for a competition. Furthermore, experts answer questions and give hints on how to solve specific problems [7].

The current evaluation concept was initiated by the regional center Graz. It is located at the Institute for Software Technology at Graz University of Technology (TUG). The center organized the first national RCJ competition in 2008 and one year later the world championship. In 2011 an international research and education project *Technology and Education for Search and Rescue Robots (TEDUSAR)* was initiated in cooperation with University of Maribor (Slovenia). A central project objective is to build up a similar regional center structure in Slovenia, as well as to foster RCJ in both countries. RCJ is well established around Graz. There is a strong cooperation between university and schools located in the city and the surrounding regions. Every year many teams from these schools participate and succeed in national and international RCJ competitions. A remarkable number of former RCJ participants are now studying at TUG. A general problem is the increasing disinterest of young people, in particular girls in science and technology studies. By improving and extending the support activities already provided by the Graz RCJ

Fig. 2. A winning junior team at RoboCup 2009.

regional center, as well as by attracting more public attention, we aim to counteract the recent negative development and attract more students to science and technology studies.

III. Related research

As robotics in education has become more and more important within the last years, various conferences and workshops have been organized around the topic. Recent examples would be the *Second International Conference on Robotics in Education* [16] in Vienna (2011) or the international workshop on *Teaching robotics, teaching with robotics* in Darmstadt 2010 [11] and Riva del Garda 2012 [12]. A listing of further conferences and workshops can be found in [3].

Numerous papers and articles on educational robotics initiatives have been published. Some of them focus on specific initiatives like *RCJ, FIRST Lego League (FLL)*[1] or *Roberta*[2]. Others deal with the more general topic of educational robotics. As explained in [3] many publications deal with technical aspects of various robot platforms for education, the development of robotics curricula and teaching materials, as well as the integration of robotics into classes. For example the authors of [18] present a low cost micro-controller board for teaching robotics in schools in Australia. They describe design objectives, technical specifications and advantages of this controller board. The article in [1] presents the use of personal robots to teach Computer Science to undergraduates. It describes the robot hardware/software and outlines the content of the undergraduate course. Nourbakhsh and colleagues [13] describe the process of designing robot platforms and the curriculum for a high school robotics course. They provide a detailed technical description of the developed robot platform (regarding hard- and software). The final chapter deals with the findings of a short-term course evaluation.

In [15] the author gives a brief overview of different educational robotics competitions and describes one specific contest in particular. But, although this educational competition has been organized in Slovakia for ten years the paper does not cover any evaluation aspects.

The authors of [9] provide an evaluation of the *FIRST Robotics Competition (FRC)*[3]. FRC, which was founded in 1989, is a high school robotics initiative located in New Hampshire (United States). The program aims to get young people interested in science and technology. The main goal of this evaluation was to assess the long-term impact of FRC on participating students as well as to investigate the impact on schools and other supporting institutions. As a first step the authors conducted a retrospective survey of 173 former FRC participants who graduated high school between 1998 and 2003. The survey, which was distributed by email and mail, contained predefined questions regarding students' careers after graduating high school, working experiences and self-reporting impact of FRC. In order to compare selected outcomes of FRC participants, with outcomes of pupils who did not participate in FRC the study used a comparison group. As a second step the authors also visited ten different FRC teams and conducted interviews with team leaders, school administrators and mentors in order to gather information on the implementation of FRC in different schools and the impact on schools and supporting institutions. Although, the evaluation covered a period of several years the surveyed region was limited to two metropolitan areas (New York City and Detroit/Pontiac).

A similar study evaluating the impact of the FIRST Lego League (FLL) on participants, schools and other involved institutions was conducted in 2004 by Melchior and colleagues [10]. One of the main objectives of this study was also to find out strengths and weaknesses of the initiative in order to improve the FLL program. Methods used in this evaluation included surveys, site visits to competitions and schools as well as telephone interviews with mentors and coaches.

The two evaluations of [9] and [10] address several questions similar to those of our endeavor, for example the investigation of the long-term impact on former participants or the evaluation of strengths and weaknesses in order to take steps for improvement. They also comprise both quantitative and qualitative data. Nevertheless, since these studies were conducted in 2004 and 2005 data is not up to date.

Similar long-term evaluations have also been done in other scientific fields such as sociology, economy, medicine and education in general (i.e. [23], [14], [17] and [5]). In these fields there already exists a big amount of knowledge regarding quantitative, qualitative and mixed research methods ([2], [8], [6]). Therefore methods applied in those studies and areas could be adapted and used for our concept of evaluating the long-term impact of the Austrian RoboCupJunior initiative.

A more comprehensive study with special focus on RCJ, covering a four-year period (2000-2004), has been done by Sklar and colleagues [20]. The authors collected data during the annual international RCJ events. The study provides both statistical data (number of students, participating countries, gender distribution) as well as evaluative results. However, the focus was put more on quantitative performance data (e.g. the number of teams) than on qualitative evaluative results (e.g. self-reporting and questionnaire data). As a pilot study authors conducted open-ended video-taped interviews of mentors at the competition in 2000. In the subsequent years quantitative questionnaires were used in order to get feedback from students and mentors. The study aims to provide a status report on the initial four years of RCJ, however only from a quantitative perspective, such as performance data (e.g. number of teams) and self-reporting data (i.e. questionnaires). The qualitative experience of RCJ was not investigated. There is a lack of knowledge on the stories behind participants' 'careers' or their future educational and personal development. Data was exclusively collected at annual international RCJ competitions. [20], [21], [22]

In [7] results of an evaluation of the first three years (2007-2010) of RCJ in Austria are outlined. The paper presents only preliminary results though, again focusing on statistical data

[1]http://www.firstlegoleague.org/
[2]http://www.iais.fraunhofer.de/roberta.html
[3]http://www.usfirst.org/

regarding number of participating students, teams, mentors and countries at annual national competitions. As already stated by the authors a more systematic evaluation, covering more than these three years and also considering later careers and the qualitative experience of participants is needed.

Beside these two works of [20] and [7] very few long-term evaluations of RCJ can be found. As stated in [3] most evaluations are limited regarding the observation period and population. Most of the available studies also seem to look for a proof of how RCJ is successful. Within the scope of this first study aiming at the extraction of role models we have decided to go for a different approach. We have decided to regard the perspective that RCJ is successful as a fact, and instead look for the reasons why this is and what are the "hooks" behind this initiative. We see that RCJ fosters not only technical skills, but also management, communication and social skills. Students learn how to handle larger projects, and how to work in teams and how to deal with conflicts. We also see how participating in RCJ increases the students' self-confidence. Our goal is to find out the reasons for why this is the case and subsequently use the findings to improve and extend on the RCJ support actions we already provide. As a consequence we hope to attract more students to participate in RCJ and to engineering and scientific educations in Austria. Furthermore, we are as well convinced that these hooks also could be applied on other topics and teaching activities. We are aware that nine qualitative interviews are just a starting point to identify the inherent values of the RCJ initiative. Thus, we planned a series of follow-up studies, such as ethnographic studies of the teachers, content-related analysis of the teaching material and a long-term shadowing study of selected students from different age ranges. Although, this paper only presents the preliminary findings of the first round of interviews it provides a proof-of-concept of the first pillar of our evaluation strategy.

IV. The Study

For this initial study we have conducted nine semi-structured qualitative interviews [25] with former RCJ participants. Qualitative research methods have their origin in the field of sociology and anthropology. Conducting interviews is one specific qualitative research technique which is frequently used in the area of psychology, educational science and sociology but also empirical software engineering (i.e. case studies). Though, qualitative interviews are rarely used in the field of robotics. Preparing and analysing semi-structured interviews is a very time consuming and resource demanding data collection technique. However, qualitative interviews provide information that could not be obtained by using quantitative methods (i.e. feelings, opinions, moods, facial expressions,...) [8].

The main goal of our first attempt was to get former participants' stories of their 'RCJ careers' and to find out if their participation in RCJ have had any effect on their careers after that. As described by Flick and colleagues in [6] a list of specific predefined questions acted as a guideline to ensure that important topics were covered during the interview. We put a lot of effort into formulating these questions in an open, none-directional way. The open-ended questions, such as *Do you remember some person, some situation or some activity especially? And why?* not only allowed the discovery of unforeseen information but also enabled the interviewer to deviate from the predefined guideline (a richer description of these questions can be found in the next section). Beforehand, interviewees were informed about the general purpose of the interview, i.e. evaluating the long-term learning effects of RCJ. The reason for stating the purpose of the interview clearly at the beginning of the interview was to avoid influencing or steering the interviewees in a specific direction. Interviewees were also asked to sign an informed consent stating that all collected data were to be treated confidentially, personal information was to be made anonymous and specific statements and stories were to be omitted in future publications and presentations of this data (the latter on request).

For later analysis all interviews were recorded. As described in [6] various different methods for analysing semi-structured qualitative interviews exist. Our approach was to transcribe and afterwards qualitatively analyse the interviews by means of content analysis in order to identify patterns for RCJ inherent values (see section V).

A. The guiding questions

From talking to former mentors and teachers at the regional centre in Graz we listed twelve specific questions and several sub-questions to be used if the interviewees not themselves came to talk about all topics we wanted information about. The first questions covered overall information (current educational program, potential work status, etc.) as well as information about the first contact with RCJ (when, how, and so forth). The second part dealt with questions about the specific activities the interviewee had taken part in, the preparations for potential RCJ competitions and the competitions (success, team-members, and so forth). The third part of the questions encompassed questions regarding positive and negative memories, remarkable situations and/or specific remembered persons during the interviewee's RCJ career. In addition two specific questions were formulated: *What did you learn?* and *Has RCJ affected somehow what you do today?* We are aware that the two last questions can be seen as too directional. As mentioned in the previous section we wanted to be complete open with our aims in order to allow the discovering of unforeseen information and new insights. After discussing this issue extensively we finally agreed on asking these additional questions only in case the respondents did not already answer them during the interview.

B. The interviewees

In order to examine a longer period of time participants who took part in a RCJ competitions before 2009 were contacted. To find such RCJ participants we browsed past national competitions lists, contacted former teachers, and as well asked the other RCJ regional centers in Austria for help. The people we ended up interviewing in turn provided us with contact information to their former teammates. It should also be mentioned that all our interviewees were immediately willing to participate in our study.

In the end we interviewed nine former RCJ participants (two women, seven men). Five attended the same gymnasium in Graz (hereinafter referred to as *Gymnasium Graz1*), one a different gymnasium in Graz (*Gymnasium Graz2*), two a polytechnic high-school in Styria (*Polytechnic Styria*) and one a polytechnic high-school in Lower Austria (*Polytechnic Lower Austria*).
Currently two of the participants are studying *Telematics* at Graz University of Technology (TUG) (4th semester), two *Software Development and Business Management* at TUG (4th,6th), one *Software Information Engineering* at Vienna University of Technology (4th), one *Electrical and Audio Engineering* at TUG and University of Music and Performing Arts Graz (6th), one *Geomatics Engineering* at TUG (4th) and two *Informatics* at TUG (4th, 2nd).

The nine interviewees were part of five different teams that participated in various national and international competitions from 2008 to 2011. Subsequently we provide a brief introduction of the interviewees and their relationship. In order to ensure anonymity we are using fictive names for both members and teams.

Johanna, *Martin* and *Roland* who all attended *Gymnasium Graz1*, are currently studying at TUG. During their RCJ time (2008-2011) they were always part of the same soccer-team (*Team II*). *Verena* and *Simon* attended *Polytechnic Styria* and are now studying at TUG as well. At the first competition in 2008 their team (*Team III*) participated in RCJ Rescue. For the 2009 competition they decided to build their own robot from scratch to compete in RCJ Soccer. Members of Team II and Team III know each other from former RCJ competitions. Johanna provided us with contact information to Martin, Roland, Verena and Simon.
Patrick and *Walter* attended *Gymnasium Graz1* and are now studying at TUG. Their team (*Team I*) took part in four different national and international competitions from 2008 to 2009 (RCJ Soccer). Although they attended the same school like Johanna, Martin and Roland they don't know each other. Together with one friend *Christian* (*Gymnasium Graz2*, now studying at TUG) formed *Team IV*. From 2008 to 2010 they competed in RCJ Rescue. There is no relationship between Christian and the other eight interviewees.
Finally *Samuel* took part in various competitions (RCJ Dance) between 2009 and 2010 where he always acted as team captain. He attended *Polytechnic Lower Austria* and is currently studying at Vienna University of Technology. Again, there is no relationship to other interviewees.

Figure 3 outlines interviewees and their relationships, their former RCJ team/school, as well as date and place for the competitions and disciplines they participated in (note: the numbering of teams has no meaning). Each of the five circles represents a former RCJ team; different frame colors indicate different schools. Touching circles (Team II and III) indicate that their members know each other and currently are doing courses together at university. Arrows pointing from one member to another mean that the 'source-member' provided us with contact details about the 'target-member'.

V. Results: The hooks

All of the interviewees are and were technically interested (computer science, mathematics, electronics, physics) even before they got involved in RCJ. Six of them stated though that RCJ was at least one deciding reason for choosing their specific study direction.

Except Patrick and Samuel none of the interviewees had comprehensive previous experiences in the field of robotics. Before getting in contact with RCJ Patrick already had a Lego Mindstorms robotic kit and together with a friend he had programmed a chess-robot. Samuel had participated in the *Hexapod*[4] robotics competition several times (before 2008). Simon stated that he never was very interested in robots before getting involved in RCJ but always enjoyed playing with Lego. Verena explained that a friend of her told stories about his participation in the Hexapod competition some years before she was introduced to RCJ. Roland only heard about robotic tool-kits using graphical programming languages but he had no practical experience before his first robotics introduction course in school.

All nine interviewees were initially introduced to RCJ by their teachers either by offering optional school subjects and projects or by providing Lego kits for designing and programming robots during leisure time.

After analysing the recorded interviews (as described in section IV) we identified patterns for RCJ inherent values, which we call *the hooks*. Three major hooks could be identified, namely "social experience", "engaged community" and "feelings of success", which will be described in detail in the following subsections.

A. The social experience

To take part in RCJ means many hours of collaborative work. Decisions have to be made, tasks have to be distributed and disputes among the team-members have to be settled. During preparation, the journey to the competition and the actual competition team-members spend a lot of hours together. However, all of the interviewees expressed their positive memories on this.
"Although this was a very time-consuming activity it was the right and good decision to take part in RCJ"[5] - Walter

Interviewees also stressed the special atmosphere and the possibility for socialising during the national and international competitions. Furthermore RCJ participants were regarded to be open-minded and helpful, in also sharing their experiences and technical skills among the teams. Johanna mentioned how, unlike the various Judo competitions in which she already took part in, the atmosphere at RCJ events is not that competitive,

[4] http://www.fh-ooe.at/campus-hagenberg/studiengaenge/bachelor-studien/hardware-software-design/hexapod-meisterschaften/

[5] All citations were translated to English, as all interviews were originally conducted in German.

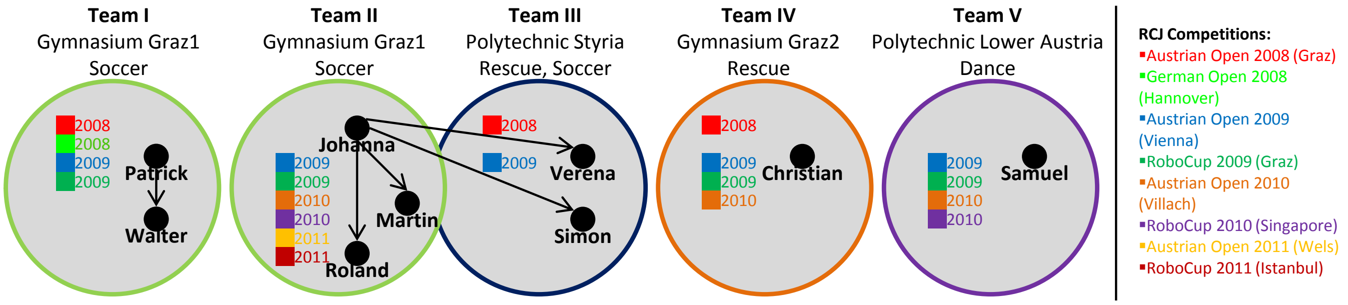


Fig. 3. Teams, schools, members, relations, RCJ competitions and disciplines.

but rather cooperative.

"During school time I also took part in international Judo competitions but I have never seen before such a strongly developed competitive thinking among participants. At RoboCupJunior it is completely different, all the helpfulness and cooperativeness." - Johanna

Patrick enjoyed the long technical discussions with other competitors and the possibility to learn from each other.

"It's good to see that there are a many other people who share the same interests. During the RoboCupJunior competition we learned a lot from other teams." - Patrick

Johanna, Martin and Roland, all members of Team II (*Gymnasium Graz1*) reported that they met everyday after school in order to prepare for the first competition. In sum the team took part in six national and international competitions. They also voluntarily acted as main referees for the soccer competitions at the RCJ Austrian Open tournament 2012. All three members are studying now. They are still friends, meet regularly and do common projects together at the university. Similar stories were told by Patrick and Walter; the former members of Team I are still good friends and although their third teammate is currently studying at ETH Zurich they manage to meet and discuss their common RCJ experiences several times a year.

Interviewees also mentioned negative memories. For instance Simon reported various problems within Team III (communication problems, two members were kicked out, the robot did not work at the day of the competition). In contrast though, his teammate Verena, who acted as project leader, did not mention these issues explicitly. The story she told was much more positive compared to Simon's. Despite their different perspectives though they are still in touch and are also doing some courses together at the university.

To continue, Samuel took part in four RCJ and various other robotics competitions. He talked about his experiences of being a team-captain, about how hard it was to motivate other team members and to delegate work. He also mentioned the problems arising when working together with good friends and described the difficult situation when another boy wanted to become captain as well. However this did not turn him down, but instead motivated him to compete again, to recruit new members and to improve his abilities in order to become a better team-leader. After graduating from school Samuel decided to become mentor for RCJ teams at his former school.

All in all the social experiences described by the interviewees can be categorized into the following components: friendship (meeting after school for preparation, still good friends, working together at university), project management (dealing with problems among members, motivating teammates, being a captain) and competitions (cooperative atmosphere, discussion with other teams, socializing with students from other countries). We don't claim that RCJ is the only reason why people stay in touch or why interviewees improved their social skills, but all of these examples and stories show that there definitely is a strong social aspect within RCJ: interviewees worked together preparing *for RCJ*, they took part in *RCJ competitions*, they dealt with controversial issues *within a RCJ team* and they experienced the special atmosphere during a *RCJ tournament*.

B. The engaged community

The interviews revealed that the schools can be considered as important part of the engaged community around RCJ. The *Gymnasium Graz1* is perhaps the best example of an "engaged community school". It is a very committed school within the RCJ community in Austria. The school offers robotics courses to their pupils. Furthermore, it provides financial and infrastructural support to student-teams. Every year several teams from this school take part in national and international competitions and achieve respectable placements. The school established its' robotics courses in 2007 (Patrick's and Walter's class was the first to participate in those courses).

As previously mentioned all interviewees were initially introduced to RCJ by their teachers. There were exclusively positive statements regarding those teachers. Half of the respondents indicated the former teacher as the most influential person during their RCJ career.

"We had a very dedicated informatics teacher. We learned a lot and he was also the reason why we initially participated in RoboCupJunior." - Verena

As another part of the engaged community we have identified academics/researchers and members of the organizational staff. For Christian the most remarkable person was a specific member of the organisational staff who also acted as trainer and judge in several competitions. Three interviewees indicated a particular university professor as the most memorable person during their RCJ career. They stressed his helpfulness in general, his support during competitions and the good

cooperation between him and their former teachers.
"This professor even tried to help us fixing a specific problem at the day of competition." - Simon

Finally, parents need to be mentioned as part of the engaged community. The interviews revealed that parents often provided financial support (i.e. for travelling) and acted as role models. For instance the fact that his father studied Mechanical Engineering led Walter to choose a technical study as well. Moreover Verena's father was the main sponsor and supporter of her team. He provided all required hardware to build a soccer robot.

Besides all the positive stories, the interviewees also brought up several negative memories and issues. Samuel for instance complained about the lack of coordination between different schools and also the lack of support provided by RCJ regional centers when organizing journeys to competitions (i.e. flights to the RoboCup competition in Singapore 2011). Although Christian spoke in high terms of his former informatics teacher (*"helpful, enthusiastic, dedicated"*) he criticised the school as such. Initially, he explained, the school was neither interested in Christian's team nor provided any support (for example they were not allowed to use the computer lab). But after the team made it to the finals at RoboCup 2009 this success was communicated as a great achievement of the school. Similarly, Christian and Samuel complained that they were given little support by their school administration (at least the beginning of their RCJ career).

We can see that students need to be supported by their engaged community. But, as it appears difficulties described might have been part of the hook itself. Students developed self-confidence, they felt proud of themselves by succeeding. This shows that provided support has to be well balanced therefore students get the chance to manage problems and difficulties on their own.

C. The feelings of success

Austria is a relatively young member of the international RCJ initiative. The first time a junior team took part in RoboCup was in 2007. Since then several notable placings have been achieved, but in all objectivity Austrian teams are still not on an international top-level. Nevertheless, the subjective feelings of students about the placings matters. During the interviews we heard various different stories of success. Both Johanna's and Patrick's teams achieved first and second places at national competitions. In addition to those measurable successes, Patrick mentioned a specific situation during their first participation in 2008. The robot crashed one day before the competition started, thus his team had to work the whole night to fix the problem. It was a great success for them to get the robot moving again and to be able to take part in the competition even if they did not compete very well. Samuel provided a detailed explanation of his robotics activities. Together with some friends he put together the first RCJ team at his school, promoted RCJ in following classes, and still gives robotics presentations to students. For him it was a big success that his achievements and activities in RCJ have helped to establish RCJ in his old school.

To conclude, we would like to quote Martin. His team came in third at RoboCup 2009, which was indeed quite a remarkable placing, and asked for the most memorable success he replied without thinking:
"When we scored our first goal, it was the 1:0, we were overjoyed." - Martin

VI. Conclusions and future work

In this paper we presented a concept based on three pillars (individual role models and careers, monitoring people on their way through RCJ, best practice examples by mentors) and first results for a long-term evaluation of the impact of the RCJ initiative. The aim is to explicitly reveal the values inherent to this pedagogical approach. For this first study we have conducted semi-structured qualitative interviews with nine former RCJ participants (two female, seven male) in order to identify what 'hooked' them. The interviewees attended different schools in Austria and took part in various national and international RCJ competitions from 2008 until 2011.

In a first attempt we wanted to preliminary test the concepts' first pillar: role models and careers. Therefore, we did not want to find evidence for RCJ being successful in how it fosters technical, management and other soft skills; we took that as a proven fact and basis for our work. Instead of gathering quantitative performance data on Austrian RCJ initiative we wanted to gather and analyse qualitative data to gain insights in the reoccurring motivational factors. These first interviews demonstrated that RCJ in its pedagogical approach generates three important factors (*the hooks*) namely the social experience (friends, teamwork, and international contacts), the engaged community (schools, motivating teachers, academics, and family) and the feeling of success (personal development, placing, and positive memories).

It is not sufficient to only know that RCJ is successful for pupils and undergraduates, but why. There is also a need for more long-term evaluation in the area of educational robotics in order to improve pedagogical approaches. Therefore we planned a series of follow-up studies, such as ethnographic studies of the teachers, content-related analysis of the teaching material and a long-term shadowing study of selected students from different age ranges. These follow-up studies will also ease the limitations of the study presented in this paper, such as the small number of interviewees, which all had successful RCJ experiences. Moreover, we later want to expand the work to different regions in Austria as well as to different countries.

Our aim is as well to set up a better supporting framework for youngsters just started with RCJ. The goal is to follow these students to learn more about the long-term effects of RCJ. Similarly, we are interested to see if the now observed trend that students keep their social network, which they established through the RCJ initiative, for their later career as science and technology student, is reported also by other students. Perhaps at some point, they even go to senior levels of RoboCup as a team.

ACKNOWLEDGMENT

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.

REFERENCES

[1] T. Balch, J. Summet, D. Blank, D. Kumar, M. Guzdial, K. OĤara, D. Walker, M. Sweat, G. Gupta, S. Tansley, J. Jackson, M. Gupta, M. N. Muhammad, S. Prashad, N. Eilbert, and A. Gavin. Designing personal robots for education: Hardware, software, and curriculum. *Pervasive Computing, IEEE*, 7(2):5–9, April 2008.

[2] M. Borrego, E. P. Douglas, and C. T. Amelink. Quantitative, qualitative, and mixed research methods in engineering education. *Journal of Engineering Education*, pages 53–66, 2009.

[3] A. Bredenfeld, A. Hofmann, and G. Steinbauer. Robotics in education initiatives in europe - status, shortcomings and open questions. In *International Workshop 'Teaching robotics, teaching with robotics', SIMPAR 2010*, Darmstadt, Germany, November 2010.

[4] A. Eguchi, N. Hughes, M. Stocker, J. Shen, and N. Chikuma. Robocupjunior - a decade later. In *RoboCup 2011: Robot Soccer World Cup XV*, pages 63–77. Springer-Verlag Berlin Heidelberg, 2012.

[5] K. M. Epp. Outcome-based evaluation of a social skills program using art therapy and group therapy for children on the autism spectrum. *Children and Schools*, 30(1):27–36, 2008.

[6] U. Flick, E. von Kardorff, and I. Steinke. *A Companion to QUALITATIVE RESEARCH*. SAGE Publications, 2004.

[7] A. Hofman and G. Steinbauer. The regional center concept for robocupjunior in austria. In *First International Conference on Robotics in Education*, Bratislava, Slovakia, 2010.

[8] S. E. Hove and B. Anda. Experiences from conducting semi-structured interviews in empirical software engineering research. In *11th IEEE International Software Metrics Symposium (METRICS 2005)*, 2005.

[9] A. Melchior, F. Cohen, T. Cutter, and T. Leavitt. More than robots: An evaluation of the first robotics competition participant and institutional impacts. Technical report, Heller School for Social Policy and Management, Brandeis University, Waltham, MA, 2005.

[10] A. Melchior, T. Cutter, and F. Cohen. Evaluation of first lego league. Technical report, Heller School for Social Policy and Management, Brandeis University, Waltham, MA, 2004.

[11] E. Menegatti, editor. *Workshop Proceedings Teaching Robotics, Teaching with Robotics*, volume ISBN 978-3-00-032863-3, Darmstadt, Germany, November 2010. SIMPAR 2010, SIMPAR 2010.

[12] M. Moro and D. Alimisisi, editors. *Proceedings 3rd International Workshop 'Teaching robotics, teaching with robotics'*, Riva del Garda, Italy, April 20 2012.

[13] I. R. Nourbakhsh, K. Crowley, A. Bhave, E. Hamner, T. Hsiu, A. Perez-Bergquist, S. Richards, and K. Wilkinson. The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment. *Autonomous Robots*, 18(1):103–127, January 2005.

[14] P. Orpinas, S. Kelder, R. Frankowski, N. Murray, Q. Zhang, and A. Mcalister. Outcome evaluation of a multi-component violence-prevention program for middle schools: the students for peace project. *Health education research*, 15(1):45–58, 2000.

[15] P. Petrovic. Ten years of creative robotics contests. In *Fifth International Conference on Informatics in Schools: Situation, Evolution and Perspectives (ISSEP)*, Bratislava, Slovakia, October 2011.

[16] K. J. Roland Stelzer, editor. *Proceedings of the 2nd International Conference on Robotics in Education (RiE 2011)*, volume ISBN 978-3-200-02273-7, Vienna, Austria, September 2011. INNOC - Austrian Society for Innovative Computer Sciences, INNOC - Austrian Society for Innovative Computer Sciences.

[17] H. H. Severson, J. A. Andrews, E. Lichtenstein, M. Wall, and L. Akers. Reducing maternal smoking and relapse: Long-term evaluation of a pediatric intervention. *Preventive Medicine*, 26(1):120–130, 1997.

[18] R. Singh, F. Maire, J. Sitte, and A. Tickle. A low cost controller board for teaching robotics. In *Third International Symposium on Autonomous Minirobots for Research and Education*, Fukui, Japan, September 2005.

[19] E. Sklar. A long-term approach to improving human-robot interaction: Robocupjunior rescue. In *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA '04*, 2004.

[20] E. Sklar and A. Eguchi. Robocupjunior - four years later. In *RoboCup 2004: Robot Soccer World Cup VIII*, pages 172–183. Springer Berlin, 2005.

[21] E. Sklar, A. Eguchi, and J. Johnson. Robocupjunior: Learning with educational robotics. In *Proceedings of RoboCup-2002: Robot Soccer World Cup VI*, 2002.

[22] E. Sklar, J. Johnson, and H. H. Lund. Children learning from team robotics: Robocup junior 2000. Technical report, The Open University, Milton Keynes, UK, 2000.

[23] UNICEF. *LONG-TERM EVALUATION OF THE TOSTAN PROGRAMME IN SENEGAL: KOLDA, THIES AND FATICK REGIONS*. United Nations Children's Fund (UNICEF), Section of Statistics and Monitoring, Division of Policy and Practice, New York, 2010.

[24] U. Visser and H.-D. Burkhard. Robocup: 10 years of achievements and future challenges. *AI Magazine(AAAI)*, 28(2):115–132, 2007.

[25] T. Wengraf. *Qualitative Research Interviewing*. Sage Pubn Inc, 2001.

Reversing Robotic Regression: Why our Culture Rejects Robotics in School

Micháel Ó Dúill
Logios.Org
logios.org@googlemail.com

***Abstract*–For over three decades robotics has been taught in primary school as a curricular enhancement. Analysis of old and new material suggests a reduction in cognitive content and regression from reality. The Technicity Thesis is introduced, from which it is possible to re-evaluate technology relative to language. From this cognitive basis the role of the computer in school is reconsidered and the notion of Turing teaching introduced. The requirement for a curriculum for mastery of the computer as a medium follows from this. In this context, the current economic constraints on robotics may be re-evaluated and serious consideration given to a curriculum consistent with neural development in childhood and constructionism.**

***Index Terms*—Robot(ic)s, primary school, historical perspective, technicity, learning medium, neurology, teaching methodology, exemplary practice**

I. Introduction

Our culture places a higher value on language than technology. This is because, to quote paleoanthropologist John Shea, we believe that: “One of the crucial elements of Homo sapiens' adaptations is that it combines complex planning, developed in the front of the brain, with language and the ability to spread new ideas from one individual to another...” There is no mention of the human capacity for technology. In this cultural milieu the development of language and discourse in seen as the prime objective of primary school. [1] In this context, the humanities and verbal arts are given high status along with mathematics, seen as cognitively complex. Science is also admitted because of its alleged hypothetico-deductive method. Technology is seen as making things, often in the context of 3D art made from junk.

For a quarter of a century, the computer has resided uncomfortably in a book-oriented institution. It has been treated, on the whole, as a multimedia teaching aid. As late as this year, it was necessary for engineers to descend upon politicians and demand a place for programming in the curriculum [2]. The situation for robotics, programming combined with construction, is worse. It is hardly possible to program a model built from breakfast cereal boxes and toilet-roll tubes

As the short historical survey below shows, there has been a retreat to the toy-box in primary school robotics over the past quarter-century. This is largely explained by the difficulties that manufacturers had found in selling to schools. The LEGO Company is one high-profile example: their Dacta educational division was so unprofitable that it closed and LEGO Education is a relatively new venture.

Whilst those who are engaged in trying to establish robotics at primary school level bravely struggle on with hopeful projects, the ethos is against them. The purpose of this paper is threefold:

1. To establish the veracity of the assertion of regression by a short historical review;
2. To present a theory about the evolution of technicity, the human capacity for technology, that displaces language as the highest cognitive capability of the human; and
3. To begin to mount a challenge to the book as the prime teaching medium in favour of the computer, the latter re-conceived as a Turing medium.

This framework offers a context in which to reconsider the regression of robotics; and to mount a challenge to the perceived economic non-viability of the subject at the primary school level. It provides a basis for discussion of a way forward; aided by consideration of two recently published approaches to robotics at primary school level.

II. History

The year 1979 saw the arrival of the Milton Bradley “Big Trak” in the toy-box. Within five years it was widely used in UK primary schools as a part of the Microelectronics Education Programme (MEP), a UK government initiative that has been forgotten by educational historians [3]. The MEP also saw the first computers in primary school, sometimes complete with a Logo floor turtle. By 1987 when the first EuroLogo conference took place Dublin, LEGO had introduced its LEGO Dacta Technic 9700 kit with Interface A and TC Logo. At the conference itself, a college lecturer and adviser to primary schools gave a Control Logo Master Class.

Roll forward a quarter century and we see the nostalgic release of a Big Trak clone (fig.1), the classroom place of which has been taken by BeeBot (fig.2). LEGO products have bifurcated into the NXT and WeDo systems. The former is more of an evolution from 9700, whilst the latter is a return to the toy-box. So, after 35 years, where are we?

We can clearly see two streams. The first is the robot in the classroom. Whether it appears as a bee or a tank, it is cognitively a ‘black box’ with buttons. (One version, Pip from Swallow systems was just this.) Their main use is in teaching left/right turns and distance estimation, which are more simply and economically incorporated in pencil and paper mazes. Playing with toy robots in the classroom, however they are clothed and with whatever play-mats or curriculum materials they are provided, is not constructive. Nor is it constructionist because nothing, no object, is constructed that is open to inspection [4]; and the toy itself is (like a Barbie doll) closed to inspection. It may be argued that this approach feeds the humanoid robotic fantasies children derive from entertainment media rather than the role of robotics as helpful disembodied automata.

Figure 1. The reincarnated "Big Trak" and its keyboard layout.

Figure 2. The modern "Bee-Bot," with keyboard layout and jungle jackets.

The second stream *is* constructionist. The LEGO system enables the child to learn to create, using a limited range of well designed elements, a host of imagined or realistic objects. Computer controllable elements: lights, motors and sensors add robotics. With the LEGO 9700 kit constructions related directly to the child's experience of 'hidden' robotic systems in the world with which they were familiar. This may be something a simple as street lights coming on at night. Their program might be simply 'lamps on' written in Logo. In primary school, this model will not be an isolate but part of a discussion of why we need lights, how we got light in the past, where the electricity comes from and the effects light has. It is not an isolated robotic experience. Moreover, the children needed to be taught the skills of constructing the model before they program it. There was a realisation that learning needs to be situated (cf. Vigotsky's [5] zone of proximal development). This was 1987.

A comparison between Big Trak and Bee-Bot keypads, mirrored in programming environment differences between LEGO 9700 and WeDo (fig.3), raises issues of curricular integration.

Figure 3. The WeDO programming environment.

The older technology enabled children to apply number and letter knowledge in a new context; a context that gave immediate feedback. The numerical keypad and Logo programming contributed to numeracy and literacy: the core objective of the primary school curriculum.

When the constructions supported by the instructions supplied by LEGO are compared, we see a similar effect. No longer are representations of reality provided, the toy-box is returned to; as the drumming monkey (fig.4) illustrates. No blame may be laid at the door of LEGO for this change: it is a toy company and needs to sell outside education. Pictorial programming is consistent with their pictorial instructions.

Figure 4. The toy-box WeDo drumming monkey.

A few primary school teachers have worked continuously with robotics or "controlling external devices" from 1987; and there is at least one nationally approved curriculum that includes robotics [6]. Economics impact on its, uptake however; the school must make a case for extra funding that is frequently not forthcoming. A few determined school teachers and university researchers manage to keep alive robotics in school by taking what opportunities come along; a strategy that relies on good fortune but is hostage to the material that is on the market. Robotics is not alone. Programming for children was kept alive in computer clubs through Scratch, which Furber [2] commends to primary schools.

Consequently, lunchtime and after-school Scratch clubs are being launched in the UK; whilst the EU supports similar clubs for robotics in Bulgaria.

The feeling of a cognitive decline is supported by a re-awakening of interest in the basics of computing, albeit nostalgic, e.g. the Raspberry PI (a Linux Micro on a chip), and inquiries such as that by the English Royal Society into computing in schools. However, the motivation for these stirrings was not the interests of the children. Furber [2] was open in his desire to see more students of computer science; cf. RiE papers dealing with the primary phase [7, 8].

As the ghost of Big Trak returns, it is time to reflect on why there has been regression not progression.

II. Theory Matters

The presupposition that language is the highest cognitive capability of the human was alluded to in the introduction. A consequence of this presumption is that language is given far higher a status in education than technology. Moreover, surprising though it might seem, there is no established idea about how humans, unlike all other animals, has a capacity for technology. The Shea quotation makes no mention of it. Psychology is silent on the issue. Both Piaget and Vigotsky [5] worked from the perspective of language-primacy. The latter, now academically fashionable, saw learning as socio-verbal and thought as inner speech. The only academic to question this was Papert [4], who claims that 'constructing objects open to public inspection' is educationally more "felicitous" than verbal instruction. Intuition is insufficient. Before technology may be seen as integral to a cognitively balanced education, it is necessary, as a minimum, to demonstrate its cognitive equality with language. This entails a foray into scientifically unexplored territory. Heidegger called it "the question concerning technology." For students of human evolution it is modern human behaviour. How is it, as Heidegger put it, that other animals use material at hand but humans challenge forth raw materials from the earth, which they see as a standing reserve? How is it that only the human makes use of godless straightedges, as Hundertwasser remarked? And why is the artist's palette a wrapped-round rainbow rather than a linear sequence as in the sky? The Technicity Thesis developed by the author offers an answer to these questions.

An implication of the nature of the technicity adaptation is that technological thinking is cognitively more powerful than linguistic thought; which will be seen to be obvious on reflection. Thus, the argument for the status of technology is made. No longer is it only an economically vital practical subject, it becomes the cognitive foundation of science.

This established, it is possible to re-evaluate teaching method and medium. Seen as a medium, the computer's capabilities may be compared and contrasted with the book. This comparison needs to take into account the fact that rapid neurological maturation that takes place through the primary school years, and experience has a major influence on the configuration of the mind.

Alan Turing's speculation on the relationship between the 'universal machine' that his thought experiment gave birth to, and the brain that thought the experiment prompts the replacement of the term "ICT" with the term Turing medium and a possible transition to Turing teaching

A. Technicity

From an entropy and information perspective technology is simple relative to the organic forms built by biology. This includes the human brain and the information it receive via the senses. This makes a problem with the second law of thermodynamics: It is not possible to generate simplicity from complexity without doing a large amount of work. The converse is far less work intensive. The classic example is a cup of tea: to infuse the compounds from the tea leaves and add sugar is far easier than trying to recover the original pure ingredients. If the process is irreversible, like making a cake, it is impossible.

It follows that the source of information on simplicity must be other than environmental. The Greek Platonists understood this when they raised the question of ideal forms and how we know that the pure colour red is red. The only non-environmental information is within the brain. This raises the question of where that information might be, how it is accessed and how it is processed. The clue to the source of the elemental information is found in the human capacity for drawing. This aspect of human behaviour is fundamental to technology; and yet nothing is known about how humans come to be able to draw. In addition, there is no evidence that our cousin species, the Neanderthal, had this capability. But it is undeniable that children begin to draw soon after they have learned to speak and that their early drawings are composed from simple linear shapes. The requirement is therefore a source of elemental information on shape. The most likely source is primary visual cortex where Hubel and Wiesel found what they called 'feature detector' neurons in the late 1950s. O Duill [9] suggested that somehow this was the source of the information necessary for drawing ability and demonstrated the 'square/diamond' effect (figure5.) If a square presented in a horizontal/vertical orientation rotates by a one eighth turn its name changes. The word 'diamond' is unthinkable in the first orientation but immediately comes to mind in the second.

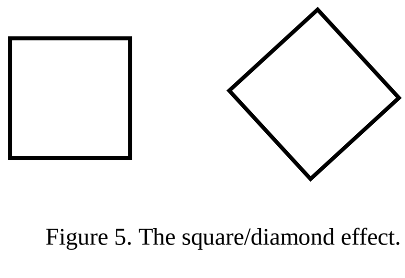


Figure 5. The square/diamond effect.

This immediately raises the question of the cognitive status of language: If a single concept can generate two different verbal responses, where does thought reside?

This finding is indicative of a plausible source of low entropy information. It triangulates with child development.

From the information on line length and orientation found in the brain, all the shapes humans create including letters, geometric shapes, and numbers, may be formed. However, the question remained open because the question of access and processing remained unanswered; and it is but a single phenomenon.

Paleoanthropologists offer a second angle of attack. One of their earliest indicators of modern human behaviour is evidence of red ochre use. This implies the capacity to seek out, mine and refine this iron oxide; i.e. the possession of an abstract concept of red. There are two information sources for colour: the retinal cones and Hubel's 'blobs' in primary visual cortex. The latter offer a colour space defined by the opponent pairs red/green, blue/yellow and black/white [10]. This wraps the rainbow around on itself to give the colour wheel, which includes non-spectral purple.

Parenthetically, humans share this mechanism with fish. So, primary visual cortex offers another source of elemental information that triangulates with human concepts and with child development where undiluted primary colour features in every kindergarten, cf. Bee-Bot. As the source of colour concepts, this would guarantee that all humans possessed the same concept of red.

Primary sensory cortex in general, and its homologue in olfaction, offers information that triangulates with uniquely human behaviour including choreography, music, scent and flavour blending.

The origin of this information is critical to the idea that technicity is an evolved adaptation. The mechanisms that have been found in primary sensory cortex do not derive their information from sensory input. The information is put there by the genome when it constructs the phenotype. This is obviously the case because the information carried by, for example, photons interacting with cones at the retina loose their information in the chemical reaction they trigger. All that remains is a nerve impulse indistinguishable from any other nerve impulse. The information that it represents can only be provided by structures within the brain that embody information about photons in the visible range. The same is true of the other so-called feature detector neurones; they embody information on elemental properties of matter built into the genome over geological time. This information is of far lower entropy than the sensory experiences of a fleeting phenotype. As such, it is more powerful than sensation.

The source of information for technology is established, as is its low entropy. All that remains is to explain, in terms consistent with evolutionary principles, how humans gained access to this information and how it could be processed to construct, as Papert put it, objects open to public inspection. Fortunately all these issues may be resolved together. The thrust of hominine evolution was a brain expansion that followed the mammalian trajectory, with an emphasis on the prefrontal area [11]. The mechanism underpinning prefrontal expansion was the invasion by prefrontal neurones of most parts of the brain. The prefrontal area provided an executive function and working memory for manipulating information gleaned from within the brain. This neuronal advance turned out to be adaptive and led to the Homo lineage. The role of prefrontal cortex has been described as inventing futures from the past. It creatively recombines information it receives and then stores that new information back in the older brain, thereby modifying its circuits. This is a creative and constructive process. But it also includes evaluation in terms of the goals of the organism. From the perspective of the prefrontal area, it is irrelevant where the information comes from; the only requirement is that it turns out to be useful. Hence, the processing mechanism for technicity was in place. All that was required was for prefrontal neurones to slightly extend their range to include primary sensory cortex and its homologues. This, uniquely in the human, is what the technicity thesis proposes. It offers an explanation for the both simple character of technology and its power. In so doing, is dethrones language and makes the highest thought verbally inarticulate. Herein lies the concern about language development expressed by educationalists. Herein is the explanation of the drawings and writing that covers classroom walls.

The primary phase of education is when technicity comes on stream as prefrontal cortex makes is connections and matures; a process that is virtually complete before puberty. Hence, experience in primary education is critical to the full flowering of this uniquely human mental capacity.

B. Differential concepts

A consequence of the technicity adaptation is that there are two different qualities of concept: those derived from perception and directly expressible in language; and those that flow from technicity. The square/diamond effect is one example. In general, the difference is that between scientific and naïve thinking. The classic example is the controversy surrounding the heliocentric universe. It is obvious to all who can see that the sun and moon revolve around the earth. This is the view from perception, from the evidence of our unaided eyes. This view may only be corrected, as in the case of the square, by a higher level of concept. For the motion of the sun, this was a combination of concrete and cognitive technology: the telescope and mathematics; the latter aided by the relatively new arabic numerals.

It is necessary to differentiate these concepts. Concepts derived from technicity will be prefixed with the letter t, those based on perception prefixed with a letter v. The differences between t- and v-concepts are summarised in table 1.

TABLE 1
SOME DIFFERENCES IN QUALITY BETWEEN T-CONCEPTS AND V-CONCEPTS

T-concept	V-concept
Technicity based (genomic)	Perception based (experiential)
Non-linguistic (constructed product)	Verbal (internal and spoken utterance)
Low entropy (simple and powerful)	Environmental entropy (complex)
Species level (universal)	Culture level (local)
Tested against properties of matter (scientific)	Tested for cultural (internal linguistic) consistency

III. MEDIUM MATTERS

By displacing language and assigning cognitive primacy to technology it is possible to view human endeavour from a different perspective. Remarkably, though not surprisingly, language reflects this new status. An example is William Shakespeare, who is described as a playwright. This places him in the company of wheelwrights and millwrights: an artisan plying a trade using technology; in his case writing. This places him apart from the oral story-teller, who uses no concrete medium, despite the fact that he is called the Bard of Avon. The use of both words as a descriptor reveals the failing of language, as it did with the square. In this case it also highlights another phenomenon: the invisibility of the medium. Whichever word is used, it is the performance not the process of creating the script that is the focus of human interest. The same is true of education. Talk is of knowledge and skills, not the properties of the medium. This tends to be assumed and is only remarked when, like the computer in the classroom, it is novel. But the novel is not perceived as a medium, rather as technology; which word connotes the novel. The technicity framework enables us to shift focus to the medium and its properties. Table 2 lists the three modes of education and associated media that this approach defines.

TABLE 2
SOME MAJOR DIFFERENCES BETWEEN THE THREE LEARNING MODES

Vigotskian	Grammar	Turing
Socio-verbal / observational	Textual	Computational
Shared with the Neanderthal	Uniquely human	Uniquely human
No external medium	Externalised memory	Externalised processing
High memory load	Demanding apprenticeship	Assistive
Environmental entropy	Mixed entropy	Genomic entropy
V-conceptual	V/T-conceptual	T-conceptual

All children start school with the well developed spoken language and social skills that Vigotsky focused upon. They can learn by observation and imitation and can talk about their learning. They can begin to relate what they learn to the wider world; and they can bring their naïve knowledge of that wider world to their learning, sometimes confusedly [12]. They can develop skills, such as playing music or riding a bicycle. Vigotsky's notion is easy to apply in such situations; and where a skill is not open to observation children's language is a good indicator of their state of knowledge. However, we are all aware of language disabled children for whom this is not so. Another weakness of this mode is that for those with good recall and a facility for language, rote learning without the capacity to apply it is possible, which may mask poor understanding. From any perspective, this medium that has no medium and which we share with Neanderthals with whom we intermarried, places a premium on memorisation and recall. There is no use of the uniquely human technicity adaptation. Nevertheless, it has been the prime means of generational information and myth transmission.

They also have the green shoots of the technicity adaptation in the beginnings of drawing and an interest in colour, shape and other properties of matter. The technicity adaptation makes the construction of meaningful marks possible. Black marks on white paper may be used to construct and communicate non-verbal ideas, as an aid to thought, or as an aide memoire. The book, the second in the triumvirate of media, is far more powerful than speech or demonstration. This is a direct consequence of the lower entropy of the symbols used. (A simple information theory comparison of speech and writing demonstrates this.) These symbols extend well beyond the communication of language over distance and time. Writing includes number, musical notation, circuit symbols, and more. The drawback of this powerful medium is the requirement to learn the grammar and semantics of a given symbol system. Whilst a musical score records the notes and tempo of a composition, it is but a desiccated husk of the original. The player must not only accurately replicate the notes and timing of the original but must add the unrepresented musicality. The same, seen most clearly in a play-script, is true of written language. Thus, this medium imposes a long and arduous apprenticeship in its grammar and re-animation. We may think of the book as a flash drive – its data is only transformed into information if there is an appropriate application. A competent reader is unaware of the medium but where it has not been mastered learning is inhibited. Teachers are aware of the limitations of the book. Some children readily learn to decode, but with limited comprehension, (reading better backwards because the meaning does not get in the way). For the dyslexic, the book is closed.

The book is a product to be consumed. Pencil and paper, on the other hand is constructive. Thoughts may be sketched and reflected on and, as a consequence, may change the state of mind of the writer. Having reflected, the writer may move on or write or erase what is written before moving on. This is the description of a Turing machine.

[Parenthetically, because the Turing universal machine is mathematically equivalent to the lambda calculus, it is often perceived as a purely cognitive entity, not the specification of a physical machine. This is to misread Turing. A read-write head and an infinite tape is a physical construction, even when mental. Turing talked in terms of disregarding the time taken for a computation. In reality, by creating a machine, Turing introduced entropy and the uncomfortable constraints of the second law of thermodynamics into the field of mathematics.]

This powerful idea is a partial expression of the interaction of the mind with the book – the medium that the technicity adaptation made uniquely available to the human. It is partial because access to thought remains linguistic: computability is a linguistic expression encoded arithmetically. The read-write head and tape, like the notebook and pencil, are constructed from information of a different quality; the low entropy information made available by the technicity adaptation. The difference between a computer and a book is that the former may change state and thereby assist the learner. For this reason the term Turing medium is preferred, leading to the idea of Turing teaching with an assistive medium. The Turing medium may function in consumer or constructive mode.

The perception that a computer is 'technology' obscures its function as a Turing medium that can read, write, and, with a little instruction, do arithmetic. Comfortable familiarity with, and indeed reverence for, the book misdirects attention from its defects.

The fundamental difference may be illustrated with the following text, combining computer and natural language:

First, write a procedure that makes sense in terms of natural language.

```
to polygon :side
drawpolygon :side :side
end
```

Second, construct a functional procedure that draws the general shape. Note that instead of using a repeat instruction, recursion is used to halt the drawing process once the shape is finished. I.e. the number of sides is explicitly counted. It is thereby possible to draw a shape of zero sides. This is conceptually different from a loop.

```
to drawpolygon :side :tally
if equal? :tally 0 [stop]
forward quotient 360 :side right quotient 360 :side
drawpolygon :side difference :tally 1
end
```

Once the general polygon procedure is written, separate procedures may be written to draw polygons by name. For example:

```
to octagon
polygon 8
end
```

(Do not try this in primary school.)

This text, when pasted into the procedures page of LCSI Microworlds Logo, even if accompanied by its surrounding paragraphs, would enable the user of the medium to draw a polygon of any number of sides by typing the words 'polygon' followed by the number of sides and pressing enter. Were the shape names to be programmed, e,g, the octagon procedure, the meanings of the shape words could be explored by the learner. Note that the learner would write the words and so discover their meaning rather than try to rote-learn captions written on the page of their text-book. Furthermore, it would be possible to perform a search of this paragraph for the word 'octagon' and ask the computer to evaluate it. (To emphasise this, the text of the program is not given a separate font, or shown as a figure. On-screen it has the same status as the body text, only when printed does it cease to be alive.)

IV. Turing Teaching

Turing teaching is simple to define: the use of assistive Turing media as the basis of education. The term was first introduced by the author in 2011 as conceptually preferable to the terms ICT and technology, which misdirect thought away from the capabilities of the medium and hence its educational consequences [13]. These latter include standards defined by an obsolescent apprenticeship in mastery of a prior medium: the book of the library of Alexandria.

A. Reason for Regression

It is impossible for an institutional infrastructure founded on a learning medium as obstructive as the book to change: all teaching methods are based on techniques to work-around the pitfalls it places in the path of the learner. At primary level, the major emphasis is on the mastery of the book as a medium and the techniques for constructing text. Handwriting, for example, is prerequisite. In such an environment a medium that does not make these demands has no place. The same is true of computation. The capacity of the computer to do sums, for which every shop-keeper is grateful, (salespeople get the bill correct and stock control is simplified), is seen as mathematically antagonistic and the possibility of the medium to aid the learning of arithmetic and the understanding of number is denied.

To paraphrase Marshall McLuhan, the medium makes the mind and there is an implicit belief that the mind will not be well-made if a learner uses a medium that carries out mental operations. This is the argument against writing that was used by Socrates. We know much more about brain maturation than we did a quarter century ago. Specifically, we know that the executive of the brain is in the front part, which is massively connected to the rest of the brain. These connections mature in the years of primary school and their strength is very highly influenced by experience. Interaction with a medium that requires an apprenticeship in grammar before its content may be accessed will mould a developing brain differently from that with a medium that can assist and may also be tuned to the developing mind. It is arguable that by doing away with the arduous grammatical apprenticeship the development of the mind may be improved. Consider the beneficial effects of writing, which eliminated the need to memorise everything. A more capable medium may well build more capable minds.

So intrinsic are traditional media to education that they are invisible. Educationalists are unaware of them and they make use of them unconsciously. This is not true of the computer. It is an alien intrusion into the process of education. For this reason it is classed as technology: information and communication technology (ICT) now abbreviated to 'technology' alone. But, a medium it is, which is why 'Turing medium' is a far better term to use henceforth. However, the failure to view it as a medium powerfully explains the regression we see in educational robotics.

If the medium is alien to education, children will not be taught to master it. Neither will the teacher have mastery of it as a medium. Their use of it is on a conscious rather than automatic level. This disrupts the process of teaching. Thus, those who wish to introduce computer-based elements into the curriculum are well advised to mask any aspects that might cause conflict with traditional teaching method.

This, it may be argued, was the case from the outset. The Logo Turtle was a novelty that apparently did not impinge on traditional maths. Unfortunately, it was all too easy to go beyond with Logo and challenge tradition. The arrival of the graphic user interface provided a welcome diversion. Use of small pictures to convey notions does not conflict with the traditional learning and nicely misdirect children's attention from the potential conflict. From this perspective, the WeDo interface is to be preferred to Scratch, which retains writing on its blocks (figure 6).

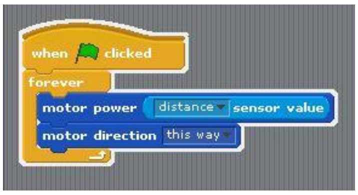


Figure 6. The Scratch equivalent of the WeDo program in fig.3..

The subject matter is also kept at a distance. The return to the toy-box, as illustrated by the WeDo models, is a good strategy to avoid any curriculum conflict whilst introducing the engineering elements that are considered necessary. This reflects an engineer's ploy of great antiquity: mechanical amusement to defuse fear of the unnatural. The drumming monkey captures this spirit beautifully. Similarly, the software is a toy-box version of an adult programming environment made as pictorial as possible. If letters and numbers are used, they are inserted in little boxes by clicking rather than writing. Finally, WeDo comes as a complete package ready to use out of the box. Thus, it is curriculum enhancement not curriculum intrinsic; and no conflict arises.

B. Reason to be Cheerful

Looking back toward 1987, a very different world comes into view: no mobile phones, no internet, no computers built into cars; no digital cameras. The Kindle e-reader and the tablet were undreamt of. The world was analogue. Today, primary school children starting school carry with them their mobile phone – so they can call home at any time. But the safety link provided by mother also has a camera and a range of apps that are ready to build a mind different from that of their parents. They carry a keyboard and screen, and a clock, calendar and calculator with them. Alexander [1] begins to recognise the change, as the following extract shows:

"Now … children are increasingly autonomous. Much of their out-of-school learning is electronic and beyond the reach of either parents or teachers. … They seek material pretty well at will, using mobile phones, PCs and laptops which are increasingly standard property in English households. … not passive surfers who read, watch and listen, but 'peerers' who use electronic media to share, socialise, collaborate and create."

But he seems unable to make the cognitive connection to the concept of a new educational medium. His focus is on evaluating information, internet danger and the purported but unsupported neurological dangers of screen-based learning.

Nevertheless the zeitgeist is hugely different from 1987 and children, if not educational traditionalists, readily embrace the new medium. Moreover, the economics have significantly shifted in favour of Turing media. Now that the infrastructure is in place, digital publication is far more economic than its paper counterpart.

C. Towards Turing Teaching

The development of teaching method intrinsic to the new medium requires a conceptual shift from traditional method and standards. Three steps may be identified.

1) Understanding the medium: One hundred years on from the birth of Alan Mathison Turing we live in a world of Turing machines. A Turing machine, by definition, is not of itself intelligent; although it can be made more clever, faster and accurate than any human. I.e. it offers mechanical support to thought; as clothes offer mechanical support to temperature regulation or the book supports memory. Like a human or textual memory it may store information. In addition it can process that information according to rules that the human capacity for scientific enquiry has elucidated. The relation of the Turing medium to verbal instruction and the book requires dispassionate evaluation, and the intellectual presumptions of traditional teaching demand challenge.

2) Understanding the human: The technicity adaptation proposal radically reconfigures our perception of what it is to be human. Technology displaces language as the cradle of cognition whilst revealing the capacity of language, once it is a publicly inspectable object, to open a window on the cognitive process. It shows that humans have an additional and more powerful quality of concept that provides entrée to science and explains its explanatory success. This adaptation comes on-stream pari parsu with prefrontal maturation during the primary school years.

3) Catalysing a transition: To date research into both computers and robotics in primary school has been limited by the constraints of traditional teaching method. The effects of the constraints of traditionalism are nicely illustrated in the Arlegui et al paper at RiE2011 [14]. It is noteworthy that traditional method has been reaffirmed in relation to the processing capabilities of Turing media in all jurisdictions. It is only in those few locations where a curriculum is in place to teach mastery of the medium, and where that curriculum is professionally taught, that indicators of how teaching might be are to be seen.

Ilieva's TRTWR2010 poster shows what might be. Here robotics is an integral part of the curriculum for mastery of the computer as a medium and the teaching of LEGO construction (table 3). An investment in LEGO bricks and Control Lab interface and (Win95) Logo some fifteen years ago provided a conceptually appropriate environment that remains better than any available. For primary education the controllable elements fit the children's world-knowledge and the software makes explicit the relationship between program and action. The longevity of the LEGO system components when depreciated over their lifetime makes investment in robotics economically viable. It becomes possible to construct a curriculum that is continuous throughout primary school. From inspection of the grid it is immediately apparent why Logo has been preferred over pictographic programming: Logo enhances literacy and numeracy whilst introducing the basics of computer science.

TABLE 3
FACSIMILE OF ILIEVA'S CURRICULUM GRID FOR ICT AND LEGO

	ICT	LEGO	TEAMWORK
1st grade	Introducing the computer. Learning to use the mouse. Working with graphics and sound. Using ToolKid, specially designed software	Getting to know the construction material. Make the first simple models. Using LEGO bricks	Individual work to a teacher example. Individual work on their own idea. First steps to learn to work in a team of two. Outcome: individual projects
2nd grade	Learning to use the keyboard. Working with graphics, text, animation and sound and combinations of these. Using ToolKid.	Make a variety of more difficult constructions. Make more realistic models with many details. Learn to recreate a first simple situation. Introducing controllable models and programming.	Working individually or in twos or threes on one common theme discussed with and agreed by all children. Every construction part of the common project. No isolated models allowed. Outcome: class project.
3rd grade	Individual and class projects that combine different types of information. Using ToolKid, MS Word and Paint and the Internet. Product: movies, stories, comics, slide-show.	First robotics projects using sensors. Programming with procedures. More complex situations.	Freedom to choose and change team membership in the context of each new class project. Learn to cooperate with the work of younger children on school projects.
4th grade	Use of the Internet, Paint, Word and PowerPoint to make individual and class projects based on the curriculum for other school subjects.	Larger and more complex projects. Programming with super-procedures and conditions.	Coordinate the work of all classes on whole school projects. Organise a presentation, introducing the work of all children, to the school and parents.

The catalytic step to transition would be a switch from using the computer to enhance traditional teaching of literacy and mathematics to using it as the prime medium. The institutional structure of education militates against such a transition at present. The pressure for change will come from app-happy mobile device wielding children and the primary school teachers who have to resolve the conflict that results, rather than from academe.

V. NO CONCLUSION

This paper set out to consider three issues. The first is proven: there has been conceptual regression in robotics. The second has been achieved: there is a compelling argument in favour of the technicity adaptation; which offers a new and exciting perspective upon what it means to be human.. The t/v concept distinction with its associated entropies explains the power of scientific over perceptuo-linguistic thought. The third has the merit of shifting focus from the technology to the characteristics of the medium; which is shown to possess greater cognitive power than text. The terms Turing medium and Turing teaching are commended for future use, in contrast to ICT and technology, where the new medium is used to its full capacity. Robotics is seen as intrinsic to Turing teaching.

The paper concludes with a rallying cry. There was a tradition in 1960s student politics for the engineers to keep a low profile. However, when they felt matters were getting silly they descended en-masse to vote down the hotheads. Engineers do not, in general, involve themselves in politics; they leave it to the lawyers. But there are times when they feel that their voice must be heard and then they do so powerfully. Now is such a moment. The traditionalists who determine what and how children learn in school do not come from an engineering background. They come from language and the social sciences. Innovation is alien to their mindset. They are alienated from the world that children are being born into. Increasingly, children arrive in school with a skill-set well attuned to Turing teaching but poorly adapted to traditional method; and their classroom behaviour shows it. Perhaps it is time for innovative engineers to make an assessment of the relative cognitive benefits of the book and computer in the beginning phase of education and demand, as a minimum, that all children are systematically taught mastery of the medium by a properly qualified teacher. The alternative is another quarter century of educational stasis in a technologically progressing world.

ACKNOWLEDGEMENT

The author wishes to acknowledge the contribution of Vessela Ilieva of NSOU "Sofia" to the thought in this paper.

REFERENCES

[1] Alexander, R. (ed.): Children, their World, their Education: Final report and recommendations of the Cambridge Primary Review, Routledge, London. 2010.

[2] S. Furber, "Shut Down or Restart: Report of the Royal Society into Computing in Schools". The Royal Society, London. 2012.

[3] D Galliard, "Education in England: a brief history." http://www.educationengland.org.uk/history/timeline.html [accessed 13/11/2010]

[4] I. Harel. & S. Papert, "Constructionism." Ablex, Norwood, NJ. 1991.

[5] Vigotsky, L "Language and Thought." MIT Press, Boston, MA. 1962

[6] Ilieva, V. "LEGO and LOGO in the Primary School – a simple way to learn through creation." In: Clayson, E.J., Kalaš, I, (eds) Proceedings of Constructionism 2010 – 12th European Logo Conference. Faculty of Mathematics, Physics and Informatics Comenius University, Bratislava. 2010.

[7] R. Janošcová, "How to attract children to mechatronics: The experiences with mechatronic after school classes" In Proceedings of the 1st international conference on Robotics in Education, RiE2010. September 2010., pp. 247-252. FEI STU, Slovakia. 2010

[8] K. Stoeckelmayr, M. Tesar & A. Hofmann. "Kindergarten Children Programming Robots: A First Attempt", In Proceedings of 2nd International Conference on Robotics in Education (RiE 2011). Vienna, Austria, September, 2011. , pp. 185-192. INNOC - Austrian Society for Innovative Computer Sciences. 2011.

[9] Ó Dúill, M:" Can there be a Science of Construction?" In: Clayson, E.J., Kalaš, I, Eds. Proceedings of Constructionism 2010 – 12th European Logo Conference. Faculty of Mathematics, Physics and Informatics Comenius University, Bratislava. 2010

[10] Hubel, D.H. (1995) "Eye, Brain, and Vision." http://hubel.med.harvard.edu/index.html [20.07.2011]

[11] Fuster, J

[12] Bransford, J. D., Brown, A. L., Cocking, R. R. (eds.). "How People Learn, Expanded Edition." Washington DC: National Academy Press. 2000.

[13] O Duill, M. "Towards Turing Teaching: Technicity to Transition". Practice and Theory in Systems of Education, Volume 7 Number 1 2012. online: http://www.eduscience.hu/1907MichealODuill.pdf

[14] J. Arlegui, A. Pina & M. Moro "A Paradox in the Constructive design of Robotic projects in School", In Proceedings of 2nd International Conference on Robotics in Education (RiE 2011). Vienna, Austria, September, 2011. , pp. 29-34. INNOC - Austrian Society for Innovative Computer Sciences. 2011.

Having Fun with Learning Robots

Pavel Petrovic
Comenius University Bratislava
ppetrovic@acm.org

***Abstract*—Artificial Intelligence has a long tradition at Faculty of Mathematics, Physics, and Informatics of Comenius University. The team around professor Kelemen published a textbook on AI fundamentals in 1992 [6] and some form of AI master study program existed since then, currently as part of both Applied Informatics study program and Middle European Interdisciplinary Master Program in Cognitive Science. From this perspective, and basing on a fruitful cooperation with our colleagues from the Faculty of Electrical Engineering and Information Technology of Slovak University of Technology, we established a course named Algorithms for AI Robotics for the final year of the bachelor study program at Comenius University, providing both a hands-on experience in lab robotics projects and a taste of the wide field of applications of computer science to robotics. This article is a contribution to the discussion on the different organisation forms and styles of the robotics courses for undergraduates, summarizes our course and the experience gained. Its main purpose is to inspire other educators and think of their own selection of AI material relevant to robotics. This is the time of important breakthroughs in the field of robotics, cognitive robotics and artificial intelligence and the contents and methods of selecting and presenting the material to students is very important for the future development and applicability of the field.**

I. Introduction

The composition of Computer Science study programs saturated over the recent decade into quite a standard set of courses and forms a solid theoretical basis of the future computer scientists and professionals. However, we learned these people are often lacking the important qualities of team spirit and effective cooperation and communication as well as various practical skills of dealing with technology. We believe it is the responsibility of the universities to provide valuable options for students to overcome this sufficiency. The ability to effectively cooperate in a workgroup has a crucial importance for companies being able to build and provide competitive products and services. Communication and managing skills are often equally important as expert knowledge in order to perform the work at a required quality. However, the higher education programs do not offer sufficient training, focusing too much at the technical and scientific content, usually ignoring the didactic aspects of the learning processes, leaving little space for the student communication, interaction, group work and group learning. As a consequence, the graduates in technology and science programmes cope with hard challenges of organize their team work efficiently and productively. In addition, the popularity of Computer Science programs in the previous decades has been traded recently in favour of more applied programs, where students receive background and training in some particular flavours of informatics. This allows us to harness the interest of these students and expose them to a hands-on course on Artificial Intelligence and Robotics, letting them learn more about connections between the hardware, software and real life.

II. Background and Motivation

Artificial Intelligence is a field of Computer Science that has generated many novel and some useful ideas throughout more than 50 years of research, often interfering with and perhaps spawning new fields that are now considered independent, such as artificial neural networks, logic and functional programming, search, multi-agent systems, or evolutionary algorithms. Thus it is often difficult to say what is still AI and what is already outside of its boundaries. Many researchers would have different opinions on that. Similarly, some may not like the term Artificial Intelligence, and rather use Computational Intelligence, or Intelligent Systems instead. Yet other researchers with strong background in psychology, philosophy, or neuroscience have deep interest in studying human intelligence and cognition and its relevance for a machine or other man-made cognitive systems. We abstain from taking any strong position on this, rather try to take the best from all the areas that are relevant to building physical machines that can ”think”. We believe it is the age of cooperation and building of bridges across the densely cluttered space of research areas.

III. Bachelor Program in Applied Informatics

The starting viewpoint of our program in Applied Informatics is to give the candidate an alternate path to standard Computer Science study program. In particular, the students are allowed to select their courses from a wider range of subjects including Computer Graphics, Machine Vision, Artificial Intelligence, Cognitive Science, Bioinformatics, Declarative Programming, Logic, Robotics, and Mathematics. Only a couple of obligatory courses are supplemented by several obligatory-optional courses and multiple elective courses from a wide selection. The graduates either continue to our Applied Informatics master's program, or Middle- European International Cognitive Science master's program with obligatory international exchange student program. Some students also choose to switch to more technology-oriented study programmes within engineering, or business-oriented computer master courses at neighboring universities.

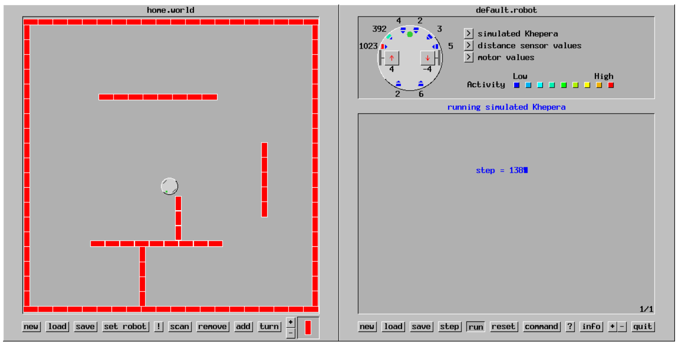


Fig. 1. A robot with a feed-forward neural network trained with the error back-propagation learning algorithm that learned to avoid obstacles in the Khepera simulator, E.Melicher.

Fig. 2. Sbot robot that learned to follow a line using Reinforcement Learning (Q-learning). It required about 50 manual restarts from the start of the line until the behavior was learned. The learned behavior was successfully verified on a different line track, P.Jurco.

IV. Project-based courses

Most of the education at all age levels in our country and world-wide is currently based on traditional academic style of education. While it is very efficient and provides solid results, it is challenged in being distant from the real-world, actual demand of the labor market, and the participants often suffer from insufficient depth of the acquired knowledge. In addition, many students especially at a younger age find the academic style unsuitable, easily loose their interest for education in general, struggle with the motivation, and as a consequence become aggressive, negligent, apathetic, or find easy shortcuts to drugs, crime, and underworld. Providing hands-on activities in the school proved to be able to attract also this kind of students and give them the opportunity to show to themselves, to their peers, and to their teachers that they are skillful, smart, and worth. Positive experience of this kind raises further their interest in learning, and improves their performance in other subjects. However, all students – and again at all age levels – benefit from the hands-on activities and project-based education in establishing the necessary links between the knowledge and the real-world, become more active in exploration and verification of the learned knowledge. Projects give the students a unique opportunity to explore beyond the standard curriculum, learn to work in groups, share and present their work within the study group and outside. Class projects often lead to small student scientific works that are presented at student conferences and similar forums.

V. AI Robotics

Although AI is a much more general field, at all times it has been looking at how its theories and methods could be applied to produce actual physical intelligent beings or devices, robots. Looking from a different viewpoint, Robotics is the latest stage or follow-up of the industrial revolution that freed the manufacturing of arduous human labour, starting from mechanisation, continuing on towards automation and robotics. These are two rather different approaches. For AI researchers the question of *what is intelligence, and how can we understand and design intelligent artifacts*, is a central theme. A typical proponent of this group is Marvin Minsky and his work [1]. What are the principles of intelligence, how can we represent various kinds of knowledge, how to reason about the environment, space, time, other agents and their intentions, how to select actions, communicate, predict, plan and prioritize, cope with uncertainty and unknown environments. On the other hand, industry is interested in precise and highly reliable, durable and productive devices that perform actions on demand. However, as the automation in factories advances, more and more operations and tasks remain for robots, including those, where complex decisions need to be taken, problems solved, and where certain level of intelligence is required. It is thus the right time for joining the efforts, forming interdisciplinary teams and getting inspired by each others' ideas and results. Our course does not make any specific assumptions on preliminary knowledge, although some mathematical and programming background is needed. The described methods and algorithms are not always studied in complete detail due to the limited time, space and scope, but we always refer the readers to the literature, where he or she can learn more. And it is also our aim to abstract from the irrelevant details, and rather provide a broader overview and explain the principles. A student who understands the principles and who can put them into actual practical real-world situations is worth ten times the one who can make a theoretical analysis of a problem, but is unable to connect this analysis to a real-world situation. And that is exactly what inspired us for setting up our course. While students learn theoretical algorithms, and methods, they are required to implement them in projects with real or simulated robots, learn and document how they were able to use them successfully. Interested students are recommended to continue their studies on selected topics further on! The study materials consist of scientific papers on various topics, chapters from textbook, and lecture notes provided by the teacher. They are arranged into chapters in the order of the course lectures. As such, they serve as the reading material for the course, explain and support the topics being covered at the lectures. The material is a dynamic entity and evolves every semester to incorporate new advances and adapt to a better content and structure.

A. Selecting the contents

Taking into account our AI perspective, we have identified several areas that are relevant for the course. We grouped them

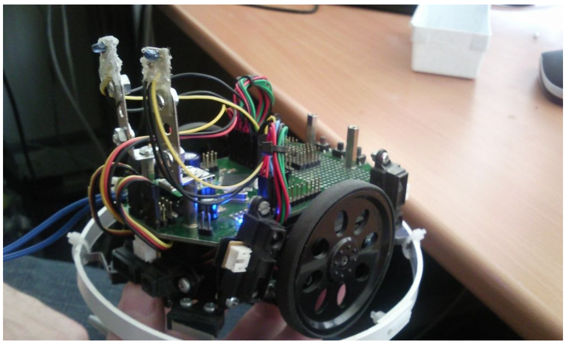


Fig. 3. A modified Sbot robot with ambient light sensors for the Braitenberg vehicles exercise, P.Hudec and R.Maurer.

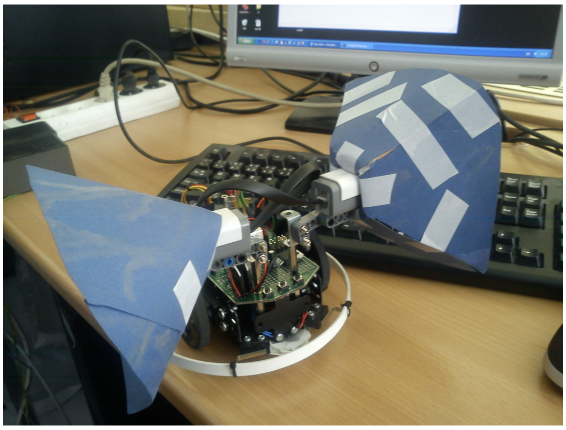


Fig. 4. A modified Sbot robot with LEGO sound sensors for the Braitenberg vehicles exercise, P.Hudec and R.Maurer.

into the following themes: *Perception and sensor systems.* In this theme, we introduce the basic nation of nature of the sensory data, types of sensors, and the challenges of signal processing. *Software robotic architectures*, where the students study the ways how robot control architectures can be organized, and learn about a few famous examples of robotic architectures. *Representation and inference in space* is a central theme of robotics, where the map organisation, localisation, mapping, and spacial planning are discussed. *Navigation and localisation* study the approaches and challenges in moving the robot, getting from place to place in the environment, and the problem of estimating the robot pose from the sequence of sensory data given that the map of the environment is known. *Probabilistic approaches* provide a collection of methods for representing and computing with uncertainty by representing and working with the probabilistic distributions. In robotics, uncertainty is present everywhere from perception, action selection, signal processing, localisation, mapping and other areas. *Logic approaches* to robot programming based on symbolic representation and standard predicate calculus, reasoning and inference offer a rigid framework for planning, high-level action selection and representation. *Simulation of robotic systems* deals with the complexity of the robotic simulation, and they way of coping with it. Introduction to simulation types, minimalistic simulations, examples of robotics simulators and their advantages and shortcomings. *Robotics and artificial life* is an alternative and fundamental approach studying how robots exhibit some features of living systems, and how the roboticists can be inspired by phenomena found in the nature. *Applications and other topics* focus on the variety of examples of real-world applications of successful intelligent robotic systems including the educational robotics systems.

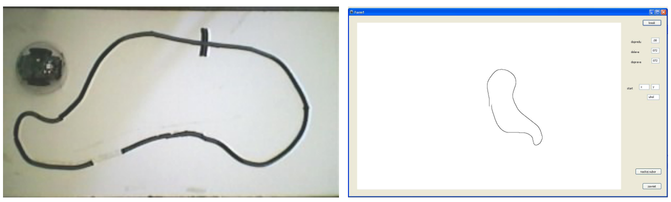


Fig. 5. A simple line track to be mapped by a robot (above) and a resulting map reconstructed from odometry by an application written in Delphi (below), E.Rapcik, R.Stupka.

VI. The Algorithms for AI Robotics Course

Having in mind the themes that we identified in the previous section, we sat down to devise the criteria for selecting the actual course theoretical content. We try to summarize the criteria it as follows:

- The material should be related to Artificial Intelligence, the more the better.
- It should be possible to use most of the theoretical material in small-size practical projects.
- The scope of the topics should be wide to cover many different areas of AI Robotics, since this will be the only robotics course for most students during their whole studies.
- The material should be accessible using the mathematical and theoretical apparatus the students already have, or alternately, the topics would have to be covered only on the conceptual level.
- There overlap with other AI courses in our study program should be minimized so that they can complement each other.
- Ideally, the topics covered should bring some new knowledge, methods, principles that are useful, or can be easily transfered to other fields than robotics.
- The selected topics should be inspiring, motivating, and fun to learn about.

A. Curriculum

The course consists of two parts. First, lectures that cover theoretical material, several common prepared exercises with hands-on activities, where the students experience the sensing, locomotion, dependence of the robot morphology and robot software, explore the basics of the signal processing. The second part of the course is a project that the students design and implement. For the theoretical part, we have selected the following topics for the lectures:

1) Introduction, overview of basic concepts I: In the first lecture, we invite the students into the world of robotics through videos of applications and research studies. We talk about the basic elements of robotic systems – locomotion, sensing, reasoning, and communication. We give examples of different locomotion types, study various sensors and motors – both from the point of view of physical principles, the signals they generate, and the way we interface them, touch the types of control architectures, and the main communication platforms.

2) Introduction and overview II: In the second lecture, we motivate the students for the topic of learning robots. We cover the different types of learning in humans and nature, and investigate the ways learning could be useful in machines and robots. We give example of simple symbolic learning system, which learns to play an animal guessing game, and the subsymbolic ALVINN system that learned to drive a vehicle. We explain the fundamental parts of the learning system – the knowledge representation and the learning rule. We learn about the symbolic frame representations, and the symbol grounding problem. By the end of the lecture, we motivate the students for the probabilistic representations due to the nature of the data robot obtains from the environment using its sensors.

3) Review of LEGO, navigation, SBOT: The third lecture prepares the students to hands-on exercise with LEGO robots and our AVR ATmega128-based differential-drive robot platform SBOT [7]. The lecture discusses also the topic of navigation in nature and robots.

4) Evolutionary Algorithms + Reinforcement Learning = Learning Classifier Systems: From the lecture four, we dwelve into more specific algorithms and learn about the main principles of one or more selected methods at each lecture. LCS [8] form an important part in the history of learning systems and introduce the students to two crucial types of learning: reinforcement and evolutionary learning. Thus we let them both explore the fundamental concepts of EAs and get the feeling of how the sparse reward gets propagated during a RL process among the states so that the agent is able to select actions even in states when it is far from receiving any reward or punishment from the task and the environment.

5) Neuroevolution through Augmenting Topologies: The NEAT [9] lecture gives another specific application of an evolutionary algorithm, but introduces the students to further important issues of species, fitness sharing, synonymical representations, gene alignment, and popular benchmark problems in control theory.

6) Fly Algorithm, CMAES, MOEA: Fly Algorithm [10] is a simple stereo-vision obstacle-avoidance algorithm that utilizes the similarity of neighborhoods of projection pairs of a population of points randomly generated in the space, Sobel gradient for favouring points on edges, and evolutionary algorithm for searching through the space of possible 3D points. Thus it forms a beautiful and yet simple and understandable algorithm that gently brings up the topics of processing visual sensory information. The Covariance Matrix Adaptation Evolutionary Strategy [11] is an efficient state-of-the-art optimisation algorithm with strong mathematical grounding and gives the students the taste of utilizing the more advanced mathematics for useful practical algorithms, a very important connection to make. Finally, we introduce multiple-objective evolutionary algorithms [12], explain the main concepts of dominance, Pareto-optimality, and discuss the various ways how to modify standard evolutionary algorithms to cope with the multiple objectives, which in usually the case in practical applications.

7) Evolutionary Robotics, Behavior-Based Robotics, Case-Based Reasoning: We finish the journey through various evolutionary methods by looking at Evolutionary Robotics, and exploring the various ways how evolutionary algorithms could be applied to robotics. In particular we study the fitness space as defined by Nolfi and Floreano [13] by devising the types of objective functions along the three axes as behavioral vs. functional, implicit vs. explicit, and internal vs. external. The second part of this lecture touches the very central topic of AI Robotics – behavior-based architectures. From Brooks's Subsumption Architecture [15] through Arkin's motor schemas [14] to hybrid architectures. Finally, we give a short introduction to the lazy learning method Case Based Reasoning [16], describe the main CBR cycle, and the important connections to the very central theme of the artificial intelligence: making analogies, associations, and providing explanations of reasoning outcomes.

8) SIFT and SURF methods for landmark recognition, Hough transform: Visual information is the most contentful, and thus it is also the most useful one for mobile robotic systems. This lecture explains the details of the Scale Invariant Feature Transform [18], and the possible applications for mapping using visual landmarks. We compare it to another efficient method Speeded Up Robust Features [19].

9) Markov Decision Problems: The last four lectures are based on the textbook Probabilistic Robotics of Thrun, Burgard, and Fox [17]. Robots perceive the environment in the form of noisy and unreliable information obtained through sensory percepts. It is therefore skewed by inherent uncertainty. The traditional algorithms assume deterministic digital information and cannot make use of information that is stochastic. However, robots are typically short of information and typically cannot afford to not use the information that is available in any form due to the criticality of their mission and too high risk in the case of mission failure. Probabilistic representations provide a suitable framework for representing the stochastic information. It is however important to realize that probability is never an objective measure. It is rather a subjective belief established on top of subjective estimates. Markovian assumption is prevalent in most probabilistic approaches. It is natural to start with MDPs that take the assumption of complete state that is seldom applicable in practice, but they formulate the essential principles of all probabilistic reasoning.

10) Partially-observable Markov Decision Problems: A more realistic scenario is when the robot/environment state is not complete – in the sense of not being fully observable. When state, action, and perception spaces and the planning

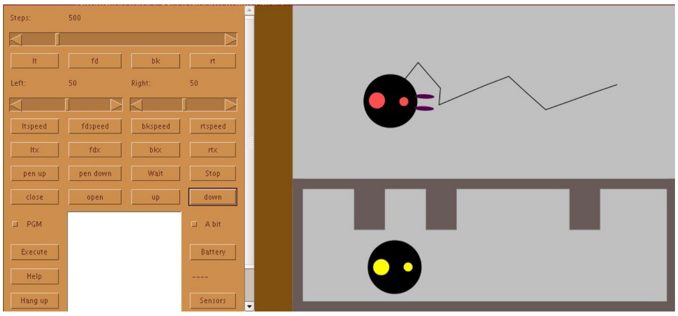


Fig. 7. Robotnacka simulator with the new functionality a gripper and the possibility to place obstacles and setup rooms with different shapes, M.Vince.

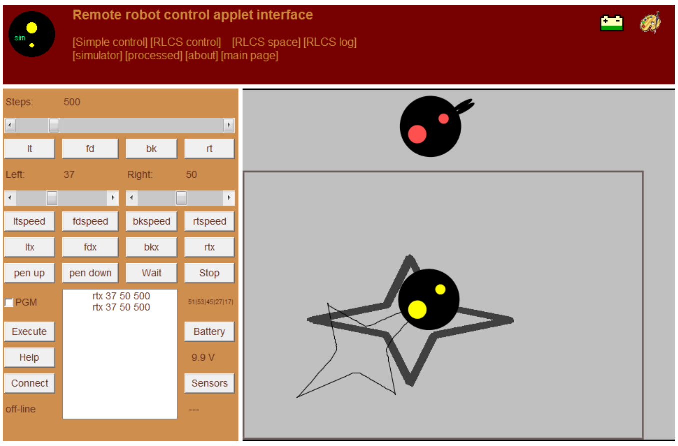


Fig. 6. A line-following robot in a remotely-operated laboratory that learns the shape of the line and draws the learned shape in a simulator, M.Svantner, S.Sitas.

horizon are finite, the ideal policy can be expressed by a piecewise linear function and obtained using the POMDP algorithm discussed in the lecture and demonstrated in an example.

11) Kalman filters: Gaussian filters are practical when representing probabilistic information that has a nature of normal distribution. They require only the mean and variance, or mean vector and covariance matrix in multidimensional case to be represented. Gaussian filters can be used when the belief over the state is probabilistic and represented by the normal distribution. When the state transition probability is linear function of state and action, Kalman filter can be used to estimate the posterior probability of the state belief. [17]

12) Probabilistic Robotics, Bayesian Robot Programming: Having seen the first three key methods in probabilistic robotics, students are exposed to wider range of topics including localisation, mapping, SLAM, and particle filters. A unifying framework of probabilistic reasoning is provided by the Bayesian Robot Programming [20] demonstrated on a little learning experiment where a Khepera robot learns to push obstacles, follow contours, or perform complex tasks in the environment. BRP framework is inspired by the concise organisation of logic programming, and attempts to provide a universal alternative that is based on probabilistic reasoning as contrasted to the predicate calculus.

The selection of the topics is based on a set of original papers that describe the methods. This is an important aspect of the course requiring the students start learning to work with the scientific literature and start preparing for the kind of work they will be required to do at the master's level.

B. Common Laboratory exercises

The exercises of the course start with several exercises for all students, where the students are introduced to different robotic platforms. This hands-on introduction allows them to experience the work with sensor data, their inaccuracy, the issues in the control, the high coupling between the mechanical and program design, and various control paradigms. We start with Lego Mindstorms exercise where all students go through a tutorial on sensors. They are asked to program the robot to drive in a square, 8-shape, avoid obstacles, react to sound, perform simple line-following, and in a line-counting task establish understanding for the difference between a pure-reactive control and control with an internal state, or even a deliberative control. The exercise has a voluntary follow-up, where the students are allowed to experiment with their own ideas and build simple projects.

The second organized exercise is centered around the Sbot platform developed by Robotika.SK. The students learn about programming this embedded platform in C language using AVR studio, learn about programming the various features of the single-chip microcomputer including timers for PWM control of servos and DC motors, analog-to-digital converters for reading from various analog sensors, digital inputs and outputs for reading from bumpers, and controlling the LEDs, I^2C for communication with advanced sensor devices and serial communication over Bluetooth. Students program simple line-following and obstacle avoidance using bumpers and SHARP infra-red proximity sensors. In a voluntary follow-up exercise, students experiment with simple projects based on their own ideas. The strength of the platform lies in the practical serial Bluetooth console with redirected standard input and output allowing instantaneous debugging output and control, as well as easy collection of data on a PC for further processing.

In the third exercise, the students work with the Acrob platform [21], which is based on the Arduino. The user-friendly development environment with the possibility to graphically visualize the sensory measurements provides a wonderful teaching platform. In addition, good-quality robotics exercises that were prepared by the Acrob author are put in use.

The last organized group exercise is working with remotely-operated robots in our Remotely-operated robotics laboratory [23] or the one of the Czech Technical University [22]. Our laboratory contains also a realistic simulator, which introduces the students to the concept of robotic simulations. The robots operating in the laboratory are equipped with high-precision stepper motors and can be viewed from an overhead network camera. The exercise utilizes the computer vision library OpenCV for recognition of shapes and undistorting the frames obtained from the camera with wide lenses.

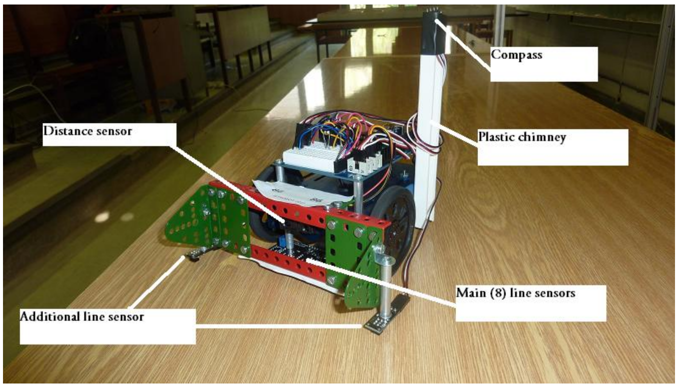


Fig. 10. Ketchup robot that won the Istrobot contest, I.Lack and F.Nagy.

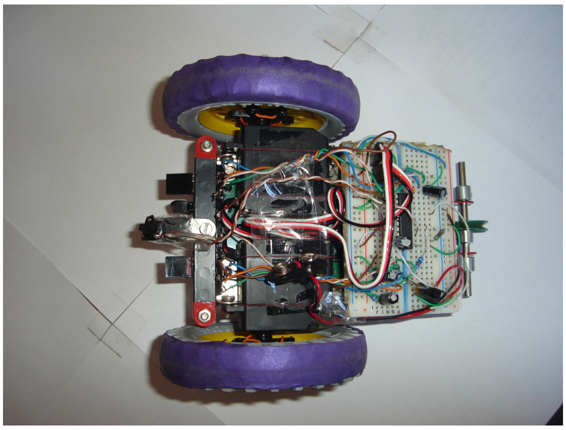


Fig. 8. A hand-made robot of a first-year physics student for the line-follower competition, R.Vanta

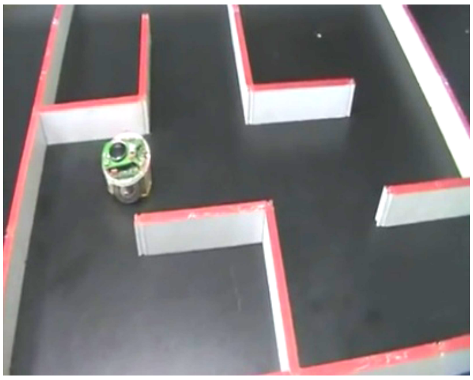


Fig. 9. E-puck implementation for the Micromouse contest, M.Galik and Z.Koysova.

C. Student projects

The student group project according to the student feedback in the poll organized by our faculty is the most praised part of the course. The students are asked to develop a simple real or simulated robotics project on a selected (or own, but approved) topic. The requirement is that the designed system is working, and that the students write a project report containing the source-code and photo or video documentation on the course wiki page. We encourage the students to use some AI algorithm or let the robots learn, although it is not a requirement. Some projects are focused more on the hardware, other on the algorithms.

The quality of the projects vary, we find some of them particularly interesting, and we describe them in this section.

The project *Obstacle avoidance training in Khepera 2 simulator via neural network* is a typical project in simulation. It utilizes the old-fashion, but simple to use simulator of the Khepera robot to train a feed-forward neural network using the standard error back-propagation algorithm, Figure 1 In this project, the student tested the ability of the neural network to learn the obstacle-avoidance behavior. Thus he first wrote a deterministic program for obstacle-avoidance, collected and filtered the training data from its run, and used it to successfully train a neural network that performed the obstacle-avoidance behavior taking the sensory readings on its input and producing the motor speeds on its output.

Line Following Sbot Using Reinforcement Learning - in this project, the student developed a RL algorithm with the purpose to learn to follow a black line on a white surface using two light sensors and SBOT robot. The robot is using a third sensor that is placed in between to compute the reward. After the robot leaves the line, the operator has to lift the robot and place it back on the start. The learning session required around 50 starts. The important aspect of this project is that unless the student writes the learning formulas and tunes the parameters of the system correctly, the system won't learn. Thus despite the simplicity of the learning task, the student must acquire a full understanding of the learning algorithm. See Figure 2.

In a similar project *Light Avoiding Robot*, the SBOT robot learns to navigate away from the light. The students built two simple analog light sensors using phototransistor and a resistor and placed them on the sides of the robot. The state of the system was determined by the sensory readings, while the actions moved the robot for half a second in one of the possible directions. After the action, the Q-value for the particular state-action pair was updated using standard Q-learning algorithm. The robot learned a working light-avoiding behavior within two minutes of learning time.

Two other projects we mention here used the SBOT platform. In the project *SBOT pushing a vehicle* the student designed a rotation sensor that detected the direction of a trolley attached to the front side of the robot using a joint that could rotate along the vertical axis. The sensor used a light sensor and LED in a sealed box so that turning the trolley resulted in changes of the light intensity detected by the sensor. The student developed a control algorithm for stabilizing the straigth direction of the robot with the pushed trolley using the designed sensor. In the project *Braitenberg vehicles implemented using SBOT robot*, the students designed several usual and unusual types of Braitenberg vehicles utilizing for instance the LEGO sound sensors, Figure 3 and 4.

Several projects always deal with our remotely-operated robotics laboratory, which serves as our perpetual playground. In the project *Controlling robots in remotely-operated laboratory using Objection language*, a student who designed his own object-oriented functional programming language developed a library for his language for controlling the remotely-operated robots, designed the corresponding interface, and implemented example programs. In the project *Gripper Functionality for Remotely-Operated Robotics Laboratory*, the student learned about the implementation of the existing simulator and implemented the new feature of gripper manipulator. In another project, *Robot with ultrasonic distance sensors*, the student designed a control board for servicing five ultrasonic distance sensors, learned about the electronic interface and the protocol for communication with the main board, developed a higher level protocol and built an extension turret for the Robotnacka robots. This extension has been in a successful operation for several years since. Yet in another project *Reproducing a learned geometrical object using drawing pen of Robotnacka robot*, the student utilized bottom light sensors and odometry to learn a shape of a drawn object, consequently, the drawing robot reconstructed the learned shape using its pen.

Students are also allowed to work on their own inventions – robots they want to build using their own parts and tools as long as their projects and reports satisfy the requirements, while they are still invited to use the lab facilities. These robots often participate in robotics competitions, example of such being the project *Highlander* built using PICAXE platform shown in figure 8. We also provide the students with robot hardware so that they can build the robots that participate in the competitions – examples being the e-puck robot in project *Mouse in Maze with robot E-puck* or the Acrob-based *Ketchup Robot* that won the first place in the Istrobot contest this year, see Figure 10.

VII. More Fun with Robots

Our students get involved with robotics also in their bachelor and master theses. Jakub Kondela examined the Khepera experiments with the Bayesian Robot Programming and reimplemented them in the SBot platform in his bachelor and master theses. Lukas Risko studied the probabilistic mapping and localisation with the robots in our remotely-operated laboratory both in his bachelor and master thesis. Dominik Misanic and Tomas Stibrany considered the problem of localisation using the distance sensors in a simulated environment and Vladimir Satura implemented a simulated Sokoban-robot and verified it on the SBOT platform. Two master theses dealt with educational robotics - Mikulas Pataky developed a set of robotics laboratory exercises for physics in upper secondary schools, while Daniela Lehocka focused on particular experiments with mechanics for lower secondary schools using Imagine Logo. In his bachelor thesis, Robert Maurer reimplemented the stereo-vision Fly Algorithm using the Surveyor Stereo Vision System and Pavol Hudec implemented a Simulator of robotic sailing robots for our cooperating partners from Innoc. Perhaps the most exciting (from here comes the title of this paper) was the master thesis of Miroslav Nadhajsky who built an outdoor robotic platform for the Robotour contest and investigated various neural architectures for detecting the path in the camera image. He has also designed the complete control architecture that integrates information from multiple sensors, such as GPS, compass, ultrasonic distance, and makes use of a map downloaded directly from the public Open Street Map server. Peter Jurco studied the various uses of the Reinforcement Learning in Robotics, and demonstrated its use in an interesting simulated example implemented using the MS Robotics Studio. Most recently, Peter Pukancik built a mobile robot with a 5-degrees of freedom arm with a 3D vision controlled by a custom-built control board and Gumstix microcomputer with Ubuntu Linux and implemented algorithms of forward and inverse kinematics for the precise arm control, while Daniel Skalicky implemented and compared various algorithms for the e-puck educational robot for Micromouse contest utilizing also its camera for maze exploration. A really funny robotic experience, however full of learning, our students experience when getting involved in one of the robotics contests - FIRST LEGO League, RoboCup Junior, RobotChallenge, Istrobot, or Robotour, all of which they are regularly volunteering as referees or supporting staff.

VIII. Evaluation

During the three years we organized the Algorithms for AI Robotics course, 45 students participated and finished with a credit. The distribution of the grades was as follows: 15% students earned A, 5% with B, 39% with C, 21% with D, 18% with E. Half of the points are awarded for the project, and the other half for a written exam containing questions from the theoretical material covered in the lectures. Students are given access to the original papers describing the algorithms, thus we focus on their ability to comprehend the ideas rather than being able to remember specific details and formulas. As mentioned above, the most popular part of the course is having fun with the robots – i.e. the practical exercises and project work. However, the theoretical content is required so that the students know where to start and get exposed to wider range of the methods in addition to the one they choose for their project. Our laboratory does not accommodate more than 6 students at a time, therefore we have a dedicated time of about 15 hours throughout the week when the students can come to the lab after they have registered on-line, and get a support from us during the registered hours in the laboratory. On one hand, this puts high demands on the teaching staff, but the students need to get the necessary personal guiding anyway as they usually work on completely different types of projects. Once they receive an introduction and get started, they tend to work individually, and require help only occasionaly, thus allowing the teaching staff to work on their own projects during the lab hours. Most students who chose their topic for the bachelor or master thesis within the field of robotics did take the course, which often inspired them to do so. To summarize, we see the following benefits of incorporating the course in the study program of Applied Informatics:

- Provides a different viewpoint on artificial intelligence, which is one of the two main specialisations of our study program. This viewpoint is being crucial since many scientific views in AI assume the body is a requirement

for an intelligent agent. Allowing the students actually experience the work with such physical agents, students can acquire a much better understanding of the issues the embodied intelligence must solve.
- One of two courses where the students work with hardware within the study program.
- Project-based education.
- Motivating aspect and benefit for the whole study program (attractive to students).
- Provides a unique bridge between theory and applications.
- Helps students select topics for bachelor and master theses.

When asking the students about the one thing that was useful, interesting, or otherwise positive, and one thing that could be improved/changed, we have received the following representative answers: 1A) I enjoyed the "playing" with robots. One finally sees the results of programming in the real world, not only on the screen. 2A) I would appreciate if the algorithms covered by the lectures were introduced more practically, perhaps some examples of use. 1B) It was interesting to see how solving simple practical problems sometimes requires a bunch of theory. 2B) When the lecture discussed something I saw for the first time, I was getting lost, I might have been missing some introduction. This suggests that the course is definitely meeting some of the objectives, but also that we still have a way to go to make the material even more accessible and understandable, making even more connections between the theoretical part and its use.

IX. Conclusions and Future Work

We described and shared our experience from a particular course on Robotics for students of Artificial Intelligence. The course is a combination of theoretical lessons covering various algorithms that are useful for robotics and a set of practical exercises, and project work. From the feedback provided by the students we learned that the students liked the course, in particular the hands-on activities. We discussed the contents of the course and some of the student projects. The article is a contribution to a discussion of how to organize the courses on robotics, which are difficult to manage, maintain and service. We find that the course suits well in the study program so that the students learn to work with technologies that were otherwise beyond the standard curriculum. We consider other benefits of our course as well. Before the next occurrence of the course, we plan to finalize a concise study text materials for the course so that the students are not dependent on reading the articles, which will thus become a supplementary reading material. We are also permanently updating the contents of the course, and the hardware provided to the students.

When setting up our course, we were not inspired by any other particular course. Robotics study program and courses at a neighboring university (Slovak University of Technology) are taking the engineering perspective, we wanted to be different. Also, the size of the course is not large enough to cover a complete introduction to robotics. There were no robotics courses in our study program or faculty previously, and thus we were doing something completely new: emanating from the tradition of a stronger theoretical background of the computer science students in our faculty and attempting to extend this tradition towards more hands-on experience and practical knowledge. When trying to compare this course to other robotics courses at this type of university, we find it unique, in the sense that it allows the AI students to peek into the world of robotics from their perspective, without having to go through a systematic process of taking a sequence of introductory robotics courses, yet, it allows them to use high-level knowledge in AI in a form of an application in this practical and interdisciplinary field.

References

[1] Minsky M. *The Society of Mind.* Simon and Schuster, New York, 1998.
[2] Cortenkamp D., Bonasso R.P., Murphy R. (ed.) *Artificial Intelligence and Mobile Robots, Case Studies of Successful Robot Systems*, MIT Press, 1998.
[3] Nehmzow U. *Mobile Robotics: A Practical Introduction*, Springer, 2000.
[4] Corrochano E.B. *Geometric Computing for Perception Action Systems. Concepts, Algorithms, and Scientific Applications.* Springer 2001.
[5] Murphy R.R. *Introduction to AI Robotics*, MIT Press, 2000.
[6] Kelemen J. et al. *Zklady umelej inteligencie*, Alfa, 1992.
[7] Gustafik D. *SBot v2.0 – Educational Robot for Clubs and Classrooms*, Robotika.SK, 2009.
[8] Sigaud O. and Wilson S.W. *Learning Classifier Systems: A Survey*, Soft Computing - A Fusion of Foundations, Methodologies and Applications, vol. 11, number 11, pp.1065–1078, 2007.
[9] Stanley K.O. and Miikkulainen R. *Evolving Neural Networks through Augmenting Topologies*, Evolutionary Computation, vol. 10, number 2, pp. 99–127, 2002.
[10] Lochet J. et.al. *Dynamic flies: a new pattern recognition tool applied to stereo sequence processing*, Pattern Recognition Letters vol. 23, pp. 335–345, 2002.
[11] Hansen N. *The CMA Evolution Strategy: A Comparing Review*, in Lozano J.A. et. al. (eds.), Towards a new evolutionary computation. Advances in estimation of distribution algorithms, pp. 75–102, Springer, 2002.
[12] Zitzler E. *Evolutionary Algorithms for Multiobjective Optimization*, in Giannakoglou et.al. (eds.), Evolutionary Methods for Design, Optimisation and Control, CIMNE, 2002.
[13] Nolfi S. and Floreano D. *Evolutionary Robotics. The Biology, Intelligence, and Technology of Self-Organizing Machines*, MIT Press, 2000.
[14] Arkin R.C. *Behavior-Based Robotics*, MIT Press, 1998.
[15] Brooks R.A. *A robust layered control system for a mobile robot*, IEEE Journal of Robotics and Automation, vol. 2, nr. 1, pp. 14-23.
[16] Kolodner J.L. *An Introduction to Case-Based Reasoning*, Artificial Intelligence Review, vol.6, pp. 3–34, 1992.
[17] Thrun S., Burgard W. and Fox D. *Probabilistic Robotics*, MIT Press, 2005.
[18] Lowe D.G. *Distinctive Image Features from Scale-Invariant Keypoints*, International Journal of Computer Vision, vol. 60, pp. 91–110, 2004.
[19] Bay H., Fasel B. and Van Gool L. *Interactive Museum Guide: Fast and Robust Recognition of Museum Objects*, in Proceedings of the First International Workshop on Mobile Vision, 2006.
[20] Lebeltel O. et.al. *Bayesian Robot Programming*, Autonomous Robots, vol. 16, number 1, pp. 49–79, 2004.
[21] Balogh R. *Laboratory exercises with Acrob robot*, in Proceedings of 2nd International Conference on Robotics in Education (RiE 2011), pp. 41–46, 2011.
[22] Kulich M. et.al. *Users Access to the Robotic E-Learning System SyRoTek*, in Proceedings of the 4th International Conference on Computer Supported Education, SciTePress Science and Technology Publications, vol. 1, pp. 206–211, 2012.
[23] Petrovic P. and Balogh R. *Experiences from Deployment of Remotely-Accessible Robotics Laboratory*, in Proceedings of the 1st International Conference Experiment@ (exp.at'11), 2011.

CITA: Promoting Technological Talent Through Robotics

Kathia Pittí[1], Belén Curto[2], Vidal Moreno[2], Román Ontiyuelo[3]
[1]Dept. of Theory and History of Education, University of Salamanca
Paseo de Canalejas, 169 - 37008, Salamanca, Spain
kathia_pitti@usal.es
[2]Dept. of Computing and Automation, University of Salamanca
Plaza de los Caídos, s/n - 37008, Salamanca, Spain
bcurto@usal.es
vmoreno@usal.es
[3]International Centre for Advanced Technologies
Calle Nuestra Señora, 65 - 37300, Peñaranda de Bracamonte, Spain
tallernxt@yahoo.es

***Abstract*—Educational robotics gives us a creative way to use technology to implement solutions based on our wit and skills, and not become just consumers of technology. Educational robotics creates learning situations and environments to the application of skills and technological processes, preparing students to live and improve their environment. This article introduces a range of activities - both informal and formal education - developed by the International Centre for Advanced Technologies that allows us the proposal of a new approach of educational robotics as a support tool to explore, identify and develop the technological talent of children and young students.**

***Index Terms*—Educational Robotics, CITA, Technological Talent, Education, NXT Workshop.**

I. Motivation

Nowadays, many difficulties at education of sciences can be observed at most countries. This situation is mainly due to the fact that the current teaching methods at subjects such as Mathematics, Physics or Computing, makes them uninteresting and difficult to overcome. A negative attitude toward science, engineering and technology appear at an early school age so students tend to avoid the obtention of related degrees and to become professionals related to these areas.

However, the studies conducted by the International Foundation of Conceptual Education "Alberto Merani" show that each person has one or more areas where his/her learning potential is outstanding. This one is called the potential talent area [1], [2]. Among these talents we can find the potential technological talent. This talent will be developed only if passion for work exists where the cognitive attitudes and expressive skills can be applied. It will also catalyze in valuable, innovative or exceptional contributions, in the specific field of technological and technical knowledge of the real tangible objects. People that owns this talent has the exceptional ability to detect problems in the relationship between humans and physical world objects and they can propose solutions which will improve living conditions [1].

Technological talent requires motor and manipulative skills to properly handle objects and tools of the physical world. The technological talent involves a divergent thinking behaviour, because when facing a problematic situation, different alternatives and search directions must be explored. Creativity at technology plays an important role because it provides a permanent potential for development. Last research works have proven that anyone can develop creativity through an intended educational process. That is, creativity behaviour can be induced, encouraged, strengthened and developed [3]. However, current educational system does not seem to encourage it, but just the opposite [2], [4].

In this regard, Educational Robotics is an excellent tool that helps us to explore, identify and develop the technological talent of all children and youth. It seeks the student's adaptation through processes in order to learn science and technology topics. Exploration strategies that use tools such as inquiry are considered. The learning environments focused on the student activity and the prototypes manipulation in controlled environments are key elements. The aim is that the student develops a structured thinking, that will develop its logical thinking when he is confronted to a problem that must solve.

Regarding education, Educational Robotics aims to arouse the students' interest on traditional subjects that are mainly related with technology. So these topics will be more attractive and inclusive for them, by creating conducive learning environments, that recreates daily problems [5]. Most importantly, Robotics provides the students with an opportunity to discover if their best learning potential [2], flow by Csikszentmihalyi [6], or his element as he called Sir Ken Robinson [4], is related to science and technology.

But the challenge goes further. We need to achieve that psychological conditions match the social and educational conditions [7] to deploy the technological talent (otherwise lost [2]) so in the future these people can bring wealth to society, because the talent and human creativity are the raw material of science and technology, art and business.

In order to generate an appropriate environment that enables to deploy the technological talent through the integration of robotics into the classroom, we consider important the need for different scenarios to overcome certain barriers, such as the lack of vision and leadership for its implementation. Many educational robots need management expertise and specific qualifications from the teachers. Most robotic platforms are prohibitively expensive and difficult to maintain in schools due to their complexity, integration into the curriculum and school evaluation.

Every time, a greater number of initiatives to promote robotics in different contexts, museums [8], international projects [9] or educational institutions [10] are developed. They are always a valuable resource for those ones that are interested in disseminating and improving this discipline and educational technology.

This article introduces, in an organized manner, the work carried out by the *International Centre for Advanced Technologies* (CITA) related to Educational Robotics. It describes the experiences implemented (both curricular and extra-curricular) and the future work. It also highlights the importance of sharing lessons learned to promote the construction of knowledge and enrich our repertoire of activities.

II. Robot Educational Activities Developed in CITA

The International Centre for Advanced Technologies (CITA http://www.citafgsr.org/cita/) belongs to the Foundation Ruipérez Germán Sánchez, located in Peñaranda de Bracamonte (Salamanca, Spain), was opened in October 2006 and has since then promoted among their activities, Educational Robotics NXT projects.

The aim of CITA is the introduction of the Information Society and Knowledge in rural areas through the qualification of human resources, access to information flows and the generation of technological services applied to education, local government, culture, equality and democracy.

For the CITA, when it comes to learning, Educational Robotics is a versatile, multidisciplinary and inclusive activity. It is equally suitable for children, youth and adults, who by solving problems in a collaborative work environment, will generate their own knowledge.

CITA, mindful of its commitment to the development of individuals and society through TIC and education, used the Educational Robotics as an innovative teaching resource.

Here are the activities undertaken in CITA to achieve this goal, its development and description. These examples are a sample of the variety of learning environments that can be generated from the same area (university, foundation, ONG, school...) and illustrate how we can use different strategies in order to excite, detect and enhance the technological talents through robotics.

A. NXT Workshops

The first initiative developed is the NXT workshops [11], [12]. Its name comes from a teaching resource used: the latest model for the construction of LEGO Mindstorms robots called NXT. This model includes the typical parts that allow building different robotic structures: sensors for the perception of the outside, motors to get the movement of the robot and a microcomputer for programming NXT actions.

NXT Workshops consist of extracurricular activities with duration of approximately 20 hours over five or six sessions. The methodological structure of the sessions is shown in Table I. One reason for the attractiveness of NXT workshops [13] is that they involve multiple design possibilities because of the versatility of the Lego Mindstorms NXT kit. Each workshop has a different subject and we have designed many different prototypes (robots that compete in the traditional scarf game, formula 1 cars, robots that play basket, humanoids, animals, robots with drawing skills, sumo, space explorers, NXT vehicle). As a picture is worth a thousand words, http://www.flickr.com/photos/citafgsr/collections/72157629051949945/

TABLE I
Methodology Workshop Structure NXT

Session	Activities
1	Introduction of the course Team building Getting to the Lego kit parts
2	Design and selection of the desired model Start of the Assembly
3	Assembly Construction (either fully guided, free or mixed)
4	Programming (using graphical language NXT-G or textual language NXC, depending on the difficulty)
5	Pre-testing Assembly of the track Fitting-out of the classroom (morning) Competition / exhibition final with family and friends (afternoon)

Workshops based on specific topics offer participants opportunities to develop skills both to find out and to solve problems, in contrast with the school activities in which students are given a fully structured problem [14]. This is important because one of the most critical parts in the design of projects in the real world is to identify and refine the problem to be solved. This aspect has been considered by including the methodology and data of the benefits gained by participants in these publications NXT Workshops [11], [12].

However, we consider relevant to show the example of the last workshop held NXT called "NXT Vehicles", whose objective was to build robots-cars. A total of seven teams were formed with a maximum of three members of 8 to 15 years. Four teams (the smallest and rookies ones) chose to build vehicles step by step, while the veteran guys first decided to design their own vehicle.

When making free designs, their first task was to define the model building by using the Internet: a tank, a caterpillar and a monster truck were the selected cases. The complexity level of design a robot without an outline is great, but these teams managed the decision taking problems as they arose to take concerted decisions.

The team "Nydea", that built the tank, decided to implement 5 engines so they needed two NXT modules to control the

robot . The team "Monster Truck" used pneumatic and gear items for the vehicle control. The final results, that were surprising, can be seen in this link:
http://linoit.com/users/tallernxt/canvases/E-infocenter%20Vehicles%20NXT

These activities allow us to identify, by observation (see section III), the participants that show a greater potential to be a technological talent and, in the following, guide them in their training.

One thing to note was the attendance of young people from neighboring towns, from other cities (Salamanca-45 km, Bejar-90 km), from other provinces (Zamora-115 km) and possibly another region (Madrid-170 km.) Their parents support and encourage their interests, regardless of distance traveled. This reveals the lack of activities for this kind of talent in Spain.

B. *Competitions with robots: First Lego League*

The constancy of some participants of the Workshops NXT takes the CITA to participate -since 2009- in robotic tournaments, specifically in the First Lego League (FLL), a very popular competition with LEGO robots that takes place worldwide and is addressed to children up to 16 years old. Each competition, a different subject. Each time, a different test. Each year a different challenge.

The first team was called "Tuercas Locas". In 2011, due to the number of young people interested in this activity a second team was created: "Locas Tuercas". For three months they work hard to participate in the FLL. If anything is striking watching the kids' work is their excitement, and this is only possible if there is enthusiasm. We know there are other ways to learn, but they are definitely more boring.

What is the secret? The seductiveness of an activity that uses a methodology based on *learning by doing*, which is capable of stimulating the eight intelligences defined by Howard Gardner [15] in his *Theory of multiple intelligences*: linguistic (presentation of their projects), logical-mathematical (robot programming), the visual-spatial (building of the robot), the musical and Bodily-kinesthetic (theatre play), intrapersonal (self-knowledge), interpersonal (knowledge of others, teamwork) and naturalistic (research project). It also gives us the ability to recognize and develop the talents of each participant. With this conviction, CITA promote and supports this activity.

C. *NXT Christmas Workshops*

The robots are also key players in the Christmas activities in CITA. Each year, we invite the local *children with their parents* to a free workshop, to discover the NXT Educational Robotics (three hours) with designs done step by step in a Christmas atmosphere. They are the students of CITA, along with their coaches, who are in charge of guiding the participants of the workshop in this wonderful family activity (show in Fig 1).

Fig. 1- Christmas workshop in CITA

D. *Videoconference with robotics groups of Latin American countries*

Due to the facilities and technologies available in CITA, we have carried out videoconferences with American robotic students, including St. Jude Tadeo College (Santo Domingo, Dominican Republic), Science Club *Electronic World* (Ushuaia, Argentina) and a group from the Technological University of Panama - *Chiriqui Regional Centre* (Panama). During the videoconference, each country introduces their designs and performs a short demonstration of their robots. This is usually done in the closing activity of the NXT workshops, or while preparing for the FLL competition.

For many of us, the experiences with remote control are limited to change the television channel from our sofa and, for the most experienced, drive a toy car down the hall at home. But what would you say if we propose to control a robot from the other side of the Atlantic? What if they were two robots which, controlled from different parts of the world simultaneously, compete with each other?

This kind of activities -the Lego NXT robot teleoperation through the Internet- has been highly valued, and we have made it with the three countries mentioned before in several stages: 'exploration of Mars', 'sumo wrestling', 'challenge ecological' (educational track manufactured by Lego) or FLL competition. These activities show the participants different technological possibilities such as:

- Videoconference (Skype software application) to see the stage and talk.
- Remote access through the Internet to a computer in another country using LogMeIn software.
- Bluetooth Communication to handle the robot using the NXT-remote application.

For example, in the sumo match, two Lego NXT robots physically located in CITA, were controlled remotely from across the Atlantic and from different countries: Argentina and the Dominican Republic. The 'struggle of prototypes' was took place in real time and all those attending the event, (the ones in Peñaranda and the ones in America) could see live the evolution of robots and live, at the same time, the emotions of the competition (show in Fig. 2).

Fig. 2 - Teleoperation Sumo robot from the CITA

E. Training for Teachers

Given the experience of CITA in the field of robotics and education, in May 2011 teachers from the Technological University of Panama -who participated in the project "*Development of scenarios which facilitate and encourage science learning and technology, making available educational robotics to students and school teachers*"- were instructed in this methodology in order to share its benefits.

In this experiment, we used the Kit 9797 educational robotics of Lego Mindstorms NXT. The invited teachers learned how to motivate students through several imaginative designs of robots, incorporating their key elements (sensors, motors, …), and how to program the robots to give them intelligence and autonomy.

Thus, these teachers acquired an overview of educational robotics and experienced how to use a robot as an educational tool in teaching Mathematics, Physics and Technology.

In order to know a set of recommendations related to project development and their integration into the classroom, we need:

- The material: the guide for each session, a student portfolio and a team guide where the proposed activities are developed in each lesson and a reflection that allows them to analyze what they made that day. In addition, project staff must have their own observation and reflection guide to what has been done in each session, as a means to to reach a continuous improvement.

- The teachers and students training that participate in the project on different days, based on their background and their respective roles.

- The scheduling of the teachers gradual training process. That is, during the first phase both teachers and students receive the same lessons, as suggested by [16] "teachers teach as they are taught, not as they are told to teach". In a second phase, the constructivist/constructionist methodology and a project-based learning approach [9], [17], are explained. A set of examples of proposals in their subjects is given. Finally, after these sessions, the teachers would plan and implement a lesson, which includes robots, in their respective classes.

- The definition of the team's size and the each member role must be done in an anticipated way. Based on our experience, we recommend that teams have a maximum size of three participants, where each can play one of these roles: programmer, engineer, journalist, and these three functions in each session must be rotated. It will allow to each of them an experience at all three roles, the enhancement of their strengths and the overcome of the weaknesses.

- Robot competitions are very popular. A challenge provides additional extrinsic motivation for students, it increases their skills of teamwork and it encourages the student to identify and evaluate a variety of views [18]. So we propose to acquire the educational resource of LEGO "Green City Challenge combo pack" to make an intercollegiate competition as the final event of the project, similar to FLL.

Some details about this Panamanian project and its results just been published [19].

F. A Visit with Mouse

Educational Robotics is also present in an activity called "a visit with mouse". This activity shows students and teachers of schools the importance of technology in the classroom through workshops in our center. The workshops include activities with interactive whiteboards (IWB), computers, tablet PCs, and, since 2011, Educational Robotics (show in Fig. 3). This program was specifically designed for groups of children between 3 to 17 years old and schools teachers from the region (Castilla-Leon) and other Spanish, who are introduced the advanced technologies in a fun and easy way.

Up to 50 people are invited to a session, which last for one hour. We usually divided them into two groups, so they get a better experience. We separate each group of 25 people in 6 teams (3 to 5 members).

We have six kits 9797 educational robotics of Lego Mindstorms NXT and six tablet PC to develop this activity. The methodology is divided into three sections:

1) *Theoretical section* (10 minutes).

- Welcome
- What is a robot and its parts?
- Examples of robots in our daily lives and its importance.
- Introduction to the Lego Mindstorms NXT educational kit.

2) *Construction and programming section* (25 minutes).

Due to time constraints, it was decided to perform the construction and programming simultaneously. That is, while one or two students from each team learn to program, their colleagues built the robot.

In order to build the robot, each team is given a step-by-step guide. After trying several models, we decided to use the model called "*Domabot*" [20]. This design is very easy to build and it also incorporates a light sensor, an ultrasound sensor and the possibility of placing either a touch sensor or a sound sensor. Some teams even tuning their robot.

We used the NXT-G software through the interactive whiteboard (IWB) available in the classroom. This enables us to provide the programmers with a dynamic learning. They are briefly explained the sections of the interface; the blocks "move", "sound", "wait" and "loop", and how to download the programs into the robot.

We analyze three basic programs in the IWB, and then each team will write this program in his table PC.

- The first program verifies that the communication between the NXT robot and the sensors/motors woks properly.
- The second one involves straight-line motion and turns (motors).
- The third one follows a black line (light sensor) and detects obstacles (ultrasonic sensor).

3) *Practical section* (25 minutes).

By the time the builders have completed the Lego NXT robot, the programmers have the programs ready to be downloaded to the robot. It is amazing to observe the expression of these children watching the robot run the first program, and even more when the robot uses the sensors! Now it is time to try to make their robot perform a sumo match, using previously learned programming blocks. We explain them a simple program and they write it on their computer. They are responsible for calibrate the distances for the ultrasonic sensor which will detect the opponent (a cardboard box in our case) and regulate the powers of the motors used, and the duration of the turn.

Then they put the robot in the ring (dohyō) and fun begins. Trial and error to get your robot meets the objective: getting the opponent out the ring avoiding going off the ring.

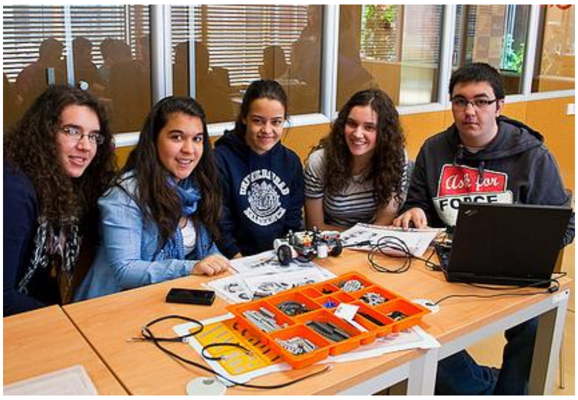


Fig. 3 - Group of students during a visit with Mouse in the CITA

G. Robotics in the Classroom Project

In most countries, the current challenge of educational robotics is being moved from the extracurricular activities and being integrated within the school curriculum on a permanent basis, as a learning resource. Not only in technological subjects, but also in those where it can serve as a support for improve teaching and learning processes, in addition to promoting the development of skills that are so requested in this new millennium.

CITA submitted to the CFIE (Centre for Teacher Training and Educational Innovation) -institution under the Ministry of Education and in charge of teacher training-, a proposal to make available to secondary teachers of Peñaranda de Bracamonte a new educational resource for the teaching of their discipline: the Lego Mindstorms NXT educational kit, in the following ways:

- Type A: technology teachers
- Type B: all kind of teachers

During the academic year 2011-2012 two schools, three teachers in category A and one teacher in the form B took part. The proposed training is divided into two phases:

Phase 1: Training of teachers on the didactic use of these resources (Lego Mindstorms NXT).

Phase 2: Implementation of an educational activity with their students.

For this project we have the same 6 educational kits Lego Mindstorms NXT with their tablet PCs. It is important to highlight certain aspects of this proposal:

- The teachers attended the course in the CITA, one hour per week (20 hours total) between the months of December and May.
- The design of the activity that will be done with students is planned during Phase 1, according to the curricular needs of each teacher. Thus, there were three different experiences (show in Table II):

TABLE II
ACTIVITIES CARRIED OUT

Activity	**Introduction to Robotics**	**Body Forward Challenge**		**Sumo NXT Competition**
Teacher's Subject	Technology	Technology/ Programming		Sport
Content	What is a robot? Why they are important? Components and examples.	What is a robot? Why they are important? Components, mechanism and examples.		Fine motor skill, Team-work, Tactics, Obeying rules, Perseverance
Level	3º ESO	4º ESO		2º ESO
Number of groups	2	1		2
Number of students	35	6		34
Place	CITA	CITA	School	CITA
Number of sessions	4	4	4	5

In the second phase, the robotics instructor leads the class, assisted by the teacher of the subject. We believe that this initial support is key for a teacher to acquire the confidence that will allows him to integrate robotics in the classroom, because he will learn to identify and solve the problems that may arise.

In all the workshops we used programming NXT-G software.

Since the school of some of the teachers who attended the workshops, had already the track for the 'Body Forward challenge' activity, they could develop the activity in the school with the rest of the pupils.

H. Other activities, and a look at the future

We have also take part in three international events:

- European Campus Party in Madrid (2010), with the project 'Red Planet NXT' (show in Fig. 4), whose objective was to show the importance of space research, through a robot inspired in the current 'Mars rovers'.

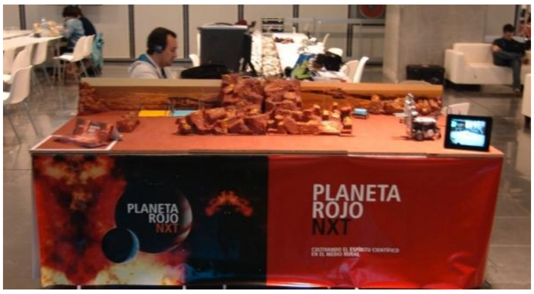


Fig. 4 - Our stand in the European Campus Party 2010 in Madrid

- In Empírika (Iberoamerican Science Technology and Innovation event). CITA decided to raise public awareness about recycling, through a "race" of robots. We emulated a recycling plant with two areas: one for paper (in blue) and one for other waste materials (in red). Visitors would guide the robot to the right place depending on the type of waste material, using a remote control (show in Fig. 5). Afterwards, the robot, in an autonomous way, would repeat the activity using a color sensor. A panel showed the time that took both the robot and the person using the remote control, to place the material in the appropriate container: the robot was faster.

  Allow direct interaction of the participants with the robot in such activities is a key point to consider in the design of activities to promote robotics.

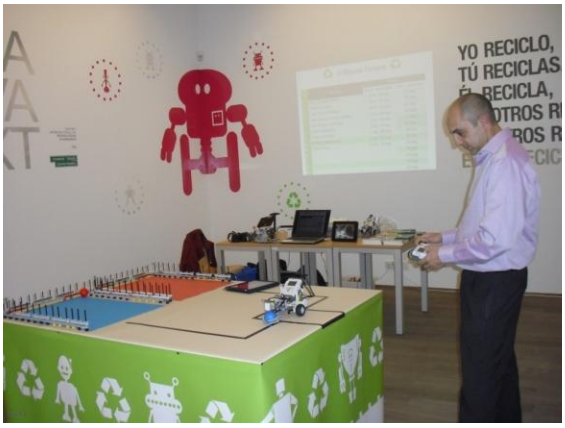


Fig. 5 - Our stand of educational Robotics in Empírika 2010

- European Campus Party 2011 in Granada, with the European project 'Robots in India', whose objective was to show our experience with robots to children in a culture as different as the Indian (show in Fig. 6).

Fig. 6 - Exhibition Robots NXT in India

The interest in robots grows more and more in Peñaranda de Bracamonte (Spain). For this reason, CITA includes, among its summer activities, robotic workshops, for kids over 10 years old.

III. Some Reflections to Recognize and to Guide the Technology Talent

After knowing the range of activities that CITA makes to promote technological talent, one of the questions that arises is how to recognize the potential in our students?. In the following, some simple but very valuable guidance will be shown [1]. They will help in the task of exploring the interests and skills related with technology talent.

How to explore the interest?

1.- Look to recognize the students interests by observing their activities, habits, games, trivia and concerns.

Technological talent likes "tinkering" with machines, computers and technology in general, as well as individual sports or team activities related. They are usually disordered with their spaces. Its curiosity is always directed to the way of how the apparatus, machines or any type of process works, and they want to know and manipulate objects and their mechanisms.

2.- Seek to identify the students interests, by analyzing their performance and inclinations at school and extracurricular activities.

This kind of talent usually has good performance in technical drawing, physical education and sports, technical areas (mechanical, electrical, electronics) and construction. Enthusiastically they can participate in team sports, technology fairs, modeling, prototypes or machines in science fairs.

How to explore the skills?

1.- Recognize the skills of its students by analyzing what is it easier to learn.

A technical talented person easily understands and interprets manuals, plans or rules of games and sports. He easily understands a toy mechanism, a machine or device, as well as the related software tools.

2.- Seek to identify the students skills by inquiring what things are considered difficult in school:

People with this kind of talent tend to be somewhat abrupt, so that social activities are often not his forte. They have a hard time understanding the art language and creativity activity, so they tend to be more specific, linear and pragmatic ones.

We now understand better why robotics is so important to identify this type of talent, as it brings together most of the above mentioned requirements. Moreover, the reality is that this kind of talent does not have enough activities to help you promote it, as it occurs with other talents (sports, arts, etc.). Therefore, the CITA seeks to promote technological talent by creating situations and learning environments that will be conducive for the application of technological skills and processes that allow exploring further.

If a student shows that he has this potential, Table III gives some recommendations to help the teacher guide the formation and deepening of his talent.

TABLE III
ACKNOWLEDGMENT TRAINING STAGES OF TALENT

Stages	***To study in depth:***	**For this:**
1st childhood (0-5 years old)	*Interest recognition*	- Encourage curiosity. - Encourage the achievement of goals increasingly sophisticated.
2nd childhood (6-12 years old)	*Aptitude recognition*	- Probe learning potential. - Teach planning, implementation and evaluation of goals - Pose challenges to seek that the achievement and improvement will be the goals. - Encourage the development of the skills through healthy competition with yourself and other ones.
Youth	*Projection of vocations*	- Channel their interests and skills to specific domains - Guide the formulation of the life project

IV. SHARING ENRICHES US ALL

Sharing experiences is an important factor to meet the challenges that the education system is currently experiencing.

- Web: http://robotica.citafgsr.org/
- Blog: http://www.citafgsr.org/educacion/robotica/
- Twitter: #roboticacita

There you can consult its workshops, activities, photos, videos and comments on the evolution of all these initiatives described.

V. CONCLUSIONS

In this paper, we have introduced the range of educational robotics activities implemented by CITA. These activities can explore, identify and develop the technological talent of the participants, that is, the potential to have outstanding performance when facing real-world problems, using tools and manipulative skills.

Thus, CITA helps to complete, enhance, maintain and meet certain educational tasks. Therefore the education system finds a good ally in CITA to enhance the technological talents using educational robots Lego Mindstorms NXT. This kit, as has been seen in the activities presented, due to its flexibility facilitates the construction of different designs of robots, according to the didactic objectives to be achieved.

Perhaps, in the future, new partnerships will be form between education centers and foundations or non-formal sector institutions. This partnership will arouse new ways to find and share solutions. In the future, we will be able to find the way to better educate our children, whatever their needs are.

Finally, we consider it essential to know and train talent in order to guide decisions on the academic future. It also requires joint efforts of academic and family in identifying and potentiating of the passions, skills and performance of the children, guiding them to build a successful life plan.

ACKNOWLEDGMENT TRAINING STAGES OF TALENT

The authors of this paper wish to thank CITA and participants of all educational robotics activities presented, for their work and enthusiasm.

Kathia Pittí is the recipient of a grant courtesy of The National Secretary of Science, Technology and Innovation (SENACYT) and the Institute for Training and Human Resources Development (IFARHU), of The Republic of Panama.

REFERENCES

[1] Fundación Internacional de Pedagogía Conceptual Alberto Merani (FIPCAM), *La robótica: Desarrollo del talento tecnológico como fuente de competencias para la vida*. Curso virtual. Bogotá, Colombia, 2011.

[2] M. De Zubiría, *Psicología del Talento y la Creatividad*, Bogotá, Colombia: FIPCAM, 2006.

[3] J. A. Marina, *Teoría de la inteligencia creadora*, Barcelona, España: Anagrama, 1993.

[4] K. Robinson and L. Aronica, *The element: How finding your passion changes everything*, New York: Penguin Group USA, 2009.

[5] A. Acuña. (2006) *Robótica: espacios creativos para el desarrollo de habilidades de diseño para niños, niñas y jóvenes en América Latina* on FOD. [Online]. Available: http://www.fod.ac.cr/robotica/descargas/roboteca/articulos/2007/frida_robotica_desarrollo_articulo.pdf

[6] M. Csikszentmihalyi, *Flow. The psychology of Happiness*, London, Rider: 1992.

[7] J. A. Marina, *La educación del talento*, Barcelona, España: Ariel, 2010.

[8] N. Fachantidis and V. Spathopoulou, "Cross-Curricular Approach to Robotics in Interactive Museum-Pedagogy Environment," in *Proc. of 2nd International Conference on Robotics in Education* (RiE 2011), p. 207-213.

[9] (2009) The TERECoP Project website. Available: http://www.terecop.eu/

[10] A. Weirich, C. Haumann, J. Steil and S. Schüler, "Learning Lab - Physical Interaction with Humanoid Robots for Pupils," in *Proc. of 2nd International Conference on Robotics in Education* (RiE 2011), p. 21-28.

[11] K. Pittí, B. Curto, and V. Moreno, "Experiencias construccionistas con robótica educativa en el Centro Internacional de Tecnologías Avanzadas," *Revista Electrónica Teoría de la Educación: Educación y*

Cultura en la Sociedad de la Información – Universidad de Salamanca, vol. 11, pp. 310-329, Feb. 2010.

[12] K. Pittí, B. Curto, J. García, and V. Moreno, "NXT Workshops: Constructionist Learning Experiences in Rural Areas," in *Workshop Teaching Robotics, Teaching with Robotics Proceedings of SIMPAR'10*, pp. 504-513, 2010.

[13] (2009) Robótica Educativa NXT website. [Online]. Available: http://robotica.citafgsr.org/

[14] N. Rusk, M. Resnick, R. Berg, & M. Pezalla-Granlund, "New Pathways into Robotics: Strategies for Broadening Participation," *Journal of Science Education and Technology*, vol. 17, no. 1, pp. 59-69, 2008.

[15] H. Gardner, *Intelligence Reframed: Multiple Intelligences for the 21st Century.* New York, NY: Basic Books, 1999.

[16] D. Alimisis, J. Arlegui, N. Fava, S. Frangou, S. Ionita, E. Menegatti, S. Monfalcon, M. Moro, K. Papanikolaou & A. Pina, "Introducing robotics to teachers and schools: experiences form the TERECoP project," in *Proceedings of the Constructionism 2010 Conference*, Paris, 2010.

[17] T. Savage, I. Arnedillo, F. O'Donnell & B. Tangney, "Using Robotic Technology as a Constructionist Mindtool in Knowledge Construction," in *Proc. of the The 3rd IEEE International Conference on Advanced Learning Technologies (ICALT'03),* 2003.

[18] M. Pisciotta, B. Vello, Bordo & G. Morgavi, "Robotic Competition: A Classroom Experience in a Vocational School," in *6th WSEAS/IASME International Conference on Educational Technologies (EDUTE '10),* pp. 151-156, 2010.

[19] I. Moreno, L. Muñoz, J. R. Serracín, J. Quintero, K. Pittí and J. Quiel, "La robótica educativa, una herramienta para la enseñanza-aprendizaje de las ciencias y las tecnologías," *Revista Teoría de la Educación: Educación y Cultura en la Sociedad de la Información*, vol. *13*(2), pp. 74-90, Jul. 2012. Available: http://campus.usal.es/~revistas_trabajo/index.php/revistatesi/article/view/9000/9245

[20] D. Kee. (2011) Domabot – Classroom Robot Design. [Online]. Available: http://www.damienkee.com/home/2011/8/20/domabot-classroom-robot-design.html

RILE – Robotic Interactive Learning Environment

Lakshmi Prayaga
Department of Applied Sciences
University of West Florida
Pensacola, FL 32514
lprayaga@uwf.edu

Chandra Prayaga
Department of Physics
University of West Florida
Pensacola, FL 32514
cprayaga@uwf.edu

Aaron Wade
Department of Physics
University of West Florida
Pensacola, FL 32514
awade@uwf.edu

Niranjan Suri
Institute for Human and
Machine Cognition
Pensacola, FL 32502
nsuri@ihmc.us

Alex Whiteside
University of West Florida
Pensacola, FL 32514
ajw22@students.uwf.edu

Jeff Hawthorne
University of West Florida
Pensacola, FL 32514
jwh36@students.uwf.edu

Miroslav Kulich
Czech Technical University
Prague, Czech Republic
kulich@labe.felk.cvut.cz

Libor Přeučil
Czech Technical University
Prague, Czech Republic
preucil@labe.felk.cvut.cz

***Abstract*—We report the design and alpha-testing of a Robotic Interactive Learning Environment (RILE) to teach introductory one-dimensional kinematics to middle school students. The environment is centered around robots which are controlled via WI-FI, and are equipped with sonar sensors to provide distance vs. time data. A student can remote-login via an application and perform experiments on kinematics on the robots and understand the usually difficult concepts of displacement, velocity, and acceleration. The system was initially tested in a middle school for multiple batches of students at the 8th grade level. Initial reactions show that the students were engaged, interested, and excited. In particular, the excitement of working with real robots kept the students alert to pitfalls in the understanding of kinematics, as shown by their responses to qualitative questions on interpretation of graphical data.**

I. Introduction

The use of Robotics offers an exciting and engaging environment for teaching STEM (Science, Technology, Engineering and Mathematics) concepts. From the early work with LEGO kits and other robots in the late 1980s with Dr. Seymour Paperts software TC Logo, the use and/or programming of robots by elementary and high-school students has been shown to improve their understanding of STEM topics such as gears, friction, light, heat, movement, velocity, acceleration, slopes, force, etc., together with the mathematical skills required to comprehend these concepts (Weisteider and Brown) [1]. In addition to the skills developed by manipulating the robots to perform the desired actions, robotics also improves the students ability to collaborate with other students and work in teams (WRRF 2003, CAST STEM Institute) [2], a much desired skill. At the same time, it is clear that providing the equipment necessary for students to control and/or program their own robots does not scale to the large number of schools and to the large number of students within the schools, due to the high cost of the equipment needed per student. We present a preliminary version of RILE for middle school physics that facilitates tele-robotics as a mechanism to provide middle school students with the ability to remotely manipulate and control real robots and their environment through a Web-based interface, drastically reducing the cost per student but at the same time providing students the engagement and excitement of working with real robots, including the difficulties of manipulating robots in the real world instead of digital avatars. We built on 1) existing applications of tele-robotics technology in education and on 2) innovative programming paradigms being developed by the researchers from leading institutions.

II. Existing Work

There is considerable research on robots in education. Major, Kyriacou and Brereton (2011) [11] conducted a comprehensive study that reported on the effectiveness of using robots including simulated robots in computer science education. Their case study reviewed 34 papers of which 23 papers reported use of physical robots and 7 papers reported use of simulated robots to teach computer science concepts both at the high school and university levels. Six of the seven papers reported that simulated environments were effective in computer science instruction. The authors Becker (2001) [5] , Borge (2004) [7], Buck (2001) [8], Enderle (2008) [9], and Ladd and Harcourt (2005) [10], reported that a simulated robotics environment was very effective in introductory computer science instruction at the university level.

Our project is novel in that it extends the notion of tele-robotics to K-12 (Kindergarten 12th grade) education and allows direct manipulation of the physical robots located in a real laboratory environment. Our objective is to better motivate students to learn STEM principles and in particular, concepts in physics. Tele-robotics is the notion of being able to control robots from a distance usually via a network (the Internet in our case) to accomplish specific tasks. Example tele robotics project include NASAs Rover, Mercury project, and the Puma Paint project [Stein, (2003)] [13]. Tele-robotics projects in higher education were proposed by A. Bicch, A. Caiti, L. Pallottino, and G. Tonietti (2005) [6], Riyanto Bambang (2007), and by Kulich, Kosnar, Chudoba, Fiser, Preucil (2012) [3] . We use the existing literature as a basis for our experiment. Our hypothesis is that RILE will provide a highly motivating and engaging learning environment for students to achieve the desired learning outcomes. An example learning outcome identified for the experiment on kinematics is described in this paper. We believe that RILE can be leveraged for achieving student learning outcomes in many STEM disciplines including computer science, IT, physics and math.

III. RILE Architechture

RILE complex architecture extends from a basic table-like base to high level user interfaces, incorporating many components in between, allowing a computationally efficient, yet functional system capable of performing physics experiments in a controlled manner. Our architecture is based on the current client-server paradigm and is split physically into three components: Robots, Servers, and External Connections. Each of these entities is both logically and physically separated, relying on network connections both over a local network and the Internet to connect and function. Not only is this necessary to allow portability and expansion, but also essential due to the various local computer and microprocessor architectures within the lab, and the client computers that the students will be using to connect. For this reason, at the software level, we use various languages including C, C++, and Java. The figure below shows a simplified visualization of the environment.

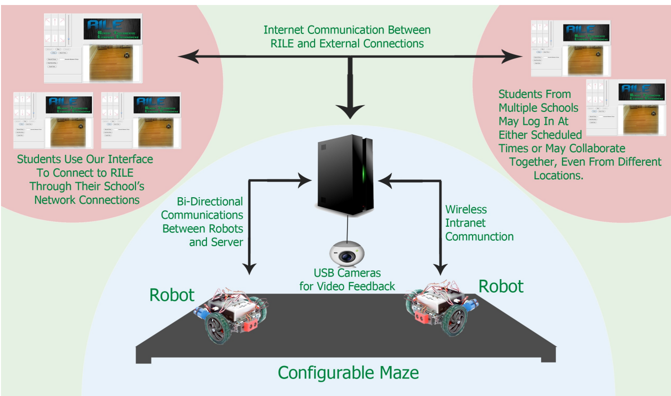


Fig. 1. Visualization of RILE's Architecture

Within the RILE system, we can separate subsystems by location: local interface (Client) and remote system (Server).

A. The Remote System

RILE's remote system includes the experimentation environment, complete with robots, a table-like field, video capabilities and a central server. Its centralization is a key part of the RILE paradigm, allowing one remote system to service numerous local systems independent of location.

At the environmental level, RILE is configured with a simple 9' (2.7 m) square table with raised edges to provide an closed environment for the robots. This field is shown in Figure 2.

Fig. 2. RILE Table

Mounted above the table are 2 high definition USB cameras, which monitor the field.

At the robot level, we have a dynamic number of robots with varying local architectures, each connected to a network via Wi-Fi. At this level, all commands and protocols are specific to each micro-processor and each robot is easily modified though hardware additions. These robots run software specific to their microprocessor which connect to the RILE API on the server and allow local autonomous routines independent of the larger system.

Within the environment, several monitoring programs run to provide information about the system to the server. An example of this is RILETracking, a video streaming service with object detection. This process reads in the multiple camera streams, combines them into one image, and searches that image for robot markers. If a marker is located, the service reports the robot ID, as well as the 4 corner locations of the marker to the server, designating the robot's exact position and orientation. A video stream is also created for external connections to monitor the video feed.

The server program is central to RILE and coordinates all connections and activities. Once devices connect, the server controls all lines of communication and allows various devices, programs and users to communicate with one another in a standardized way. It preforms safety functionality, including keeping robots form colliding; maintenance, including reporting issues to administrators; and security, preventing threats to its users and itself.

While these software modules handle communications and robot control, RILE also provides a flexible system for monitoring robot sensors, reporting information and presenting it in a graphical format. The flexibility resides in the idea of a module tray, which lies between a user interface and its connected robot. This tray allows numerous modules to be loaded, increasing functionality. Modules currently include a dataset grapher, a position monitor, a velocity monitor, and a data distributer. These modules provide near limitless extendibility for the RILE system as they can be created by users for specific functionality.

At the top of the remote system lies a connection secretary. This program handles all physical connections relating to the external system, both internal and external. These include robot sockets, video streams, user connections and more. This secretary acts as a gate-keeper to the system, allowing one central connection interface.

B. The Local System

The local system within RILE is contained within a single graphical user interface (GUI). This GUI allows students, teachers and administrators to easily connect to the remote RILE system, preform experiments, watch video lectures and more in a user-friendly manner. This system must be installed on the computer the user is sitting at, but requires nothing other than an internet connection to fully utilize RILE.

Upon startup, the local system connects to the designated remote system and authenticates the user via a username and password. From there, the program forks into either student, teacher or administrator mode based on the user's credentials.

Students are forwarded directly to textbook mode, the primary module of the local system. While similar to a typical textbook, RILE's textbook interface (shown in Figure 3) organizes material in a logical, hierarchical system, allowing multiple classes, grade levels and disciplines to use the same textbook, decreasing cost and student acclimation between classes. This novel redesign of the textbook promotes the teaching of topics as a logical piece of a puzzle, instead of a linear chapter in traditional textbooks. We believe that this design will not only improve understanding about the connections between lessons, but also allow independent use of the system without spending time sorting through an index.

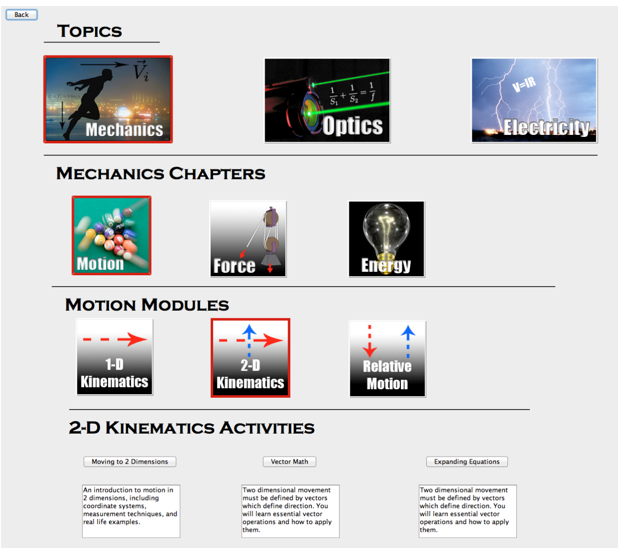


Fig. 3. Textbook Interface

Within this interface, as students select the appropriate levels, lower menus populate with appropriate sub-materials, ending with activities which can be selected.

Once an activity is selected, students are presented with a simple pre-test to estimate current subject knowledge. They are then shown a video lecture of the topic, supported with figures, graphs, and data, providing a stimulating initial presentation. Once finished with the lecture, students are shown a pre-lab document describing the experiment in detail and connecting the experiment to the topic they were just presented. Students may then move on to the experiment itself, the key feature of the RILE system.

Upon entering the experiment panel, students are given the option to preform the experiment or watch a live experiment in progress. This feature allows an entire class to benefit from experimentation, even with limited robot hardware. Viewers receive all video and raw data from the experiment, and are given their own options for graphing and reviewing data, separate from the controller. However, if the preform option is selected, the student is also given access to robot navigation and sensor control panels, customized for the specific experiment, allowing controlled experimentation. A helper block helps walk students through experimentation, connecting live robot data to previously discusses topics. At any point, students can return to the pre-lab or lesson video to revisit information. An image of this interface is shown in Figure 4.

Once the actual experimentation is complete, students continue to the data review pane to analyze their data. Within this pane , students can access all of their recorded data sets and graph them to visualize their results. These graphs and datasets can be exported for lab reports. Finally, the lesson ends with a conclusion and a post test.

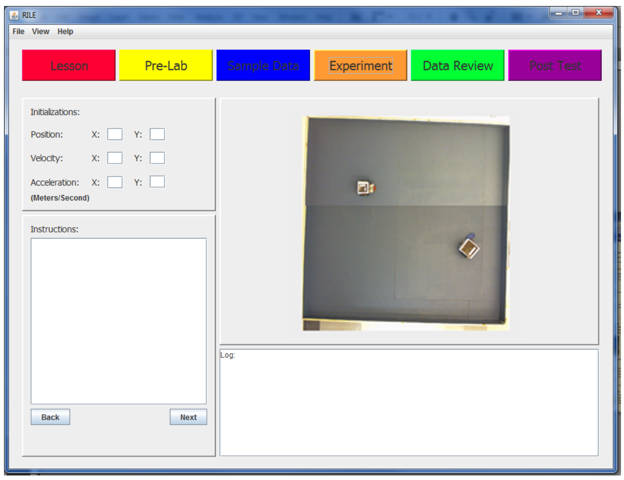


Fig. 4. Experiment Interface

If the user is a teacher, they are given the option to use the RILE system as a student, or to access the teacher controls. These controls allow the creation and manipulation of classes and student accounts within the class. These accounts keep track of student experiments and results as well as test scores for teacher review. Administrators have full access to the server and can create student, teacher and administrator accounts as well as control server behaviors.

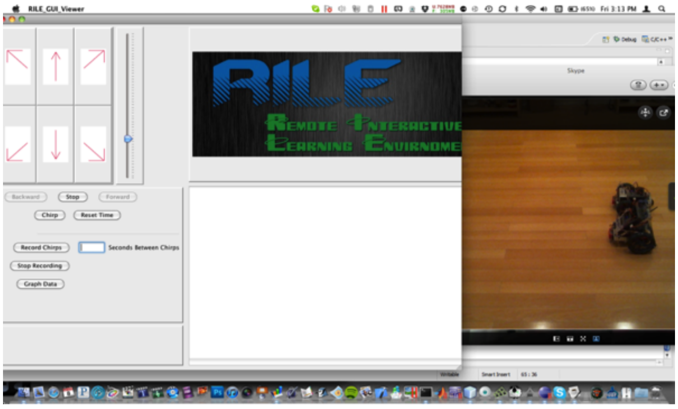


Fig. 5. Alpha Version User Interface

IV. Alpha Testing

Preliminary testing of RILE was performed in a middle school in Florida to evaluate the technology, the impact of the learning environment, and student interest. The experiment was conducted in five 8th grade sections (age group 14 years) with a total of 85 students. Two sections were taught in a traditional manner using chalk and board and the other three sections were introduced to the same concepts using the RILE system.

The concepts taught were part of one-dimensional kinematics. We concentrated on four concepts: distance, displacement, speed, and velocity. This test of RILE was for just one class period, so no attempt was made to teach acceleration, though the system itself includes acceleration as one of the concepts that can be taught. We chose kinematics for two reasons: (1) In any standard course in physics, kinematics is the first topic taught. (2) The difficulties in teaching kinematics concepts are well documented in the literature. Physics education research shows that student understanding of concepts in mechanics (kinematics and dynamics) suffers in a traditional classroom lecture environment, where students learn 20% of the presented material in a traditional lecture course in introductory physics [McDermott, (1993)] [12]. Considerable research exists on student misconceptions in mechanics, including the lack of ability to interpret kinematic graphs. Some of the recurring misconceptions are [Dykstra (2004)] [4]:

Inability to distinguish between distance and displacement
Inability to distinguish between speed and velocity
Inability to recognize the existence of acceleration when only the direction changes (uniform circular motion)
Inability to associate slopes of graphs of position vs time with direction of velocity
Identifying zero velocity with zero acceleration
Associating force with motion, even uniform motion.

Targeted Student Learning Outcomes:

Student demonstrates the difference between distance and displacement
Student distinguishes between speed and velocity
Student demonstrates connections between graphical representation of motion and the physical motion itself.

A. *Trial Methodology*

A pretest on these concepts was first administered to all the classes involved. In the robots-based class (the treatment group), there was an initial (10 min) introduction to the concepts, and the students then congregated around the experimental area. In the experiment, a robot was allowed to move in a straight line under commands sent by a student via the RILE interface. The GUI designed for RILE was sufficiently easy and allowed the students to quickly understand how to control the robots from the computer. Less than 5 min was spent on actual acclimatization to the system which is shown in figure 5. This GUI has since been updated to improve usability and promote structured experimentation.

The robots were equipped with a sonar sensor mounted on the rear of the robot that measured the displacement from a fixed wall. This was considered the position of the robot, and the robot was programmed to acquire this data at fixed intervals of time, typically once every second. The client control station was also programmed to produce an on-screen graph of the position versus time. The data and the graph were ported to four other Observation computers in the lab, so a group of 3 - 4 students were stationed with each computer. All the links between computers and robots were through WiFi. The layout for the experimental setup is shown below in figure 6.

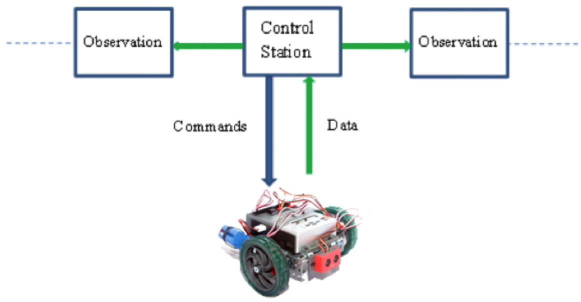


Fig. 6. Alpha Testing Setup

The students experimented with the robot by commanding it to move with constant velocity, and then inspected the graph. The experiment was repeated, with differing velocities, including changes in velocity and velocities in the opposite direction, and the students noted the qualitative features of each graph, such as the fact that a higher speed results in a steeper graph, the slope of the graph changes sign with the direction of the velocity, etc. The data points generated from the sonar sensors are shown in Figure 7 and the graphs generated from the software are shown in Figure 8. During this the course of this experiment it was clear that students began predicting the resulting graphs with more and more certainty.

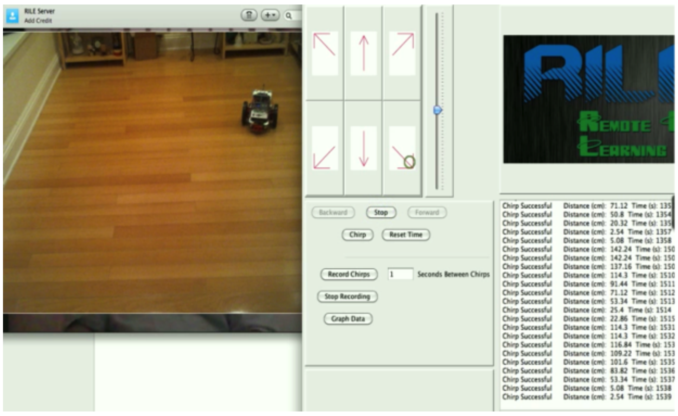


Fig. 7. Text Based Sensor Feedback

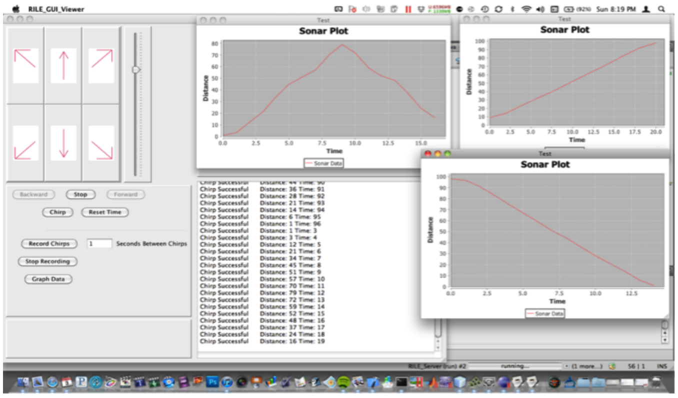


Fig. 8. Graph Based Sensor Feedback

Within the control group, the same concepts were covered in a traditional method using the blackboard. The theme of robots moving under student control was used as the background for introducing the concepts. The students were introduced to the ideas of position, displacement, velocity, distance and speed. A few exercises were done under supervision, where position vs. time data was given in a table and the student was asked to calculate the displacement and velocity during specific intervals of time. The students were also shown qualitative graphs of position vs. time, and were asked questions such as, In this region, is the robot moving faster or slower?

B. Results

The alpha tests were evaluated by observing the amount of student participation compared to the traditional lecture, the learning curve of student manipulation of the robots, the students ability to orally interpret the physical meaning of graphs, and how well the students were able to make the robots behave according to a position versus time graph.

The active learning environment when utilizing the robots resulted in the class being highly engaged when compared to the traditional lecture where the instructor had to break from lecture every 5-7 minutes to obtain the students' attention. This time spent controlling the class far exceeded the 5 minutes necessary to train the class in how to use the client GUI. This resulted in more available class time to discuss the course content. In addition, the short length of time necessary to train the students in how to use the GUI is a testament to the ease of use of the interface.

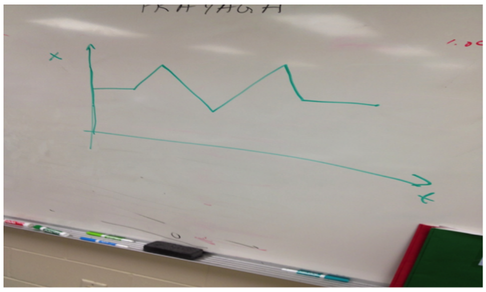


Fig. 9. Graph Based Sensor Feedback

When the instructor drew several graphs of position vs. time on the board (Figure 9) and asked the students to evaluate the graph and make the robots move with the same relative motion as the graph. Most students were able to drive the robot and compare the system generated graphs, which were pretty close in achieving the required result. Qualitatively the students were able to:

1) Associate the horizontal axis to the physical notion of time. When presented with a graph that had the time flowing backwards (see Figure 10 below), several students in each group were able to recognize that time cannot flow backwards even before attempting to control the robot.

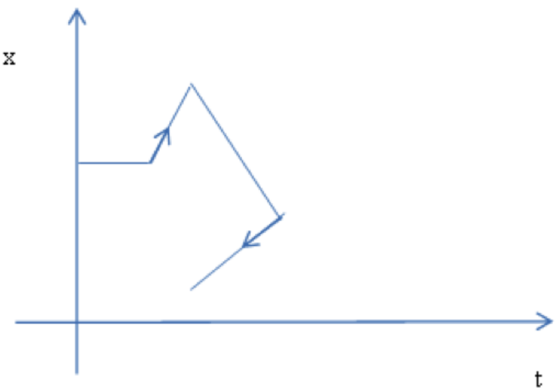


Fig. 10. Graph Illustrating Backwards Time Travel

2) Understand that position can be a positive or a negative value and that it is relative to an associated origin.
3) Some students, not the majority, could say that both backwards and forwards velocity could have the same speed and were able to associate the steepness of the graph to higher speed.
4) The instructor drew an arbitrary graph of position versus time on the board, with different sections of the graph showing higher or lower speeds, and some sections with the robot not moving (velocity =0) The students were

then asked to make the robot move according to the graph.

By comparing the graphs drawn on the board to the graphs generated by the client GUI when manipulating the robots, the number of errors quickly decreased and the students were able to reproduce the original graph immediately.

The response from the students from all the five batches of the class was uniformly encouraging, and the teachers were enthusiastic about using the system for future classes and also on other topics in physics.

V. Conclusion

A remotely located Robotic Interactive Learning Environment has been designed for purposes of teaching one-dimensional kinematics to middle school students. Initial testing shows that the system does provide an engaging environment for the student to learn the traditionally difficult concepts of kinematics, the foundation of physics. The system allows remote login and robot control through an internet connected Wi-Fi network. Students recieve live data from the robots over the internet, and also visually interact with the robots via a video link. This system provides a central experimentation environment capable of supporting numerous classes, making it a cost effective alternative to classroom robot sets. Within the RILE system, new technologies and innovations in educational methods provide a complete educational experience through a logically organized textbook based interface; while in-system quizzes, instructions and structured experimentation allow teachers to focus on teaching material and answering questions instead of lab setup and materials distribution. Overall, it seems to be a viable implementation of robotics in education.

VI. Future Work

The system is in the initial stages of development. Further developments involve systems which can be used to teach more complicated concepts in physics, including high-school level physics - such as 2-dimensional kinematics, force concepts, energy and power considerations, concepts in electricity and magnetism, and optics. Many interfaces are being updated to provide a more user friendly and dynamic experience while keeping the system logical and easy to use for both students and administrators. External applications are also being developed to provide more accurate environmental information such as robot position, lighting and connection statuses. This knowledge will lead to more autonomous behaviors, including autonomous charging and pre-lab setup.

In order to test these improvements, we are reaching out to other schools within the region to preform beta testing as well as promote the importance of robotics education.

References

[1] Weisteider & Brown (2008) (Virginia Westheider, Patrick Brown, Enhancing K-12 STEM Education with Engineering, Proceedings of the 2008 American Society for Engineering Education, Annual Conference, Pittsburgh, PA. .

[2] Western Region Robotics Forum, http://wrrf.org/wrrf/backgrounder/.

[3] Kulich, M. - Košnar, K. - Chudoba, J. - Fišer, O. - Přeučil, L.: User's Access to the Robotic E-Learning System SyRoTek. In Proceedings of the 4th International Conference on Computer Supported Education [CD-ROM]. Porto: SciTePress – Science and Technology Publications, 2012, vol. 1, p. 206-211. ISBN 978-989-8565-06-8. .

[4] Dykstra, D. I. (2004). Why Teach Kinematics ? An Examination of the Teaching of Kinematics and Force – Part I. Physics Retrived from: http://web1.boisestate.edu/physics/dykstra/.

[5] Byron Weber Becker. Teaching cs1 with karel the robot in java. *SIGCSE Bull.*, 33(1):50–54, February 2001.

[6] A. Bicchi, A. Caiti, L. Pallottino, and G. Tonietti. Online robotic experiments for tele-education at the university of pisa. *Journal of Robotic Systems*, 22(4):217–230, 2005.

[7] Richard Borge, Annita Fjuk, and Arne-Kristian Groven. Using karel j collaboratively to facilitate object-oriented learning. In *Proceedings of the IEEE International Conference on Advanced Learning Technologies*, ICALT '04, pages 580–584, Washington, DC, USA, 2004. IEEE Computer Society.

[8] Duane Buck and David J. Stucki. Jkarelrobot: a case study in supporting levels of cognitive development in the computer science curriculum. In *Proceedings of the thirty-second SIGCSE technical symposium on Computer Science Education*, SIGCSE '01, pages 16–20, New York, NY, USA, 2001. ACM.

[9] Stefan Enderle. Grape – graphical robot programming for beginners. In Achim Gottscheber, Stefan Enderle, and David Obdrzalek, editors, *Research and Education in Robotics — EUROBOT 2008*, volume 33 of *Communications in Computer and Information Science*, pages 180–192. Springer Berlin Heidelberg, 2009.

[10] Brian Ladd and Ed Harcourt. Student competitions and bots in an introductory programming course. *J. Comput. Sci. Coll.*, 20(5):274–284, May 2005.

[11] L. Major, T. Kyriacou, and O.P. Brereton. Systematic literature review: teaching novices programming using robots. *IET Seminar Digests*, 2011(1):21–30, 2011.

[12] Lillian C. McDermott. Guest comment: How we teach and how students learn—a mismatch? *American Journal of Physics*, 61(4):295–298, 1993.

[13] Matthew R. Stein. The pumapaint project. *Autonomous Robots*, 15:255–265, 2003. 10.1023/A:1026216520523.

Index of Authors

FACULTAS MATHEMATICA PHYSICAQUE

STU FEI

innoc

IEEE
Czechoslovakia Section