Educating Teacher Students and Pupils Through Robotics Courses and Olympiads: A Tiered Approach

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Abstract

This paper proposes an educational environment in which teacher students and school pupils form a learning community coping with common robotics challenges. The robot prototypes developed by the students are used by the pupils for experiential robotics studies. Our educational research focuses on the analysis of learning behaviors and the effect of the experimentation on development of creative thinking. It is found that collaboration of students and pupils in the common robotics environment is effective for educating both the teacher students and the pupils.

Introduction

Educational robotics has been recognized as a way in which students can learn various CS and engineering subjects through practice and scientific experimentation. The experiential learning process is especially effective if it involves the learner in concrete experimentation, reflection on the experience, and its conceptualization (Kolb, 1984). Leifer (1995) showed that embedding the experiential learning process in designing a mechatronic system can provide the alliance of the technical and instructional goals of the robotics course. There is a need to prepare teachers capable to develop and implement robotics courses based on this approach. The Carnegie-Mellon University teacher education program (http://www.rec.ri.cmu.edu/education/), and the Tufts University course (Bers et al., 2002) present successful examples in which teacher students studied robotics and assisted in teaching it to school pupils.

This paper proposes an educational environment developed at the Department of Education in Technology and Science, in which Technion students and school pupils form a learning community coping with common robotics challenges, including participation in robot competitions. In this environment Technion students are involved in developing various robots, instructional materials, and assist in teaching a robotics course to middle school pupils. Our study applies the tiered approach (Lesh and Kelly, 2000) considering the two different groups of learners (university students and school pupils) through their collaboration in order to develop effective strategies of robotics education as part of teacher training programs and middle school curricula. The focus of our educational research is on the analysis of learning behaviors and creative thinking in robotics studies.

Educational Environment

Our educational environment comprises laboratory equipment, instructional robots, robot kits, and learning materials. The main part of the instructional materials is a collection of robot prototypes and related instructional units developed by pre-service teacher students in the framework of the Teaching Methods in Design and Manufacturing course projects. In this course the students design and build robots and propose ways of using them for teaching various science and technology subjects. They also practice teaching their instructional units to school pupils.

The prototypes are built mainly using the Robix kit (http://www.robix.com/default.html). They are mechanical devices driven by the servos which are connected to the host computer through the electronics interface. The software supports a script language for generating point-to-point motion sequences. Scripts run by operator from console and also programmatically from C/C++, Visual Basic, or Java.

Since the 2003-04 academic year middle school pupils have come to our departmental laboratory of technology to study an extra-curriculum robotics course. This 26-hours course fits the "Systems in Science and Technology" section of the Science-Technology Curriculum for Middle Schools (http://www.education.gov.il/tochniyot_Limudim /mada/tochnit.htm) and covers the following topics: robot definition, mechanical arms and end-effectors, basics of robot control and motion planning, motors, sensors, robot applications. The topics were studied theoretically and experientially using the instructional units and robot prototypes developed by the teacher students.

Robot Prototypes

Ellipsograph

Mechanisms for drawing algebraic curves are widely studied in machinery design and mathematics (Norman, 2001). In this context, we run a number of projects in which Technion students develop computer controlled mechanisms for automatic drawing mathematical curves. One of them was a mechanism for drawing ellipses (see Figure 1A). The experiments made by the student with the ellipsograph included the following: selecting an optimal drawing instrument, the influence of the slider-crank parameters on the curve shape, and the drawing accuracy. The student in this project deepened in linkages and gear trains, and programmed the mechanism for drawing an accurate ellipse.

Catapult

The ballistic experiment in mechanics courses usually applies an elastic thrower or is performed in a simulation mode. In our course the students developed a tool which provided a real ballistic experiment and the opportunity to control its parameters. The project assignment was to develop a robot system capable to throw ping-pong balls into a target (a cup). It included a 4 DOF mechanism, infrared sensor and light source (Figure 1B), and was programmed in C. Through rotary scanning, the system determined a current location of the cup and threw the ping-pong ball into the target. The following experiments were made with the system: motor calibration for determining angle velocities in the mechanism's joints, the effect of different factors on the throw accuracy, and the use of an optical lens to improve light sensing.

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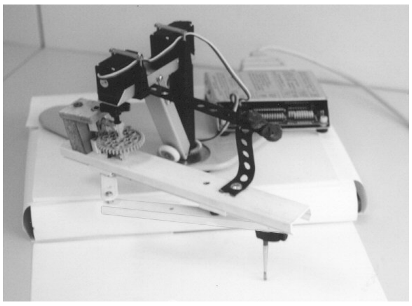

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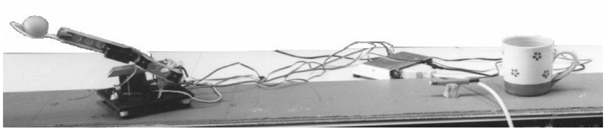

Figure 1. A. Ellipsograph; B. Catapult

Bio-inspired Projects

A series of projects performed in the course related to the development of computer controlled mechanisms which model different types of locomotion behaviors. The projects developed models imitating snake crawling (Figure 2A), spider motion (Figure 2B), and human-like walking (Figure 2C).

These projects were carried out by the students through the following stages:

- Movement creation - understanding biological principles of the given type of locomotion.
- Kinematic scheme synthesis - examining alternatives and creating a robot scheme.
- Mechanism analysis - determining the robot structure, dimensions and parameters.
- Building a prototype and its optimization.
- Programming robot movements and locomotion experiments.

The experiments with these models were directed to their optimization through review-revise-prototyping cycles. The following factors were examined: gravity center position, friction and inertia effects, mechanism's stability, balance and coordination. The students in these projects focused on the optimization of mechanical structures and programming locomotion behaviors.

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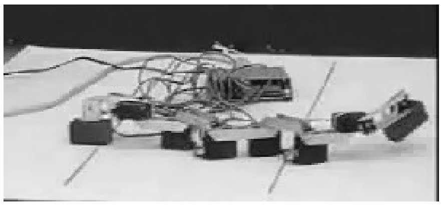

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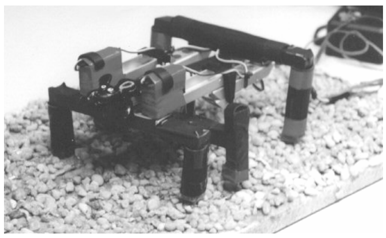

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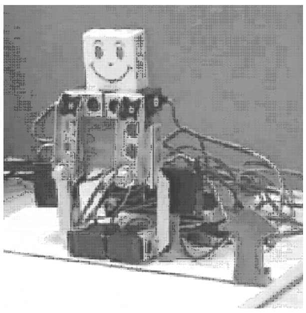

Figure 2. A. Snake; B. Spider; C. Walker

Cooperative Robotic Arms

One of the projects in our course dealt with designing and building two autonomous robotic arms which carry out a common manipulation task through their coordination and communication. The project assignment was to develop a two-arm robotic system which detected location of an object (a ball) and grasps it through coordinated action of the arms. The system prototype is presented in Figure 4. It includes two manipulators built using two Robix kits. The 3 DOF manipulators are connected to different computers. Each of the computers is equipped by a radio communication module working under the RS 232 communication protocol. The light sensor rotary unit is connected to one of the computers and used the ball detection.

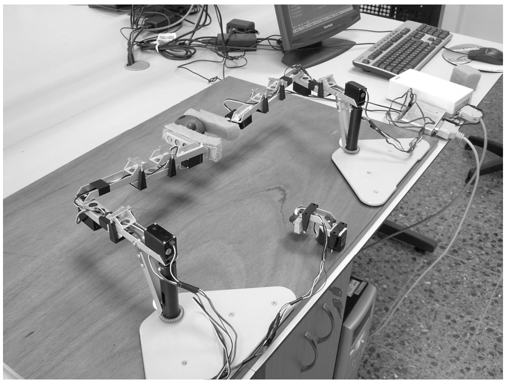

Figure 3. The two-arm robotic system

Experiential Learning Approach

The course involves students in the experiential learning process which can be described using the Kolbian circle model (Kolb, 1984). According to this model, the learning process is a circle which consists of four steps: (1) Carrying out a particular action; (2) Perceiving effects of the action through observation and reflection; (3) Understanding the general principle under which the particular instance falls through abstract conceptualization; and (4) Application through action in a new circumstance within the range of generalization.

In our course the students develop understanding of robotics and educational concepts through their involvement in two different but connected learning circles. The first is the design circle in which the student develops a working robot prototype. The second is the educational circle in which the student develops, implements, and evaluates a unit for experiential learning using the prototype. The two circles are connected so that the student designs the robot as an educational tool and teaches the concepts which can be effectively studied using it. In the educational circle the students recognize the robotics concepts which can be effectively studied using the robot, and get real feedback which helps them to revise their prototypes.

For most of the students, designing a robot is the first experience of rapid prototyping. Rapid prototyping is a methodology for designing and building accessible instructional tools for understanding systems or processes through experiential learning. This methodology "presupposes a design environment which makes it practical to synthesize and modify instructional artifacts quickly" (Tripp and Bichelmeyer, 1990, p. 38). It tends to utilizing unified and cost-efficient components and modular technology. The potential educational advantages of rapid prototyping in our course are:

- It encourages active student participation in the design process.
- Due to its modularity and flexibility, the prototype can be easily modified enabling experiential learning of different concepts.
- By reducing the time needed to modify the prototypes, the students obtain opportunities to develop their creative skills through examining more alternative design solutions.

International Robot Olympiad

The International Robot Olympiad (IRO) is part of the Federation of International Robot Soccer Association (FIRA) program (www.iroc.org). The Olympiad offers an annually updated series of robotic assignments for different competition categories addressed to three different age groups (under 12, 13-18, and over 19). The regular competition categories focus on implementing a certain robotic assignment and gaming. Examples of contests in regular categories are “Robot Line Tracing” for juniors under 12 years old, “Stair Climbing Robot” for ages 13-18, and “RoboSoccer” for adults. The creativity category implemented a different model of robot competitions with focus on the theme embodiment and performance. The competition in this category lasts four days and consists of the four contests described below.

Robot concept design

In this contest the teams have to develop a concept of a robot related to an assigned theme and document it by presenting a poster. The teams work under 5-hours time limit. They can use internet but not assistance of others. The teams do not know the design theme before it was announced at the beginning of the contest. When assessing the poster the contest judges pay attention to the following aspects: theme embodiment, systematic observation of robot functions, design solutions quality, clear presentation, and aesthetic appearance.

Robot Construction

The theme of this contest is announced in advance. The teams use time before the competition to design their robots. But at the competition, they are assigned to build robots from scratch and demonstrate its operation to contest judges. They have six hours to perform the assignment without assistance from others. Evaluation of the projects focuses on the following aspects: theme embodiment, design concept, technical implementation, operation quality, and understanding principles of robot operation.

Oral Presentation

The teams give 10 minute talks in which they presented robot systems, described design problems and explained their solutions. When evaluating the presentations the judges looked at understanding robotics concepts, level of problems, quality and originality of solutions.

Written Test

The 50 minutes test consists of multiple choice questions which cover the areas of mechanics, electronics, programming, and sensors. The questions present real problems which could arise during the robot project and require a solution based on theoretical background and practical experience in robotics.

Robot Olympiad Projects

Stair Climbing Biped Robot

The biped robot was developed in our lab in the framework of the Technion International Youth Summer Research Program SciTech 2004 and subsequent International Robot Olympiad. Our 6 DOF robot (Figure 4) implements two kinds of locomotion: climbing steps by somersault rotation around itself and balancing, and hill scrambling by crawling.

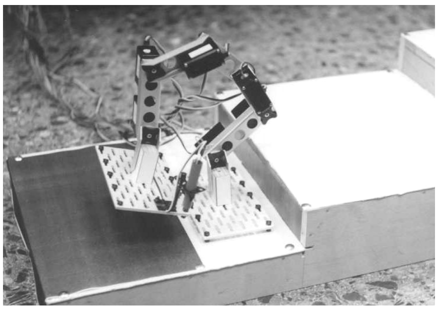

Figure 4. Stair climbing robot

In building the project team we implemented the tiered approach (Lesh and Kelly, 2000) in which different groups of learners collaborate in a common assignment. In our case, the team included two high school pupils from Bulgaria (participants of the SciTech), three Technion teacher education students and a supervisor (Verner). In the project the students practiced teaching robotics subjects through the experiential learning approach, one of them (Korchnoy) mentored the pupils and conducted the educational follow-up. The pupils participated in the IRO 2004 and succeeded to win first place in the Creativity Category competition.

Dancing Robot

This project was developed in the framework of SciTech 2005. Its goal was to develop a biped robot capable to simulate movements of a certain dance and perform the dance with the given music. The students also were assigned to investigate the static and dynamic stability of the robot and the synchronization of its steps to the music. The robot included a 6 DOF mechanism, a sound detector, and decor (Figure 5). The C++ program filtered and interpreted the input from the sound detector, compiled the robot motion sequences and run them.

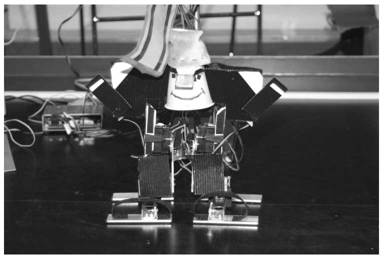

Figure 5. Dancing robot

The team of two high school pupils from the U.S.A. worked together with three Technion students guided by the authors. One of the pupils presented the robot at the exhibition of the International Robot Olympiad and won the Robot Pioneer Award.

Shaving Robot

After our 2004-2005 robotics course for middle school pupils the team was formed for carrying out a robot project and participation in the IRO 2005. The team consisted of three Israeli middle school pupils (grades 8 and 9) mentored by the authors (a faculty and a Ph.D. student who taught the course) assisted by an undergraduate student. The idea of this project - to develop a cost-efficient shaving robot, which helps the handicapped, was motivated by the 2005 Olympiad creativity category theme "Robotics for handicapped people". The robot system developed in the project (Figure 6) provided the following functions: (1) Performing shaving process by an electric razor; (2) Bringing the razor up to user's face by a 5 DOF robot manipulator; (3) Voice control by microphone, to identify and run the user's individual shaving program; (4) Video-monitoring of the process aided by a web camera.

The team won the first place in the IRO 2005 Creativity Category competition.

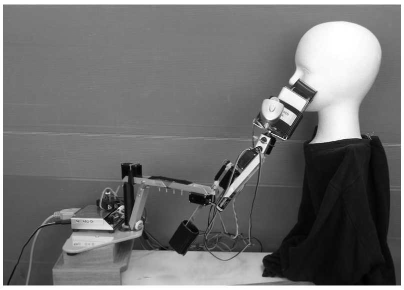

Figure 6. Shaving robot

Discussion

The reasons for our research focus on the consideration of learning behaviors and creative thinking are as follows:

- The learning behavior is an indicator and measure of learning outcomes from the behavioral, cognitive, and social perspectives (http://suedstudent.syr.edu/~ebarrett /ide621/cognitive.htm), and we examine its possible use in robotics education.
- In the robot project students are closely involved in programming robot behaviors, and we examine if this practice can change behavior of the students.
- The students consider creativity as an essential characteristic of the robot project (Verner, Waks and Kolberg, 1997), and we test if the robotics studies can influence changes in students' creative thinking.

The learning behaviors description was extracted through inductive analysis of records of our observations and students' reflections on their practices in the courses and projects. Changes in creative thinking were measured by means of the figural Torrance Test of Creative Thinking (TTCT) and interpreted through analysis of robot prototypes, reports, and experts' judging at the Olympiads.

Learning Behaviors

By the inductive analysis of observations and reflections we indicated the following main characteristics of learning behaviors in the robotics studies: self-confidence, help, cooperation, interest, seriousness, self-dependence, capacity for work, responsibility, work stress, creativity, power of observation, and perseverance (persistence). We revealed that the behavior characteristics of the students evolved during the robotics studies and implemented literature recommendations for the learning process improvements.

As for the self-confidence characteristic, we found that the self-confidence growth was an important condition of student and pupil success in our robotics courses and projects. Recommended ways to develop learner's self-efficacy (self-confidence) (Bandura, 1986) are:

- Mastery experiences in which the learner overcomes obstacles through perseverant effort;
- Observing examples of successful experiences of other learners;
- Benevolent appraisal of the learner's achievements by the mentor and avoiding possible failure situations;
- Positive spirit and mood in class.

When teaching robotics we are addressing all these recommendations. Mastery experiences are provided using the scaffolding instruction approach (Jonassen, 1998). Accordingly, we assign robotics tasks which are above the level of what the learners can do by themselves, but help them to acquire knowledge and skills needed to accomplish the tasks. The learners observe examples of robot prototypes from our collection of past projects and attend seminar talks given by other students. The friendly atmosphere of robotics community in the departmental laboratory of technology stimulates students and instructors. We found benevolent mentoring especially important for teacher students who have limited background in control and programming.

Creativity

From the previous study (Verner, Waks and Kolberg, 1997) it was found that creativity is a dominating factor of student's attitude towards robotics studies. In this study we paid special attention to indications of creative behavior shown by the learners. In their reflections students and pupils pointed to the cases in which they gave creative solutions during their robotics experimentation. With this regard, we decided to test a possible effect of the robotics course on the middle school pupils ability to think creatively.

The figural Torrance Test of Creative Thinking (Torrance, 1972) was conducted before and after the robotics courses given to six groups in 2004-2006 (N=63). The two of its sub-tests were conducted: the Picture Construction test examined learner's originality and elaboration, and the Incomplete Figures test concerned fluency, originality, flexibility and elaboration categories (scored separately).

The pre-course and post-course test elaboration scores are compared in Figures 7A and 7B. The figures present diagrams, in which personal results of the pupils are presented by square marks. Each square mark in the diagram presents results of one of the students so that its X and Y coordinates are his/her pre-course test and post-course test scores. As shown by the diagrams, most of the square marks are located above the dotted diagonal. It means that the majority of pupils (83.9%) performed on the post-test better than the pre-test. T-test indicated that the improvement in both sub-tests is significant with level of significance $\alpha = .01$.

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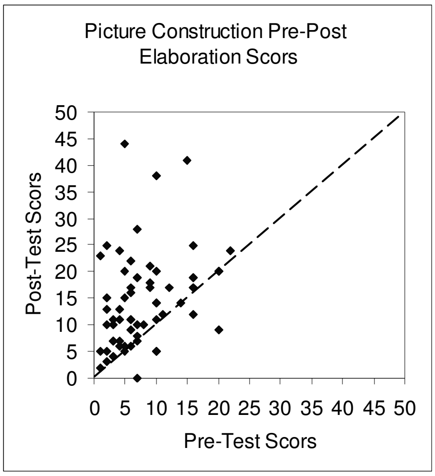

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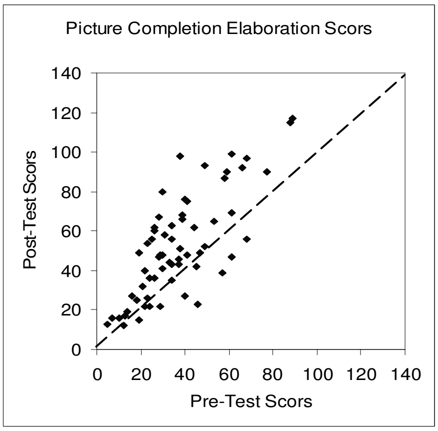

Figure 7. Pre-course vs. post-course test elaboration scores: A. Picture Construction test; B. Picture Completion test

The learners made significant progress in the ability to develop their own ideas related to the given theme. A possible reason for this improvement is that in the course experimentation the pupils developed their own robots, grounding on the prototypes developed by the teacher students. The International Robot Olympiad Creativity Category competition focuses on facilitating students' creativity. A similarity between the Robot Concept Design test and the Torrance Test of Creative Thinking can be noted. Therefore, learning practice of modifying robot prototypes can be recommended in order to prepare students for the robot competition.

Conclusion

Modern education requires teachers' involvement in guiding student projects which include designing and building computer controlled technological systems. Our Technion course "Teaching methods in design and manufacturing" presents a possible approach to teacher training in the subject. It is found that collaboration of students and pupils in the common robotics environment is effective for educating both the teacher students and the pupils.

The collection of robot prototypes is an important part of the learning environment which facilitates the interdisciplinary learning process. The practice of studying prototypes and creating new robots helps the learners to improve behavior characteristics and advance their learning skills.

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