Experiential Learning and Teacher Training through Designing Robots and Motion Behaviors

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Abstract

This paper considers educational practice in the Technion in which engineering students develop various robots and practice in teaching robotics to school pupils. The students and the pupils collaborate in the experiential learning process which integrates designing, producing and operating robot prototypes with learning engineering concepts. A number of robots built from construction kits through this collaboration are presented. Students' reflections on their learning practices are discussed.

1. Introduction

A robotics course at the introductory level of engineering education involves students in hands-on practice through which they can learn many engineering subjects and applications. The robotics course can be especially effective if it meets two goals:

1. Practical-technical -- designing and producing a working robot prototype capable of performing the given assignment through a project-team effort.
2. Instructional -- providing systematic learning of science and engineering subjects by all the students in the robotics course.

An experiential learning approach which organizes learning-by-doing processes so that the learner can acquire both practical skills and theoretical knowledge was proposed by Kolb[1]. Leifer[2] 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.

An important impetus to educational robotics development was given by a conceptual framework of digital manipulatives[3] which extended the traditional learning with manipulative materials. Accordingly, the computational and communications capabilities are embedded in mechanical parts of a construction kit. The students use the kit to create various devices and program their movements.

This paper presents 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. 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 educational study applies the tiered approach[4]. It considers two different groups of learners (students and pupils) and their collaboration in order to develop effective strategies of robotics education as part of teacher training programs and middle school curricula.

2. Educational Framework

The Technion Department of Education in Technology and Science offers undergraduate and graduate teacher education programs in a number of disciplines including the engineering track. Many students receive a degree in science-technology education in addition to their main degree from one of the Technion engineering faculties.

Science-technology education involves teachers of engineering disciplines at school and tertiary levels in guiding student projects. The project is effective if it answers the following criteria: (1) engages students in real-world challenges and presents new technologies; (2) includes designing, building and programming system prototypes; (3) imparts knowledge in science and technology to students with different backgrounds; (4) promotes reflective and divergent thinking, self-directed learning, and encourages collaboration.

The need to improve project-based instruction and include studies of the project method in pre-service teacher education is emphasized in literature[5]. However, only minimal information is available on educational approaches and examples of courses which prepare teacher students to guiding design projects. Clear recommendations for development of such courses are currently required.

This paper considers our Teaching Methods in Design and Manufacturing course in which students study engineering subjects and gain project guidance skills. The students perform laboratory and project assignments, develop instructional units (on subjects related to these assignments), and practice teaching them using the project method.

The course is given in the departmental laboratory of technology. It consists of three modular parts. The first part includes lectures and laboratories. The lectures consider pedagogical aspects of experiential learning and subjects related to systems and control design. The laboratory activities include the following: (1) assembling sensor systems and implementing feedback control processes; (2) computer aided design and producing machine parts; and (3) programming robot manipulations. The second part of the course focuses on robotics projects. The third part of the course is students' practice in teaching robotics to middle school pupils in our laboratory of technology.

Robotics has been risen an especially effective medium for engineering education[6]. It involves students in self-directed learning, interdisciplinary design, teamwork, professional communication, technical invention, and research. We believe that robotics as part of a teacher training program can help engineering students to develop professional and pedagogical skills needed for their careers.

3. Instructional robots and experiments

Many prototypes of computer-controlled mechanisms in the course are built using the Robix kit[7]. This robot construction set implements the concept of digital manipulatives. It contains essentially all components required for desktop robot construction. Its mechanicals include servomotors, aluminum links, parallel-jaw wrist-and-gripper assembly, construction bases, and other parts. The learner uses them to build various mechanical devices driven by the servos. An electronics interface (EI) is connected to the host computer through the parallel port. It has servo outputs, on-off outputs for device control, and sensor inputs (analog-to-digital and switch-closure). EI serves for controlling and powering servos together with sensors and other devices introduced by the learner. The software supports a script language for generating point-to-point motion sequences, each move with matched velocity trapezoids and motion parameters per-servo. The user can define the positions (points) in "teach pendant" or “coordinate” modes. Scripts run by operator from console and also programmatically from C/C++, Visual Basic, or Java.

Below in this section we consider a number of robots developed in the course, the reasons for their development, design stages, and learning experiments.

3.1. Bio-inspired projects

Animal-like robots are attracting an increasing interest in biology, engineering and AI as a way to examine the general cybernetic ideas and principles of locomotion. 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 3A), spider motion (Figure 3B), and human-like walking (Figures 3C and 3D).

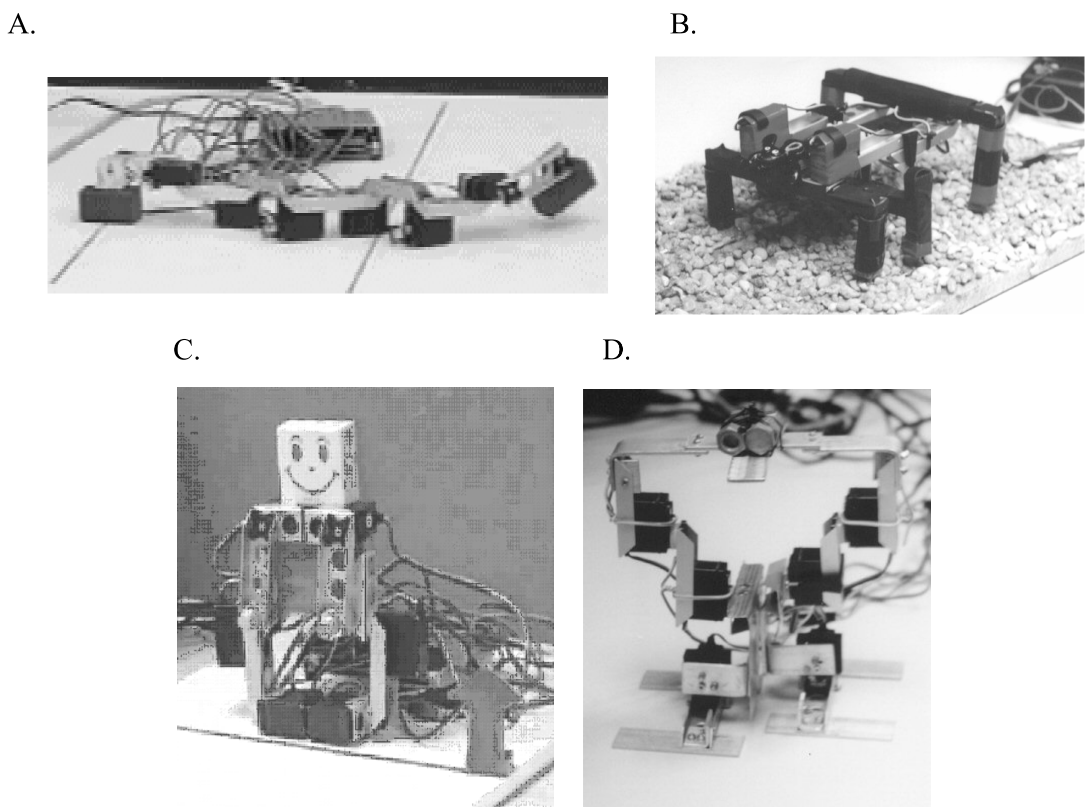


Figure 3. Bio-inspired projects: A. Snake crawling; B. Spider motion;
C. Human-like walking (stiff feet); D. Flexible feet walking

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.

3.2. Cooperative robotic arms

Coordination and communication of robots is a central subject of modern robotics which will be introduced in the introductory robotics in the near future. In this context, 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 cooperation. 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.

The stages of the system development were:
- Selecting an object detection method.
- Developing a remote communication.
- Designing and building mechanical arms.
- Developing a system and applied software in C.

Experiments performed by the students throughout the project include the following: testing communication parameters (time, reliability, and distances), arm prototyping, light sensor functioning factors, and arms positioning accuracy.

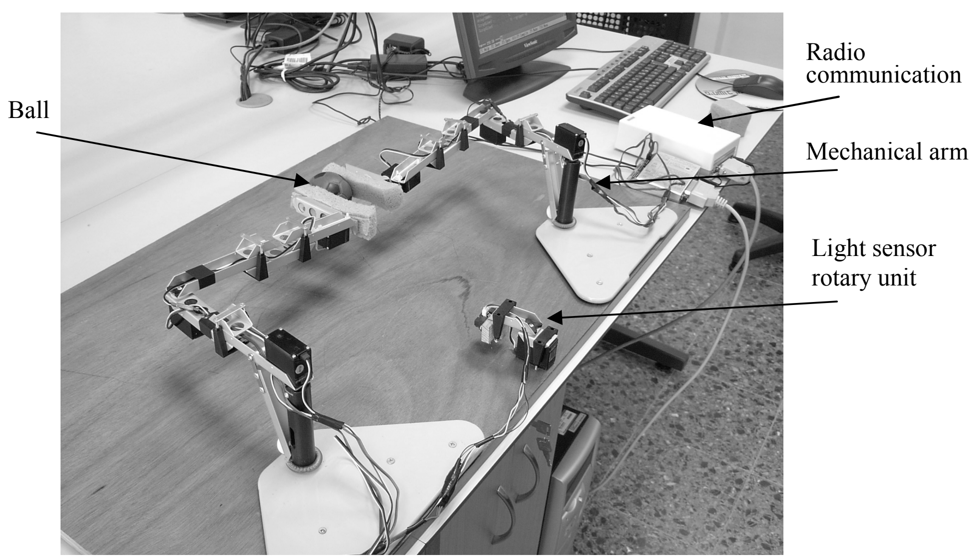
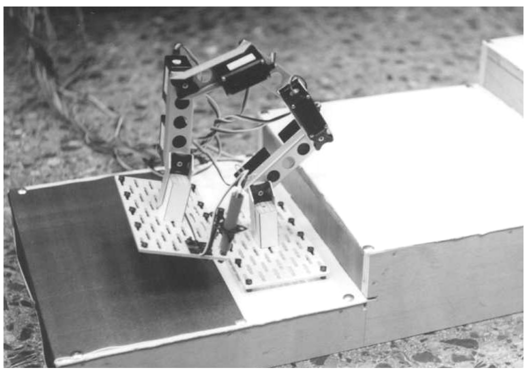


Figure 4. The two-arm robotic system

3.3. Stair climbing biped robot

Raibert[8, p. 1-3] argued the following advantages of studying biped robots: (1) legs provide better mobility in rough terrain than do wheels or tracks requiring a continuous path of support; (2) studying legged robots helps to understand human and animal locomotion.

The biped robot presented in this section has been developed in our lab in the framework of the Technion International Youth Summer Research Program SciTech and subsequent International Robot Olympiad (IRO) in Korea (www.iroc.org). Our 6 DOF robot implements two kinds of locomotion: climbing steps by somersault rotation around itself and balancing (see Figure 5A), and hill scrambling by crawling (Figure 5B).



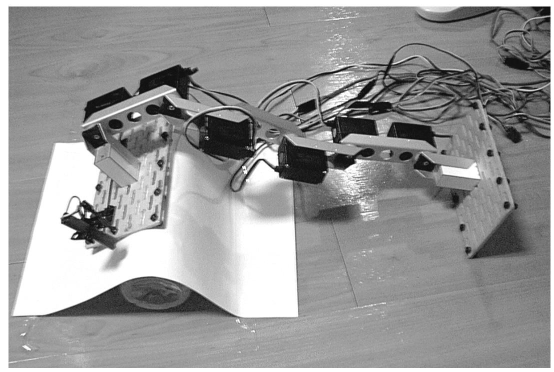


Figure 5. (A) Rotation around itself and balancing, (B) clambering obstacles by crawling

The project was motivated by the IRO stair climbing robot assignment. In building the project team we implemented the tiered approach [9] in which different groups of learners collaborate in a common assignment. In our case, the team included two high school pupils (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.

In the "Creative Category" competition of the IRO the pupils participated in four contests: (1) a written test, (2) a robot concept design, (3) building, programming and running a robot within the scope of the assigned theme and time limits, and (4) oral presentation of the project. They succeeded to win first place in the competition. This success indicated that the proposed team organization effectively helped to introduce robotics subjects, didactical issues, and educational research methods.

The 3-year experience of integration of robot projects in the Technion teacher-training course indicated their significant impact on students' learning motivation in both engineering and education domains. The projects formed an environment which we use for teaching robotics to school students and for educational research.

4. Experiential learning approach

Through experiential practice in the course the students study different robotics subjects which include the following: mechanisms, motors, kinematics and dynamics, control processes, sensors, programming, and applications. In addition, the students learn educational concepts and methods: experiential learning, design theory, technological literacy, team guidance, authentic assessment, technical skill development. The students in the course also apply their knowledge to practical teaching of robotics subjects.

The course involves students in the experiential learning process which can be described using the Kolbian circle model[1]. 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" [10, 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.

The robots and lesson units developed by the engineering students are used in the introductory robotics course (IRC) which we give to middle school pupils at the departmental laboratory of technology. In the IRC the pupils learn basic robotics concepts and perform experiments with the robots. The instructional robots form a learning environment which exposes the pupils to different applications of robotics in science education.

5. Observations and reflections

The Kolb's model[1] emphasizes the essential role of student's reflective observation in experiential learning as a way to perceive effects of the experiment towards their understanding. Shoen[11] distinguished between reflection-in-action which is embedded in the practice and reflection-on-action undertaken after it is completed.

This section considers students' reflections on their practices in our course as an important source of educational data. We summarize some of these reflections which refer to the course activities and contributions. The students' reflections were collected through personal interviews after completion of the course projects and were studied by means of the protocol analysis.

All the interviewees pointed that the projects assigned open problems and new environments. They required studying new subjects through self-directed learning and practical activities. As mentioned, "creativity was an integral part of the project". The project offered a "tangible assignment". It included the building stage which verified the design solution and the prototype application stage. Many of the reflections related to repeated experiments that the students made in order to find the suitable solutions implemented in the projects.

The student who participated in the walking robot project emphasized the importance of planning project time and work. One of the students mentioned that his coffee-maker project required him to learn a number of subjects in chemistry. The same was reflected by the female student who dealt with the steps-climbing robot and had to learn new subjects in biology. The student who performed the ellipsograph project pointed that his experiments referred to defining the mathematical model, arranging the gearing unit, and selecting a drawing instrument.

With regards to the contribution of the course, all the students expressed great interest in the projects and noted that the interest grew with their progress. The value of dealing with real situations and prototypes was emphasized. A student's typical comment was that practice in building, assembling and breaking parts was the best way to learn machines and understanding design. One of the students said: "If people do not see my real prototype not all of them can perceive what I did".

Many interviewees pointed that the project for the first time introduced them to problems which required taking account of many different factors at one time: "I did not know that this is so complicated in nature". With regard to teaching robotics to school pupils, the students noted that teaching robotics projects at school can significantly improve learning achievements and motivation of pupils. The Technion students found that their robots rose great interest of middle school pupils, and their assistance helped the pupils in the introductory robotics studies.

One of the pupils participated in the SciTech Program and in the Robot Olympiad summarized his reflections about the project as follows:

> "When I chose this project, I chose it because it appeared to involve more than just physics or just mathematics or just computers: it appeared to involve all three. The real project did not disappoint me; more than that, it incorporated two other concepts - logic and creativity. With this project I had also an experience with engineering and technology - and a fascinating one. It struck me so much that I am even considering studying technology in my university education.
> The project was not only interesting, but also useful. It taught me new concepts and skills and improved some of my old ones. While I worked on the design of the robot, I became more and more familiar with the method of trial, and error. I also learned the value of the method of rapid prototyping and became able to apply it to my assignment. In addition, I understood that a theoretical preparation is required for the successful completion of any technical task and the more theoretical ideas are applied, the better the final product is.
> Through this project I became familiar with kinematics graph and became able to draw and use them. I gained experience with the concept of power and learned - unknown to me beforehand - the concept of torque. Not only this, but I understood how to apply them in a practical situation. As a whole, this project taught me many aspects of technology by providing me with a hands-on experience of it."

6. Conclusion

Modern engineering education requires teachers' involvement in guiding student projects which include designing and building computer controlled technological systems. It follows that the integration of engineering and pedagogical aspects is essential for teacher training. Our Technion "Teaching methods in design and manufacturing" course presents a possible approach to this integration. It combines the study of robotic systems and experiential learning methods.

The three-year experience shows that the course achieves its goal of involving students in self-directed learning, interdisciplinary design, teamwork, communication, technical invention, and research. The projects offered by the course involve engineering students in designing and building robot systems which function in various physical environments. The students use their robot prototypes as instructional tools for teaching different subjects.

We found that rapid prototyping based on the use of robot construction kits is effective for creating accessible robotic systems and understanding engineering and educational concepts through experiential learning. It provides the students with experiences of machine control, involves good practice of applying mathematical methods, and promotes development of spatial imagery, creativity, technical and practical skills.

Students' reflections on their experiences in the course indicated its significant contribution. In the professional domain the course introduced the students to designing tangible instructional tools for engineering education. In the pedagogical domain it introduced them to instructional design concepts and experiential learning guidance.

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