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Learning through designing robots in the framework of school graduation projects in Israel

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Abstract

This paper describes how students in Israel develop robots and participate in the Trinity College Fire-Fighting Home Robot Contests in the curricular framework of the school graduation project. We consider robotics projects developed in the Mevohot E'ron High School in 1999-2002 and specify the interdisciplinary activities of the teams designing fire-fighting robots. Our research focuses on the assessment of learning while working in the teams. The proposed approach is based on the triangulation of ethnographic observations of teamwork, examination of learning achievements, and analysis of robot contest surveys. Results of the study gave a picture of students' behaviours at different stages of the design process, as needed for the individual assessment. As found, each of the students had made progress in a number of subjects and took a significant part in making the robot.

Keywords

robot, design, technology, project, education, Israel

Introduction

Graduation projects are offered to students in the final year of secondary education (grade 12). In Israel, Graduation Project (GP) is an optional matriculation subject in science, technology, or humanities. It can be studied at the basic, intermediate or advanced level. GP in technology combines practical designing and building a product with research in technology and application of science methods. Many GPs prepared in the last five years relate to designing, constructing and operating robots. They have been carried out in connection with the Machine Control discipline. (Verner and Betzer, 2001: 263–272)

A number of schools are implementing robotics projects inspired by the fire-fighting robot contest program. Since the 1998-99 school year, high-school students in Israel have participated in the international Trinity College Fire-Fighting Home Robot Contest (TCFFHRC), Hartford, CT, and in the local robot contest organised by the Israeli Ministry of Education. The Israel delegation at the TCFFHRC included 24 students and five robots from five schools in 1999, 73 students and 8 robots from seven schools in 2000, and 81 students and 10 robots from seven schools in 2001.

The goal of our research is to examine learning through designing robots in the framework of school graduation projects. This paper presents results of a case study of the fire-fighting robot projects developed in one of the schools in 1999-2002 with attention to the content knowledge, learning by making processes, and assessment.

Fire-fighting robot assignment

The TCFFHRC attracts a wide range of designers, including faculty and engineers, master and bachelor degree students, as well as high and junior high school pupils. The participants compete in one of several divisions (experts, senior, high school, junior). The contest assignment (Ahlgren and Mendelsohn, 1998) is to develop a mobile robot (maximum dimensions 31 x 31 x 31cm³) that can navigate autonomously through a model house (a 2.5m x 2.5m maze), find a lit candle placed at random in one of the rooms, and extinguish it. The maze includes four rooms and connecting hallways with black floors and white walls. White 2.5 cm wide lines mark the rooms' thresholds. The robot score in the contest is the sum of the fastest two run times of the allowed three runs.

Fire fighting project in Mevohot E'ron High School

A fire-fighting robot project at the Mevohot E'ron high school has been developed since 1998 by one of the technology teachers (a co-author of this paper) in connection with his graduate studies at the Technion. In 1999-2000 the Mevohot E'ron robot team consisted of 13 students divided into five groups dealing with structure, sensors, fire extinction, software and management. The structure group designed and built the robot structure. The sensors group was responsible for the calibration of sensors and real motors and the kinematics of straight and circular robot motion. The fire extinction group examined several possible solutions for extinguishing candles, chose a suitable propeller device, mounted it on the robot and tested it. The software group dealt with maze navigation logic and programming robot movements. The management group coordinated the project schedule, logistics, reports, and presentations. The team participated in the TCFHRC 2000 and shared places 12 to 16 (among 48).

As a result of the project evaluation study, several improvements were made in the curriculum of 2000–2001. The team consisted of 8 students divided into 2 groups of equivalent amount of project work and responsibilities: structure and fire extinction (S&FE), and sensors and software (S&S). The S&FE group examined a number of variants of robot structure and fire extinction means through physical and mathematical modelling and CAD. The S&S group dealt with robot XY kinematics, application of shaft encoders for position control, and algorithms and software for maze navigation. The team developed another fire-fighting robot, which took seventh place (among 36) in the 2001 Trinity contest. In Figure 1a the robot is shown after it found a lit candle in the maze and was about to extinguish the candle and complete the task.

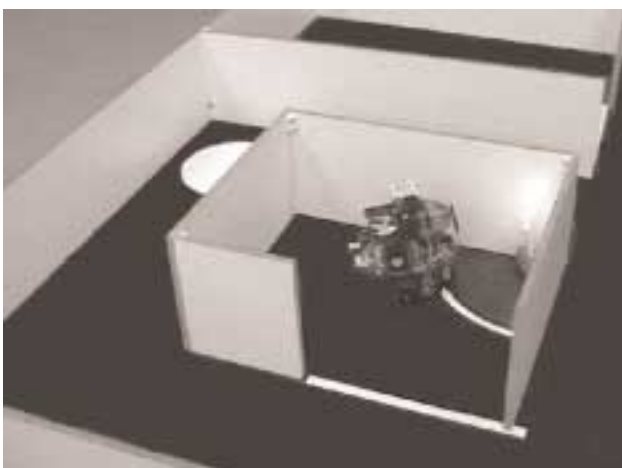


Figure 1a: The 2001 robot in the maze.



Figure 1b:
The 2002 tiny
fire-fighter.

The 2001-2002 project involved 25 students divided into three teams, who worked on three new and different fire-fighting robots. The first team built a 20 x 20 x 30cm³ robot with a caterpillar drive system for participation in the expert division contest. The second team developed a tricycle robot of the same size. The third team designed a tiny fire-fighter, 10 x 10 x 15cm³ (see Figure 1b). The teams designed robots following the general outline developed in the 2001 project.

2001 project outline

The project was conducted through a sequence of regular work meetings of the subject groups and the whole team. The meetings were in two stages: preparation and project work. At the preparatory meetings, conducted by an instructor, the students put to practice subjects studied theoretically in the technology course, for further application in the project. They used the Interactive C language to interface with controllers and operate DC motors. They also made drawings using CAD tools, calibrated sensors and analysed data on Excel spreadsheet. As a result of these activities, the students realised the value of the project and acquired the confidence to face its challenge. The project work meetings were managed by students themselves and were directed purposefully towards the project goal. The students recognised the range of tasks included in the fire-fighting robot design process and performed them. The main tasks are presented in Table 1.

Educational study framework

The fire-fighting robot program of the Mevohot E'ron High School is followed by a case study, which examines learning in the fire-fighting robot projects with focus on the following aspects:

- knowledge and skills in robot design and how they could be addressed in the high school graduation project
- learning by reflective practice directed to facing challenges of the robot contest

Table 1: Tasks and products in the 2001 project.

| Task | Products |
|---|---|
| 1. Mechanical modelling of robot structure, drive mechanism and extinguishing device | |
| 1.1 Design 2–3 possible robot structure solutions. | CAD technical drawings and cardboard models |
| 1.2 Design a special drive mechanism for each of robot structure solutions | |
| 1.3 Place sensors on each of possible robot structures | Sensor substitutes and an extinguishing device attached to the cardboard models |
| 1.4 Design a special extinguishing device for each of possible robot structure solutions | |
| 2. System software | |
| 2.1 Develop an algorithm for robot motion along maze hallway with a given distance from its walls | An Interactive C program tested on the standard mobile robot |
| 2.2 Develop an algorithm for identifying position and orientation of threshold whitelines on the maze floor | |
| 2.3 Develop a robot motion algorithm for navigation from each room to any other room in the maze | |
| 2.4 Develop an algorithm for identifying each room of the maze | |
| 2.5 Develop an obstacle avoiding algorithm | |
| 3. Project robot implementation | |
| 3.1 Build the robot platform including motors, sensors and the extinguishing device | A physical robot platform |
| 3.2 Adapt the system software modules to the project robot | Interactive C programs tested by the project robot |
| 3.3 Integrate the algorithms of specific robot behaviours into an entire procedure for the contest assignment | Robot system software |
| 4. Robot contest | |
| 4.1 Provide robust performance of the contest assignment in diverse situations | A reliable robot system |
| 4.2 Fashion an aesthetic outward appearance of the robot | An aesthetically fashioned robot |

- individual assessment of learning achievements in the team project.

In teaching principles of the design process and guiding the fire-fighting robot design project we apply the methodology of ‘total design’ proposed by Pugh. (1991) Learning objectives and activities in the project are closely connected to stages of design, as shown in Table 2.

Educational evaluation and assessment in our study is based on ethnographic observations of the teamwork, examination of learning achievements, and analysis of the TCFFHRC Survey. (Verner et al, 2000) The study is conducted in the form of action research. One of the authors (a faculty member)

directs and shapes the study, and conducts the contest survey. The second author (a teacher) manages and conducts it in a school as well as guides the project team. The field research data throughout the project are gathered in two main sources: a team portfolio and a teacher’s logbook.

Educational surveys were carried out at the 1999, 2000 and 2001 fire-fighting contests at Trinity, to assess learning outcomes of contest-oriented curricula and attitudes of the participants to the program. The contestants were asked to fill out the survey forms.

Answers given by the Mevohot E’ron team members to the survey questions reflected their personal involvement and views of the project.

Table 2: Stages and contents of the design process.

| Stages | Learning objectives |
|---|---|
| 1. Project idea: Recognition of the need | Definition of need and demands and formulating the project proposal. |
| 2. Specification: Concept layout, spatial allocation. | Finding, examining and making decisions about ways to implement the project through recognizing sub-problems and approaches. |
| 3. Concept design: Subsystem design and analysis | Finding feasible solutions and their analysis through theoretical considerations and experiments. Formulating the best solution concept in terms of components and processes. |
| 4. Detail design and creation: Component design and analysis, creation and testing prototypes | Systematic consideration and implementation of the best solution through iterations of creation, integration and functional testing of product sub-systems. Product testing in laboratory conditions. |
| 5. Operation and tuning: Product exploitation and maintenance practice | Testing the product in a real environment in diverse (including extreme) situations. Improving the product towards more effective, reliable and aesthetic performance. |
| 6. Evaluation: Presentation learning results, assessment | Public presentation and demonstration of the product. Preparing a project report and external examination. |

Findings of the educational study

Research in class

The analysis of teacher's logbook and students' portfolios focused on notes related to different stages of the project. At the first stage of shaping the project idea the central didactic objective was to provide students with the incentive to meet the challenge of the project and put in the effort to bring it to completion. The study showed that the project achieved this objective, as indicated by the following student behaviour:

- contributing time to self-directed extracurricular teamwork
- curiosity and motivation in inquiring about project-related subjects
- concentrating on solving project related problems
- taking personal initiative in project promotion
- feelings of empathy towards the robot.

At the second stage of the project, the didactic focus was on development of technological systems thinking skills, as defined in ITEA. (2000) We found that learning achievements in this aspect depended on the selected model of the design process. In 2000, stages in the design process were performed as separate tasks step-by-step, with focus on activities in mechanics and control. In 2001, we turned to a multifaceted iterative design approach. (Pugh, 1991) This change provided students with involvement in a wider range of aspects of fire-fighting robot design.

At the concept design stage, the emphasis was on students' understanding and shaping of possible solutions and on collaborative decision-making about an optimal solution for each design problem. This was achieved through gathering technical data and making real world experiments. Unlike professional designers, in examining solutions the students needed to build physical prototypes in order to focus their thoughts. The students mentioned that through building the prototypes they discovered new problems, of which they were unaware at the previous design stage.

Detail Design and Creation (DDC) was the stage in which the students implemented the optimal solution found in the earlier design stages. This was performed through coordinated work of the software and structure crews. The structure crew was concerned with building the robot. The students planned the robot assembling process, ordered relevant standard parts, and manufactured special parts for the project by carving, milling, drilling and soldering. The software crew received the physical robot from the structure crew and wrote a computer program adjusted to it. The central didactic issues at the DDC stage were: involving the students in a variety of activities, promoting their technological creativity, and planning collaborative work.

At the operation and tuning stage, when building a robot and programming its functions were completed, the team performed systematic tests to integrate the

functions and execute the contest assignment in various real conditions. While in many other graduation projects the students do not test and improve their products systematically, in the fire-fighting robot project the incentive to get to a complete product and succeed in the contest motivates the students to maximum effort at this stage.

Contest survey

The survey findings relate to the summative evaluation and assessment of the project. In this section we will focus on two survey questions. The first question asked each team-member to estimate his or her progress in the following 17 fields: electronics, computer communication, microprocessors, assembly language, high-level language, motors and gears, mechanical design, robot kinematics, sensors and measurement, data analysis, physical field concepts, mathematical modelling, control systems, CAD tools, systems design, robot programming and teamwork. For each field the respondents evaluated their progress in theoretical and practical knowledge. The answers revealed that each of the students had made progress in the absolute majority of subjects in both theoretical and practical domains. High progress was mainly in programming, robot kinematics, sensors, data analysis, control and teamwork.

In the second question the team-members were asked to describe their own practical activities with main robot components (drive mechanism, mechanical structure, micro-controller, control circuits, sensor system, steering planning, system software and extinguishing device). For each component, they were asked to specify their involvement in various types of activities: designing, constructing, testing, implementation and installation). Students' answers showed differences in activities of the two crews. All the students from the structure crew were involved in all types of activities with the drive mechanism robot structure, steering planning and extinguishing device. They also installed and tested the microcontroller. The software crew students were involved in all types of software development. The robot sensor system was the common contribution of the entire team.

Conclusions

An educational program that has been developed in Israel successfully introduced learning through designing robots in the framework of school graduation projects. In many schools these projects have been inspired by the Trinity College Fire-Fighting Home Robot Contest.

In 1999-2002 we developed fire-fighting robot projects in one of the schools with a follow-up of learning in the project teams. The study characterised tasks and

students' behaviours, which are central at different stages of the design process, and proposed an approach to individual assessment of learning achievements. The contest was found to be an important motivator for self-directed learning inquiry in a variety of engineering subjects.

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