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Characteristics of learning computer-controlled mechanisms by teachers and students in a common laboratory environment

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Abstract Growing popularity of robotics education motivates developing its didactics and studying it in teacher training programs. This paper presents a study conducted in the Department of Education in Technology and Science, Technion, in which university students and school pupils cope with robotics challenges of designing, building and operating computer-controlled mechanisms. The university students were involved in developing robot prototypes and related instructional materials, and assisted in teaching robotics and guiding projects to middle school and high school pupils. The study focused on behaviors of the two groups of learners and aimed to elicit and analyze typical characteristics of learning in the developed robotics environment. We collected qualitative data on learning through robot design and experimentation activities and, by means of the ground theory method, elicited and analyzed typical behavioral characteristics of students' and pupils' learning: self-confidence, help, collaboration, interest, seriousness, self-dependence, learning effort, responsibility, coping with learning pressure, learning through observation, and perseverance. As found, the behavior characteristics evolve in the course of robotics studies and their evolution can give indication on the development of the desired competences.

Keywords Computer-controlled mechanisms · Experiential learning · Learning behaviors · Multi-tiered approach · Robotics education · Robot projects · Technology teacher training

Introduction

One of contemporary trends in research and development of technology and science education is prioritizing practices, in which the learners construct conceptualisations through interaction with the real-world environment (Singer et al. 2000). Such practices can foster integrated learning of science, engineering, mathematics, and humanities, as well as social

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development (Steak and Mares 2001). The constructivist learning can be reinforced by engaging the learner in creating "meaningful and sharable" artifacts, such as education robots (Turbak and Berg 2002), as proposed by the theories of constructionism (Harel and Papert 1991) and learning by design (Kolodner et al. 1998; Ryan 2003). The reinforcement mechanism is based on learners' interest to apply the acquired science knowledge and implement their own ideas in creating tangible products (Kafai 2005). The created artifacts can be used as models and visual aids for further learning (Verner 2004). A number of studies provide evidence that learning by design facilitates development of creative thinking (Waks and Merdler 2003), teamwork and communication skills (Roth 1996), cognitive abilities (Boucharenc 2006), self-confidence (Davies 2000) and other skills.

Robotics is an interdisciplinary field of common interest to engineers, scientists, and educators. Several studies of robotics courses indicate students' progress in science and engineering subjects (Turbak and Berg 2002; Verner and Hershko 2003; Nourbakhch et al. 2004; Verner and Ahlgren 2004; Verner and Korchnoy 2006). The robotics courses integrate robot design, building, and operating activities with studies and discussions of mechanics, electronics, computers, engineering design and other relevant topics, consultations with experts, problem solving, and laboratory experiments. Involvement of students in robot contests offers additional educational benefits including the following (Wilczynski and Flowers 2006): motivating student creativity, self-directed learning, and research; developing teamwork and communication skills; fostering interest in science and technology.

Learning processes in the robotics courses can be designed and studied using the experiential learning theory (Kolb et al. 2001). Accordingly, the learning processes are cyclic, when each of the cycles commonly consists of four stages (Kolb 1984): concrete experience, reflective observation, abstract conceptualization, and testing in new situation. Experiential learning designs are recommended to implement the following principles (Barron et al. 1998):

- Defining learning-appropriate goals that lead to deep understanding.
- Providing scaffolds such as "embedded teaching", "teaching tools", sets of "constructing cases", and beginning with problem-based learning activities before initiating projects.
- Ensuring multiple opportunities for formative self-assessment and revision.
- Developing social structures that promote participation and sense of agency.

An important impetus to educational robotics development was given by a conceptual framework of digital manipulatives (Resnick et al. 1998) which expanded the traditional learning with manipulative materials (construction kits). Accordingly, the computational and communications capabilities are embedded in mechanical parts of a construction kit. The students use the kit to create and program the movements of various devices. The kits assist in the development of manipulative skills, enhance imagination, and increase socialization (Parkinson 1999).

Zubrowski (2002) points the need of integrating science, mathematics and technology education and emphasizes the following principle characteristics of the learning by design process: (1) The students are self dependent in selecting project assignments and solutions, getting a fixed set of materials and limited guidance from the teacher; (2) The project assignments are connected to a science-technology course and focus on creating models and experimentation; (3) Student projects are parts of an integrated program organized around a "big idea"; and (4) Students design and build a working model of a technological system and operate it for experimentation purposes.

Researchers in technology and science education point out that analyzing students' behaviors can be relevant for studying experiential learning and predicting its outcomes (Ray 1991; Dym et al. 2005; Kafai 2005). Schoenfeld (1992) proposes to characterize and predict long-term behavior and performance in problem solving and practical group work by means of behavior patterns revealed in specific learning situations.

Researchers in the field of educational robotics traditionally have been focused on developing and evaluating learning environments. Less attention has been paid to the analysis of learning behaviors.

A number of studies elicited characteristics of learning in robotics courses by analyzing students' behaviors. Martin (1992, 1996) examined the freshmen robot design course in order to understand the learning process and find ways to improve it. Jarvinen (1998) by observing a primary school robotics course in the Lego/Logo environment found that the interactive behavior affected success of problem solving activities and knowledge transfer among students. Nourbakhch et al. (2006) developed a robotic exhibit for exposure of the Mars Exploration missions in science museums and studied visitors' behaviors while observing the exhibit. It was found that the robotic exhibit fostered family discussions of the missions and robotics, from which children acquired "measurable knowledge in these areas".

An important research problem relates to the analysis of experiential learning in a community that includes different groups of learners collaborating in a common environment. For such a community, the effective strategy of designing collaborative learning environments is apprenticeship Barab and Hay (2001). Kafai (2005) implemented apprenticeship in mixed-aged groups of primary school students involved in software design projects and found its effect on the development of collaborative behavior in students. Several studies considered educational frameworks in which pre-service teachers studied robotics and assisted in teaching it to primary school students Bers et al. (2002) and Cejka et al. 2006).

The research presented in this paper was conducted at the Department of Education in Technology and Science, Technion in the framework of the Masters and PhD studies by Korchnoy under supervision of Verner. The learning environment developed in the research was described in our previous paper (Verner and Korchnoy 2006). In this environment pre-service teachers of technology are involved in developing various robots, instructional materials, and assist in teaching robotics and guiding projects to middle school and high school students, including participation in robot competitions. We applied the multi-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 school curricula.

Our qualitative study examined learning behaviors of university students and school pupils studying robotics in the developed environment. The next section of the paper introduces the educational framework and the following sections present and discussed the study and its findings.

Educational framework

Robotics environment

Our educational environment comprises laboratory equipment, robot kits, instructional robots and materials. The main part of the instructional materials is a collection of robot prototypes and related instructional units developed by pre-service teacher students under our guidance. The robots are built mainly using the Robix construction 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 robot prototypes are programmed using the script language, C/C++, and Visual Basic.

Our robotics environment is used in the Technion teacher training courses, in the Course for Middle School Pupils and in robot contest projects performed collaboratively by students and pupils.

Courses for Technion students

In the Teaching Methods in Design and Manufacturing course Technion students study robotics and pedagogical subjects and gain project guidance skills. The students perform laboratory assignments, design and program computer-controlled mechanisms, develop instructional units (on subjects related to the mechanisms), and practice teaching them using the project method. Through these activities the pre-service teachers are engaged in designing, building and programming system prototypes, adapting guidance to learners with different backgrounds, reflective and divergent thinking, self-directed learning and collaboration.

The course 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; (3) programming robot manipulations. The students enhance their product design skills through performing hands-on tasks and experiments with virtual environments. Thirty-nine Technion students participated in the course for the period of this study. Most of them (19) majored in Technology Education–Mechanics. Among other students, thirteen were from the Faculty of Civil Engineering, five majored in Technology Education–Electronics. Single students majored in Physics Education and Mechanical Engineering.

In the Selected Problems in Engineering Mechanics and Selected Problems in Design and Manufacturing courses students perform individual projects. Each of the students selects an original topic related to the course subject, develops a tangible model and instructional unit for teaching the subject, and gives a lesson to the peers. Eighty-eight Technion students participated in the courses for the period of this study (2003–2006). Most of them (40) majored in the Technology Education–Mechanics. Among other students, 24 majored in Civil Engineering, two in Technology Education–Electronics, four were Physics Education majors, ten students came from the Faculty of Mechanical Engineering**,** one from Computer Science, two majored in Computer Science Education, two in Chemistry Education, two in Mathematics Education and one student was from the Faculty of Medicine.

Not all projects in these courses were in robotics, but the authors encouraged the students' motivation to this field through personal discussions with the learners before choosing the project's subject and by aligning their interests and instructional objectives. As a result, 26 robotic projects were performed.

A number of robot prototypes developed by the students are described in (Verner and Korchnoy 2006). An additional example is a coffeemaker robot presented in Fig. 1a.

The instructional associated with this prototype involves the learners in experimentation with robot arm kinematics and manipulating loose materials (coffee and sugar), which includes solving problems of physics, chemistry, and mathematics.

Fig. 1 Robots and pupils: (**a**) coffeemaker; (**b**) pupils experimenting with the coffeemaker; (**c**) shaving robot for disabled

A course for middle school pupils

In the framework of this research a robotics course was given to six groups of middle school pupils from one of Haifa schools. In total 132 middle school students participated in 2003–2006. The pupils studied robotics in our laboratory as an optional extracurricular course. The 26-h course fits in the Science-Technology Curriculum for Middle Schools, in particular its “Systems in Science and Technology” section. The following topics are covered: robot definition, mechanical arms and end-effectors, basics of robot control and motion planning, motors, sensors, robot applications. In the course the pupils used the instructional units and robot prototypes developed by the Technion students. A group of three middle school pupils experimenting with the coffeemaker robot is shown in Fig. 1b.

Five teacher students assisted in teaching the course to middle school pupils. They gave 15–20 min Powerpoint presentations and helped in guiding learning activities with the instructional units and robot prototypes.

Robot contest projects

Three projects have been developed in our laboratory in the framework of the Technion International Youth Summer Research Program (SciTech) and subsequent International Robot Olympiads (IRO) in 2004 and 2005 (www.iroc.org). One of them is the shaving robot project inspired by the IRO 2005 theme “Robotics for Handicapped People”. The shaving robot (Fig. 1c) was a product developed through the collective effort of middle school pupils, teacher students and the researchers. The team of three middle school pupils (grade 9) involved in the project participated in the IRO 2005 and won gold medals in the age category 14–18.

The study

The goal of our study was to observe learning behaviors of teacher students and school pupils and elicit characteristics of their experiential learning in the common robotics environment. The hypothesis was that through keen observation and analysis of behaviors of students and pupils studying robotics in our laboratory common characteristics of their learning could be revealed.

The study was conducted as action research, meaning that both authors were involved in research and teaching the courses for Technion and school students, and in project guidance. Participants of the study were:

- Technion undergraduate students ($N = 24$) who took our courses and performed robotics projects. Before enrolling in our program all these students passed basic mathematics, solid mechanics, electricity and programming courses, but only few of them had background knowledge in mechanisms, dynamics, design and robotics.
- Middle school pupils ($N = 132$) who studied a semester-long robotics course. Among them the group of three pupils participated in the 2005 International Robot Olympiad. The pupils had elementary knowledge in mathematics and physics but did not study technology before our course.
- Two groups of high school pupils ($N = 4$) who participated in the 2004 and 2005 International Robot Olympiads. The pupils had knowledge in school mathematics, physics and programming, but had no background in robotics.

The study was designed as multi-case research (Yin 2003; Wiersma 2000) that observed, and analyzed student and pupil behaviors in the courses and robot projects. In each of the cases we collected data using observations of learning activities, taped and transcribed semi-structured interviews, diary notes, and written reflections included in projects portfolios. The data were analyzed based on the grounded theory (Strauss and Corbin 1998) and using the inductive method of analysis (Goets and LeCompte 1984). The learning characteristics were determined and refined incrementally in the process of comparative analysis and generalization that consisted of the three stages:

Stage 1. The goal of data collection was to get general and detailed descriptions of the learning processes, including their cognitive and affective aspects. Through the inductive analysis of these data we identified the common salient themes of these descriptions.

Stage 2. The data collection was focused on the identified themes. By the inductive analysis of these data we formulated the characteristics of the learning processes connected to the themes.

Stage 3. The data collection was directed to obtain specific and detailed descriptions of students and pupils behavior related to the formulated learning characteristics. By the inductive analysis of these data we determined the features of the learning characteristics.

In order to increase the internal validity and reliability, we observed a significant amount of cases each of which during at least one semester long period, confronted findings from different research tools, conducted a relatively large number of interviews with the students and pupils, made observations inside and outside the laboratory. We also implemented methodical recommendations related to the elicited learning characteristics and received evidence of their effectiveness.

Findings

The eleven typical learning characteristics and their features elicited by the data analysis are presented in Table 1 We found that these characteristics and features adequately describe learning behaviors of both students and pupils.

Discussion

In this section we discuss the elicited learning characteristics presenting selected citations, relevant methodical recommendations, and our experience of their implementation.

Table 1 *Learning Characteristics and their sub-features*

Learning Characteristics	Features
Self-confidence	Fears of meeting the challenge; development of personal initiative; interest enhancement and rise in curiosity; success in overcoming intermediate challenges; inquiry through the project; progress in the project; knowledge application capability growth; readiness for meeting new project challenges
Help	Giving help, getting help, readiness to help, need help, and ask help
Collaboration	Collaboration in developing new ideas, collaboration in robot building, and collaborative learning in the project
Interest	Interest in practical experimentation, interest-driven initiative, interest-success interplay, and interest in robotics subject
Seriousness	Recognizing the importance of robotics studies, facing interesting and non-trivial robotics problems, and taking responsibility for problem solving and learning
Self-dependence	Inspiration to realizing initiatives, experience in robot building and self-learning, liberty of action and responsibility, interplay between self-dependence and self-regulation, creation of new solutions
Learning effort	Collaborative learning, rapid prototyping, initiative realization, project requirements, interest in robotics, and teaching practice
Responsibility	Pre-service teachers' responsibility for students' outcomes; pupils' responsibility for their learning; responsibility for project results; responsibility for self-depended work, and shared responsibility in collaborative work
Coping with learning pressure	Difficulties at the beginning of the project, difficulties in solving open problems, project time limits, and lack of robotics background
Learning through observation	Observing visual materials, robots and prototypes
Perseverance	Aim to invest time and effort in robotic assignments, withstanding inconveniencies for achieving the goal, learning in depth, and positive spirit

Self-confidence

The data analysis indicated the growth of self-confidence which was an important factor of the learner's success in the robotics courses and projects. The school students and pre-service teachers overcame their initial learning and teaching fears in the course of the robot project:

> "I felt rather frustrated in the beginning of the work… The traits that changed in particular in my behaviors are that I became organized, patterned, calculated, expressing, outspoken and relaxed." (High school student's reflection).
> "I am highly influenced by participation in the project. At the beginning I was afraid that the subject is very difficult, but while performing the project I understood that it can be accomplished step by step. And I have motivation to run such a project at school." (Pre-service teacher's reflection).

The learner's self-confidence grew as a result of the development of initiative and knowledge application capability:

> "During the work, when I delved deeply into the project I has become more self-depended." (Pre-service teacher's reflection).

"This (due to my becoming more and more task oriented) forced to focus more and more on the goals of the project and allow me to work more effectively." (High school student's reflection).

"Through this project I became familiar with kinematics graph and became able to draw and use it. 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." (High school student's reflection).

Every (even minor) achievement fosters learner's self-confidence:

"When you see that it works and that you made it, then your confidence rises." (Pre-service teacher's reflection).

"At the beginning I was sure that this is an impracticable project because my background in robotics was limited. But after passing the initial stage and reaching first achievements—this gives motivation and reinforcement to continue work." (Pre-service teacher's reflection).

With identifying the self confidence characteristic and its features we studied the related literature. The recommendations about the ways to develop learner's self-confidence are (Bandura 1993):

- 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.

In our robotics courses we address 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 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. Our 5-year observation has indicated that after completing the course many of the students are getting involved in teaching robotics in various frameworks, including outreach programs, middle and high school courses and projects, and college courses. Some of our graduates working in industry evaluated the contribution of the course for their work place adaptation.

Help

In the individual robot projects the pre-service teachers needed and got our help in subject selection, problem definition, work organization, information search, and construction kit familiarization. At the subsequent stages they acted more independently and even helped each other. The team projects involved pre-service teachers and school students. In this setting help was given through apprenticeship, when the pre-service teachers impart to the school students their experience acquired in the individual projects. In the middle school robotics course the student had opportunities to discuss problems and share ideas with classmates. Through this communication they give and get help to each other.

Pre-service teachers helped each other and school students in building robots and understanding theoretical concepts:

> "I helped him because we are friends. I saw that he had difficulties in building the robot. When I solved my problem, I helped him."
> "First of all I helped pupils to build robots because they never did this. I helped the pupils to understand theoretical concepts that they studied in the course. I also helped them to program the robot."

In the course of self-directed work the learners encountered difficult problems that they cannot overcome by their own. Striving to cope with the challenge, the learners asked help and got it from the supervisors and other students:

> "I got help from the teacher on how to treat the friction problem in the mechanism. I also got references to the theoretical material." (Pre-service teacher's reflection).
> "I learned that if I want to study something, I simply have to ask teacher's help. I did not know this before the course." (Middle school student's reflection).
> "They seat all together, help each other, move from robot to robot. Are interested in all the projects and deal with them." (Pre-service teacher's reflection).

During the robotics studies the learners recognized the value of mutual help as a necessary teaching and learning skill. The students acquired confidence that they will get help when needed. They became sensitive to the needs of others and understood that the helping behavior contributes to the projects success:

> "Before the robotics course I preferred to work individually, because it is much more convenient. Now I know that there are tasks that require teamwork. I learned much from my communication with the team members of our Olympiad project." (Middle school student's reflection).

The data collected in our research showed that help is the important learning characteristic of individual and team projects. In order to foster helping behavior we implemented a number of instructional methods recommended in literature. Our interaction with the learners was based on the scaffolding method. In our instruction we adapted the four main scaffolding strategies proposed in (Barron et al. 1998): (1) teaching embedded in robot project activities; (2) teaching aided by tools such as robot kits and instructional units developed by the pre-service teachers; (3) demonstrating a collection of robot prototypes as "construction cases"; and (4) beginning with problem-based learning activities before performing robot projects.

The interaction of pre-service teachers and school students grounded on the principles of apprenticeship. Following recommendations of Collins et al. (1989), we involved the pre-service teachers in developing meaningful tasks, conceptual tools and appropriate scaffoldings for school students. The pre-service teachers developed robots and instructional units for experiential learning, constructed dynamic models for explaining concepts of mechanics, and assisted in mentoring students' robot projects.

When promoting helping within groups of learners we applied recommendations of Ng and Van Dyne (2005) related to supporting group consolidation, dividing responsibilities, forming mutual aid norms, and operative resolving conflict situations.

Collaboration

The development of collaborative behavior of the learners was prominent in the group projects. When starting the robot project, most of the learners preferred to work individually and had doubts regarding partners' contribution. But in the course of the project they saw that it can be performed only through the collective effort. This can be illustrated by the following citations:

> "An important characteristic of robotic environment design is group work because of its importance in brainstorming ideas for efficiency. Also, by working in a group ideas are passed from person to person, each person can create more effective robotic functions." (High school student's reflection).
> "The discussing and showing our thoughts would be good for the project, because this way we would be able to extract the best ideas out of both of us and combine them into a powerful and scientifically correct theoretical background for our robot." (High school student's reflection).
> "Also, important was the positive and creative influence upon me by the other participants in the project and our common orientation for the completion of the assignment." (High school student's reflection).
> "I realized that telling and discussing ideas with others would be in favor of the project, and the robot itself." (High school student's reflection).
> "Due to the project we acquired knowledge in programming, robot construction, mathematics, and learned to strive for success and excellence. We acquired teamwork skills – one of the most important results of the project." (Middle school student's reflection).

The learners highly appreciate the project contribution to the development of collaboration skills. This result is in line with other studies which note the impact of robot projects on the development of collaboration skills (Verner and Hershko 2003; Frank 2005). Our strategy of fostering collaboration skills fits the recommendations given by Cuseo (1992): (1) the project team members were selected intentionally with attention to the mechatronics background, learning achievements, and teachers' recommendations; (2) the robot projects were performed through regular meetings during an extended period of time; (3) interdependence and collective responsibility of the team members for individual and common results was promoted; (4) explicit attention was paid to the development of communication skills and group identity.

Interest in robotics studies

Interests are understood as incentives realizing different situations and requirements (needs) at the very center of the activity of an individual or a group (Gasparikova 1999). The reflections of pre-service teachers and school students collected in our study showed that they recognized robotics as an important subject and had a strong desire to learn it. The pre-service teachers and the school students displayed strong interest in learning by doing and self-depended work. The following pre-service teacher's reflection is typical:

> "It is most prominent in the robotics lesson that students are really interested in self-directed experiential practice. Not only see demonstrations, but perform by their selves. These young kids used to act rather than listen to the teacher. When I

conducted an experiment, the students were more attentive because they were interested." (Pre-service teacher's reflection).

The learners often mention that their initiatives in learning and actual doing rooted in their interest in robotics, as illustrated below:

"When the subject is interesting and the interest increases, the students want to push things forward and search more information. If the project does not interest me from the beginning, then it is difficult to work out and overcome the problems. But in my case both the technological subjects and the practical project were interesting." (Pre-service teacher's reflection).

Typically, the learner's interest in robotics grew with her/his success in solving project problems:

"When working on the project problems and succeeding to find their solutions I have become more interested in the project subject." (Pre-service teacher's reflection).

The learners are interested in robotics and wish to study it intensively, as they understand the importance of the subject:

"I enjoy studying robotics. I want to be an engineer or designer and robotics helps me. I learn robotics because this is an interesting subject which will have big progress." (Middle school student's reflection).
"Even when returning to the bus after the lesson we are discussing the project. The things we will do next time. The mathematics calculations that we need to make at home in order to save time for lab experimentation."

When teaching robotics we implemented the recommendations of Edelson and Joseph (2004) for fostering learners' interest: determine learner interest, align instructional objectives and learner interest, use context to initiate and maintain motivation. In particular, at the beginning of the project we held discussions with the learners. They selected robot project assignments and topics to learn in depth according to their interests. The interdisciplinary context also contributed to learners' interest in the projects. We offered the middle school robotics course only to students interested in robotics. In the course the students had opportunities to make more experiments with their favorite robot prototypes.

Seriousness

The learners consider robotics as an important rapidly growing field and connected to their personal carrier expectations:

"I want to be a designer or an engineer. Robotics helps me to learn physics. Robotics is a field that is expected to grow seriously. This is an interesting field which I see as a tool for my future professional work." (Middle school student's reflection).
"My personal motivation is to make best use of time of my studies at the Technion. For my opinion participation in the project is very effective for my professional development. During the project I acquired experience of how to work with pupils. Now I am more patient and made progress especially in programming. I learn by my own Visual Basic which is used for robot programming." (Pre-service teacher's reflection).

The real interdisciplinary problems of robotics were new to the learners. They found the problems interesting and challenging:

> "For my view, the middle school students did not work seriously at the beginning of the project. One of them tended to draw attention to less important topics. Other student performed tasks only if it was required by the instructor. But later, when the students saw the real progress opportunity to participate in the robot contest, their behavior substantially changed and became serious." (Pre-service teacher's reflection).

The learners' seriousness is expressed also in investing plenty of time and effort for robot projects:

> "It is difficult to learn several subjects from different disciplines. But I seat, think and spend many hours on this learning, also at home." (Middle school student's reflection).
> "I take the project seriously. This relates also to the course grade. My seriousness is expressed in investing my free time to come to the laboratory and work many additional hours to build and program the robot. I also bought some materials for my project." (Pre-service teacher's reflection).

The necessary condition of any successful learning is "professing it", i.e. taking it seriously by the learners and the instructors (Shulman 1999). This particularly means that the learner and the instructor share responsibility for memorizing, understanding and applying knowledge. Following this recommendation we fostered the learners' seriousness by implementing the following instructional strategies: delegating major responsibilities to pre-service teachers and school students participated in the projects; involving the learners in international robot contests, and embedded teaching.

Self-dependence

The principle importance of self-dependence was emphasized in most of the learners' reflections. The learners come with initiatives and realize them by their own:

> "We choose what to do, how to do, the robot to build, and how to program it. We started from scratch, from the Lego brick." (Middle school student's reflection).
> "I built the robot from different parts, not only from the kit. I bought and found additional parts." (Pre-service teacher's reflection).

With gaining project work experience the learners became initiators:

> "At the beginning of the work on the project, my behavior could mostly be described along several patterns: unorganized, unstructured, and receiving. Later, however, as I became engulfed into the process of rapid prototyping under the guidance of my mentor, my behavior changed gradually. I started turning from a receiver to an initiator. This was after we have abandoned the unorganized way of working and have started to apply theoretical methods in practice." (High school student's reflection).

The pre-service teachers recognized the importance of providing to school students freedom of and responsibility for implementing their ideas:

> "We should give students to build their own model from Legos. Give them to try and check by themselves if they are right or wrong. Then we can make a discussion on why the robot behaves in the way observed in the experiment." (Pre-service teacher's reflection).

> "At the beginning the school students had to propose a project idea. I mentored the students trying to interest them and let them feel that they selected the project direction by their selves." (Pre-service teacher's reflection).

The school students noted changes in their learning behavior:

> "Before the robotics course I usually learned from explanations at the blackboard without asking questions and deepening. Now, after the course, I listen more carefully and then write. When interested, I ask questions, sometimes too much. Now I think that it is important to concentrate on the learning material and on teacher's instructions. I should focus on difficult subjects and understand them. I should continue to learn by myself at home. (Middle school student's reflection).

The learners invested their time and effort in finding original solutions:

> "We did not find ready solutions for our projects on the Web and in literature. I had to reach the solution by my own. I tried to solve the problem for several days and the solution suddenly popped up. Then I succeeded to implement it." (Pre-service teacher's reflection).

In the study we followed the instructional principles for self-regulation development (Ley and Young 2001). The pre-service teachers and students were closely involved in preparing and structuring their learning environment. The focus of the learners' activities was on applied problem solving, creative thinking and reflection. Through these activities the learners developed their ability of self-depended work.

Learning effort

Most of the learners participated in the study put considerable intellectual and practical effort in experiential learning throughout the robotics studies. In the robotics course the middle school students learned intensively. In addition to the personal assignments they actively collaborated with others:

> "The students work as a single group. They seat together, help each other, move from one work place to other, are interested in all the experiments, and make them." (Pre-service teacher's reflection).

The use of rapid prototyping, i.e. robot design through constructing, analysis, and improving prototypes, is effective but requires considerable efforts from the pre-service teachers:

> "I made many experiments with the new spoon (the spoon was used as an end-effector of the coffee maker robot—E. K. and I. V.). Then I fixed it on the robot arm. However, in the experiment the spoon was stuck. It became clear that the spoon is bigger than needed. I also searched literature and found that plastic spoons safe shape when heated, if the temperature does not exceed 100°C." (Pre-service teacher's reflection).

In many cases the dynamic models that the pre-service teachers developed and demonstrated in the robotics course motivated the middle school students to come with initiatives and put effort in realizing them:

> "One of the middle school students incorrectly solved a transmission ratio calculation problem. After that, I constructed a transmission model and demonstrated it in

class. The student's reaction was that he identified the error in his solution, made a new calculation, and got the correct answer. He even made a calculation for a different transmission that I implemented in the model." (Pre-service teacher's reflection).

The learners put considerable effort in order to fulfill the project requirements:

"The work amount was more than expected, but I overcame this. When I faced a problem then I invested extra time to solve it." (Pre-service teacher's reflection).

The interest in robot projects motivated the pre-service teachers to invest their free time and effort for improving the project:

"To carry out the project I worked in the lab till night. It was not simple but interesting. This is attractive even though it requires much work in addition to the classes. I continuously spent my free time in order to improve the project and operatively implement my ideas." (Pre-service teacher's reflection).

The pre-service teachers put considerable effort in developing lesson plans and materials because they used them in real teaching:

"I prepared the complete lesson plan and knowledge assessment questions. I developed a lot of instructional materials because I saw that the middle school students "grasp" so quickly." (Pre-service teacher's reflection).

In teaching robotics we attempted to organize learning in the most effective way in order to reduce the project workload. Recent research Kember and Leung (2006) indicated that student perception of workload is strongly influenced by the learning environment. As found "It appeared to be possible to encourage students to perform a great deal of high-quality work, without complaining about excessive workload, by attention to this environment". In our study we implemented this approach by developing a common environment in for pre-service teachers and school students which facilitated learning for both groups of learners. The rapid prototyping using modular robotics kits facilitated experimentation and creating robots. The embedded guidance and apprenticeship supported the learning efforts.

Responsibility

Personal and team responsibility of the pre-service teachers and school students were crucial for self-directed and collaborative learning and for performing the project assignments in the robotics laboratory environment. Hersh and Schneider (2005) point out that human responsibility relies "upon such virtues as honesty, self-discipline, respect, loyalty, and compassion". The pre-service teachers display honesty and self-discipline when preparing lesson plans and materials, trying to address the school students' needs:

"I examined huge amount of literature because I had to understand the new subject and then explain it to children and help them to make progress."
"For my opinion, the best way is first to ask the children what they think about the phenomenon. Then, let the children by their own make an experiment and see what really occurs. And after that, explain the phenomenon."

The middle school students are becoming more loyal learners during the robotics course:

"As compared with the beginning of the course now the children take the lessons more seriously. They seat and learn."

The learners carefully plan and control their progress in the projects:

"I had strong feeling of responsibility throughout the project and completed it with high grade. My responsibility expressed in managing the work according to my schedule. I planned the project work and strived to have progress every 2 weeks." (Pre-service teacher's reflection).

The projects required self-dependence in learning and practical experimentation:

"The project assignment is open and requires a lot of self-directed learning. I have to learn, act and make experiments by my own. No spoon-fed." (Pre-service teacher's reflection).

The middle school students took responsibilities for their parts of the team projects. One of the pre-service teachers participated in the team projects noted:

"The student was absorbed in programming the robot. Every time he had a new version of the program which enabled additional functions. He was very busy with the project and invested his free time to solve the programming problems." (Pre-service teacher's reflection).

When discussing ways for developing learners' autonomy, Sharle and Szabo (2000, pp. 3–11), consider responsible learners as learners who understand that their efforts are crucial to progress in learning, are ready to cooperate with the teacher and other learners, and monitor their learning progress. Devon and De Poel (2004) point out that engineering design per se is a collective effort which fosters responsibility of the people involved. In the robotics courses and projects guidance we facilitated developing responsibilities of the learners through selecting project assignments that match learners' interests, allotting responsible roles for all the learners; cultivating self-directed theoretical studies and practical work; and self-assessment and self-monitoring throughout the experiential learning process.

Coping with learning pressure

The learning pressure was typically indicated in our robot projects, as caused by the lack of experience and difficulties in solving open problems. This pressure was expressed by the following learning features: difficulties at the beginning of the project, difficulties in solving open problems, project time limits, and lack of robotics background.

At the initial stage of the project the learners faced difficulties that caused fears and concerns for possible failure:

"At the beginning when I entered the laboratory of technology, I tried to find suitable materials and push the project forward. These days I stayed in the lab alone for 3–4 h and felt stressed. This really was an excitement." (Pre-service teacher's reflection).

Solving open problems of robot design requires from the learners investing considerable effort and time:

"All the time I felt strained because I was unsure that the designed system would function. I really worked seriously. I built several prototypes and finally got the right model." (Pre-service teacher's reflection).

The need to complete the assignment in time pressed the learners in their project work:

"I felt the project pressure only because time deficit. I studied also many other courses. I worked on the project about full day a week during the whole semester. I learned the new material, constructed the robot model, prepared the report and made the presentation." (Pre-service teacher's reflection).

Some of the tasks included in the project were especially unfamiliar and difficult to the learners:

"I had no experience in writing reports. This work was really boring for me and I forced myself to do it." (Pre-service teacher's reflection).

While considering stress as a factor associated with active learning processes, we implemented literature recommendations for decreasing it: instructor's recognition of learners' personality and anxieties (Wilson 2000); and facilitating a free communication, trust, and helping each other in the learning groups (Argyris 1999).

Learning through observation

The pre-service teachers and school students learned when they observed objects and processes in the robotics environment. Watching thematic movies and illustrations increased learning motivation and gave ideas for robot projects:

"From the movie the middle school students saw that children of the primary school age participated in the International Robot Olympiad in Korea, and that students of the same age built sophisticated robots. The movie rose desire to build robots and study robotics." (Pre-service teacher's reflection).

When observing robots and robot manipulations the learners are involved in constructing mental models of three-dimensional objects:

"The middle school student looks at the robot body, identifies different mechanisms, recognizes light and touch sensors, and establishes their locations. From this observation he generates in his imagination the picture in which the components are connected in an entire robot structure." (Pre-service teacher's reflection).

When designing robots the learners apply their observation skills in order to examine and improve the robot prototypes:

"I focused my observation on a part of the ellipsograph mechanism to see the reason of its malfunction. From the observation I came to understanding the problem and fixed the robot." (Pre-service teacher's reflection).

Observation is considered as a basic learning skill that should be highly promoted in education (Armantier 2004; Haury 2002). In the robotics courses and projects we followed recommendations for developing scientific observation skills given in the Project 2061 report (Science for all Americans 1989). Our special attention was paid to rational organization of robotics experiments, accurate measuring and analysis of the data, and promoting the learners' reflections.

Perseverance

The perseverance in studies and projects helped the learners to cope with robotics challenges. When starting the project, that was a new enterprise for the learners, they recognized the need to invest considerable time and effort:

> "I understood the need to work hard and invest much time in the project." (Pre-service teacher's reflection).

When striving to succeed in the project the learners develop ability to overcome uncertain situations caused by lack of experience in robotics:

> "For my opinion, in order to succeed in the project we should change way of thinking. We need to be more concentrated and patient, learn from mistakes, accept that they can happen. We do not always succeed. Patience and systematic work are important. If the solution is not successful we need to find other solution." (Pre-service teacher's reflection).

The learners not only use theoretical methods but also examine how they work through practical experimentation:

> "To build a mechanism you put effort not only in learning because the reality is often not identical to theory. For example, after calculations we build the system and it does not work. So we should understand why this happens, what is lacked in the theory, and what should be improved. All this requires engineering thinking in addition to learning." (Pre-service teacher's reflection).

The learners are very positive about the opportunity to present to others an impressive robot made by their own:

> "When building a model, it is important that other people could see it. We build the robot that exhibits human's walking. And people will see it. There is nothing better than seeing tangible results!" (Pre-service teacher's reflection).

When fostering the learners' perseverance in our robotics courses and projects we implemented recommendations (Bole 1999; Russell and Atwater 2005) such as: promoting self-efficacy and teamwork, selecting personally meaningful project assignments, maturing meta-cognitive skills by supporting reflection in and on robot design experience.

Summarizing the discussion, we emphasize that for us the elicited learning characteristics and their features are not just a theoretical result. They enabled us to improve our instruction in the courses and projects by highlighting the aspects that in the past slipped our attention. We found that the evolution these characteristics in the course and robot project can give indication on the development of the desired competences. In particular, the level of self-confidence, self-dependence and responsibility, and the ability to cope with learning pressure largely indicated students' achievements in performing robotic assignments and competence in robotics subjects. The pre-service teachers' ability of observation pointed to their competence in mentoring the experiential learning process. Interest in robotics and readiness to help and collaborate were indicated the competence of extra-curricular instruction. The inverse is also true: from our experience successful learning in the course and robot project led to the growth of self-confidence, perseverance, learning effort, seriousness, readiness to giving and getting help, and the ability to cope with learning pressure.

Conclusion

Modern science and technology education requires teachers' competences in design and analysis of mechatronic systems and robotics instruction. The challenging requirements to the robotics teachers include the following (Verner and Ahlgren 2007):

- Be competent in mechanical design, electrical systems, sensors, and computer programming.
- Integrate lectures, demonstrations, and laboratory exercises.
- Combine formal and extra-curricular frameworks, frontal instruction and project guidance.
- Be broad-minded and smart learners of robotics applications in different areas of human life.
- Invest significant effort and funding in lab equipment, course preparation and their continuous updating.
- Organize and supervise students' participation in robot competitions.

To foster these competences in our technology teacher training program we developed, implemented, and evaluated a complex approach which integrates four main components: creating a laboratory learning environment for robotics studies; involving pre-service teachers in developing the environment and in teaching robotics to school students; guiding projects for youth research programs and robot contests; and conducting follow-up research.

When evaluating the progress in the competences development, we kept in mind that in robotics education learning is inseparable from practical work. Therefore, our study focused on exploring students' and pupils behaviors embedded in robot design activities. The learning characteristics reveled in the study can serve as indicators of development of the desired competences.

Grounding on the results of the study we can conclude that the robotics environment created in the framework of the Technion course "Teaching methods in design and manufacturing" fostered development of skills and habits that form competences required for teaching mechatronics and robotics. This learning environment was found effective and can be recommended for teaching robotics to school students. The interaction between the pre-service teachers and the school students was reciprocally beneficial. Experimentation with modular robot prototypes played the central role in forming the learning characteristics revealed in the study. The authors recommend examining possible use of the learning characteristics as oblique indicators of learning in other mechatronics and robotics environments.

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