Technology Teacher Education and Outreach using the CDIO Approach

Igor M. Verner

Department of Education in Science and Technology, Technion – Israel Institute of Technology

ABSTRACT

Many countries are struggling to meet the increasing demand for qualified school and college teachers of technology. To help in solving this problem in Israel, the Technion has recently established a program under which undergraduates and graduates from all faculties may get full scholarships to study an additional B.Sc. degree in science and technology education. The program has caused significant increase in the number and quality of students enrolled in the department and particularly in our technology/mechanics education track. This has posed the need to upgrade the content and pedagogy of our courses. We did not find in teacher education literature suitable recommendations for updating the curriculum and decided to adapt for this purpose the Conceive-Design-Implement-Operate approach. CDIO prompted us to reorganize the laboratory and combine in the courses learning pedagogical fundamentals, training technological skills, and teaching practice. The approach helped us to formulate the target benchmarks: deliver the program with more extensive involvement of employers and social partners, connect education and research, provide prospective teachers with up-to-date knowledge, enhance the role of teaching practice, and promote labor market insertion. The benchmarks not only facilitated the development of the updated curriculum but also gave a new impetus to our research and educational outreach. In this paper we discuss the changes in the curriculum, inspired by the CDIO approach, and illustrate implementation of the proposed benchmarks by examples of updated teacher education and outreach courses.

KEYWORDS

CDIO approach, Technology teacher education, Educational robotics, Digital design, Standards: 1 – 8, 11.

INTRODUCTION

The need for people capable to develop solutions for problems of the modern technologically oriented world is constantly increasing. It requires the incorporation of engineering education as an inseparable element of present-day education, and as preparation for technological and scientific careers. The educational system in Israel offers studies of different technological disciplines, four of which are defined science-rich subjects, including mechanical engineering (Volansky, 2010; Verner & Betzer, 2001). The technology/mechanics track at the Technion Department of Education in Technology and

Science is the only authorized university undergraduate program in Israel for training teachers of the subject.

The Technion has recently called upon undergraduates and graduates from all faculties to study for an additional B.Sc. in Science and Technology Education, and offers them full scholarships. The students of the technology/mechanics track and others, who take our courses, come from different backgrounds. Although the majority of them are mechanical engineering majors (graduates and students), others are from civil, aeronautical, and electrical engineering as well as from physics and mathematics teacher education programs. The students are at different levels of education from BSc to PhD. Many of the students are Technion graduates studying BSc in education (including the teaching certificate) in the Views program (Hazzan & Ragonis, 2014). Views students receive study scholarships to complete their studies in four semesters, without the obligation to work as a teacher.

The increase in the number and quality of students led the Department and the technology/mechanics track to the need to upgrade the infrastructure, curricula, and pedagogy of the courses, and meet the associated challenges in educational research and development.

We did not find in teacher education literature suitable recommendations for updating the program and decided to adapt for this purpose the CDIO approach to reforming engineering education (Crawley et al., 2007). This approach proposes to focus engineering programs on conceive-design-implement-operate experiences, i.e. on assignments and projects in which students study engineering fundamentals and apply them to design, implement, and operate technological processes. We found that CDIO recommendations to engineering programs can serve as relevant benchmarks for updating our technology teacher education program:

- *Deliver the program with more extensive involvement of employers and social partners*. Following this recommendation we act to strengthen partnership with the Ministry of Education, Haifa municipality, MadaTech museum, schools, technical colleges, Technion faculties, hi-tech companies, and other institutions).
- *Connect education and research*. This guideline directs us from one side to engage students in research projects and, from the other side, to follow-up the program development with educational research).
- *Provide prospective teachers with up-to-date knowledge*. This benchmark calls us to update both engineering and pedagogical knowledge imparted in the course.
- *Enhance the role of teaching practice*. This recommendation led us to redesign our courses and include real teaching and technological assignments.
- *Promote labor market insertion*. We actively assist students in finding jobs as teachers.

Our interpretations of the CDIO guidelines are in line with the challenges noted in the OECD review of technology education in Israel (Field & Kuczera, 2012). The CDIO approach also calls to reorganize traditional laboratories into modular workspaces for all levels of engineering education. It emphasizes the role of laboratories in fostering creativity, learning motivation, teamwork skills, and “understanding of the engineering discipline prior to choosing an area of study" (Crawley et al., 2007, p. 106).

In this paper we discuss changes in the technology-mechanics teacher education courses aimed to enhance students' knowledge and skills in teaching robotics and digital design: updating the laboratory to introduce different pathways into robotics, modern CAD software and 3D printer; and implementing the conceive-design-implement-operate (CDIO) approach to balance learning pedagogical fundamentals, training technological skills, and teaching practice.

TECHNOLOGY EDUCATION LABORATORY

The departmental Laboratory of Technology plays a key role in the technology education research and teacher training:

- The Laboratory serves a ground for experiential learning practices in robotics and digital design.
- The Laboratory is a venue for presentations, discussions, and meetings of the research group.
- Laboratory activities are included in all technology education courses. Some of these courses are open for students majoring in science and mathematics education and for students from other departments.
- Some of the courses are based on project-based education, in which the assignments require to design and make a model and develop an instructional unit, using the model as a teaching aid.

The lab is equipped with different instructional systems. Among them are instructional robot manipulators Scorbot-ER 4 and 5Plus, a software package RoboCell used to create and control virtual robotic workcells, and a milling machine Spectralight 0400. Robot construction activities are carried out using the PicoCricket, LEGO NXT and EV3 kits. Through practice with Bioloid Premium kits the prospective teachers study basics of humanoid and service robotics. We update the laboratory equipment with careful consideration of specific needs as well as space and staff limitations of the teacher education lab.

With support and collaboration of PTC (Parametric Technological Corporation) we adopted the instructional systems that support practice in digital design and fabrication: Creo computer aided design software, Mathcad engineering calculation software (both provided by PTC), and a 3D printer. Creo is a rich environment for learning by design. Students' self-learning is supported by a special Creo student edition which is a free-download full design environment. Mathcad is used for automation and validation of mathematical calculations related to engineering design. It also serves as an educational tool for creation of calculation sheets which combine text and formulae and enable to document mathematical inquiry of engineering problems. An advantage of Mathcad is that it is interoperable with Creo, i.e. 3D model’s parameters can be calculated and explored mathematically. The 3D printer is an important component of the laboratory environment. It offers a rapid prototyping of small-scale physical models, thus providing operative feedback to the student. Furthermore, 3D printing minimizes the constraints in the design, and removes barriers in the transition from design to manufacturing. We equipped the lab with a desktop FDM 3D printer manufactured by PP3DP (Figure 1A). This 3D printer is affordable, compact, and easy to use and maintain.

DESIGN EDUCATION COURSE

In this section we will consider implementation of the CDIO approach in the course 216144 "Advanced issues in teaching design and manufacturing". The 4 hours per week course was given in the spring semester 2013 with 2 hours of lectures and 2 hours of laboratory classes.

A. B.

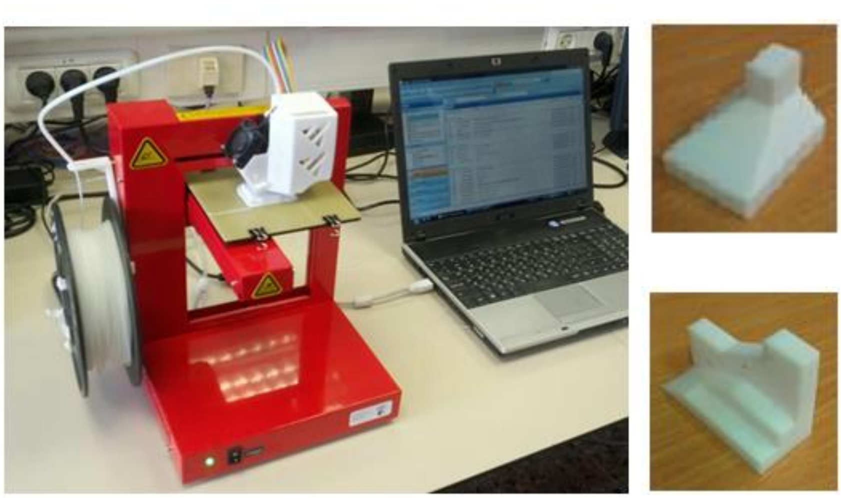

Figure 1. A. The 3D printer; B. The produced objects

The lectures focused on the theories of learning: constructivism, social constructivism, instructional scaffolding, constructionism, and experiential learning. The theories were presented in the technology education context. The lectures also considered models and modeling in science and technology education and the CDIO approach. Every lecture was followed by a home task, in which the students analyzed the theoretical material in the context of their experience. A special lecture on product design and development was given by the PTC leading expert. Each of the students in the course was assigned to give a short lecture on a certain aspect of teaching design and manufacturing. The topics included the following: user-centered design, social implications of industry automation, student engagement in design and manufacturing, connections between religion/ethics and engineering, ergonomics in engineering design, fostering creativity in learning design and manufacturing, teaching through industrial visits, 3D printing in design education. Every lecture posed a homework question that requested analysis of the lecture content.

The laboratory classes focused on assignments that combined practice in computer aided design and 3D printing with development of lesson plans and inquires on teaching topics related to this practice. The main topics were:

- Principles of CAD and parametric design: applying materials and units, use of parameters, types of models, basic Creo operation.
- 2D sketching: planar constraints, complete and incomplete sketches, applying dimensions.
- From 2D sketching to 3D modeling: creation of solid bodies.
- Advanced 3D modeling: engineering features, subdivision modeling and meshes.
- Assembly modeling: spatial constraints, partially-, fully- and over-constrained components, from partially-constrained components to mechanism design.
- Analysis: geometry analysis and basic measurements, orthogonal, cylindrical and spherical coordinate systems, projections, advanced measurements, mass properties, generating featured measurements and data.
- Graphics and Rendering.
- Generating 3D printable models.

Teaching assignment

The teaching assignment in the course was constructed based on the CDIO approach which proposes to educate students by engaging them in conceive-design-implement-operate learning practices. We adopted the approach in the course by posing an assignment that threads the course activities and culminates in real teaching practice, as described below.

Educational problem. At one of the course meetings the technology education coordinator from an urban school in a low-income community area of Haifa presented to the students a real problem faced by the 10th grade class majoring in mechanics. The class studied the technical drawing course and some of the pupils had difficulties “to see” projections and cross-sections of 3D objects and vice versa “to construct” 3D objects given by projections. The coordinator asked the Technion students to give in his class an auxiliary lesson and help pupils to prepare for the matriculation exam in technical drawing, based on individual guidance. He proposed at this lesson to perform exercises with 3D objects given in the matriculation exams in the last years.

Conceive. Through discussion the students identified the concepts that the pupils need to know in order to perform the exam tasks. They came to the idea that visual models of the spatial objects, that pupils need to imagine in the exam tasks, could help to overcome the difficulties. Then, the students elaborated the concept of the lesson, in which they could apply the knowledge and skills acquired in the course.

Design. The students designed with Creo digital models of the 3D objects used in the past technical drawing exams. They produced physical models of the objects using the 3D printer (Figure 1B).

Implement. Each of the students prepared a lesson plan and a PowerPoint presentation for guiding pupils individually or in small groups. The students presented the lesson plans in class and got feedback.

Operate. The students came to the high school and gave a 2 hour lesson to the pupils (Figure 2). For many of the students this was the first teaching experience.

Figure 2. Auxiliary lesson in the high school

Assessment

Students' grades in the course were based on formative and summative assessment, taking into account the following learning outcomes: understanding theories of learning, practice in computer aided design with Creo, the lesson given to high school pupils, and the lecture given to students in the high school. The student group was heterogeneous, with regard to their prior knowledge of CAD. Therefore, students' outcomes were assessed based on their progress in the course.

Results indicated that all the students acquired capabilities of correct and robust 2D sketching, solid modeling of basic shapes, and basic assembly modeling. They succeeded to prepare lectures and give them in class. The students demonstrated correct usage of 3D constraints and understanding principles of 3D printing. Above 60% of the students acquired more advanced capabilities of using advanced 3D features and tools (e.g. Pattern, Mirror), methods of parametric design, rendering and basic analyses. Two students achieved a mastery level in using modeling tools (2D, 3D and assembly), subdivision modeling, and mechanism design. They demonstrated deep understanding of 3D printing processes, high creativity, and skills of modeling complex 3D objects.

Students' reflections

Both students and pupils highly positively evaluated the lesson experience. The students noted that personal, informal connection with pupils was crucial for success of the lesson. From their reflections: *"There was even an emotional side to this collaboration. We made good connection and it helped us."* The students recognized the importance of careful lesson planning. They noticed that the 3D printed models were helpful as teaching aids and also helped to engage the pupils and "break the ice". One of students mentioned: "*The pupils said that the printed models were very cool. They enjoyed holding the model, examining it and even took photos of the models"*.

ROBOTICS OUTREACH COURSE

Participants of the course were twenty 10th grade students majoring in mechanics technology in an unprivileged vocational high school located in the Haifa's suburbs. The mechanics technology students experienced difficulties in learning technical drawing and computer drawing subjects, including spatial vision problems. To support the students and increase their engagement in learning, the school asked us to deliver an extracurricular robotics course at the Technion.

The course was given by our group at the CIM and Robotics Laboratory of the Faculty of Industrial Engineering and Management in close collaboration with school teachers who helped to organize the experimental groups in the years 2011-2012 (2 students), 2012-2013 (6 students) and 2013-2014 (12 students). The 16-hours course curriculum consisted of three parts. Each part focused on a certain aspect of robot programming and operation and on training one of the main categories of spatial ability: spatial perception, mental rotation, and visualization. The course included eight 2-hour laboratory lessons.

The first part focused on robot pick-and-place operations in the workspace and spatial perception tasks. After demonstration of an automated manufacturing process the students learned about the structure of the robot arm, the types of joints, and motion in the workspace.

Then they studied the robot control language ACL, learned to define robot positions by coordinates, and practiced in programming the robot to assemble piles from cubic parts.

The second part of the course dealt with rotation of objects by the robot and mental rotation tasks. The students learned rotations around coordinate axes, and the ways to perform them by means of the robotic arm. A cube with an arrow drawn on one of its sides was used as a test object. The students worked with the RoboCell software and practices in operating a robot in the virtual environment. Then they performed in the virtual environment an exercise of assembling a 6 cube picture puzzle identical cubes with geometrical symbols drawn on their sides (Figure 3).

Figure 3. Assembling a pile in the virtual environment

The two last lessons in the third part of the course were devoted to performing robot assembly and visualization tasks with real robots. The first task was to assemble a 6-cube picture puzzle through teleoperation. To provide visual feedback, the robot workspace was equipped by two digital cameras transmitting the images to the operator console screen (Figure 4).

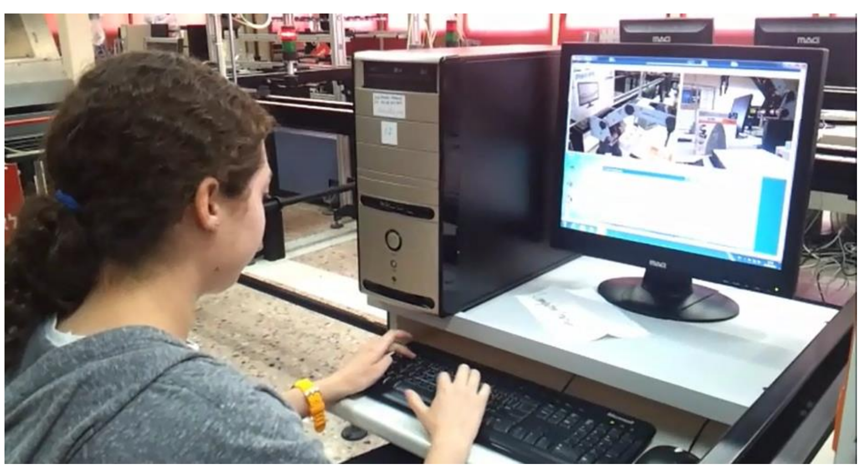

Figure 4. Teleoperation task

The second task aimed to make a connection between our robotics course and the technical drawing subject that the students studied at school. For this task the students used identical cubes, each cube with 6 different geometric figures drawn on its sides. The task was as follows: the three orthographic projections (front, top, and side views) of a cubic solid are presented in Figure 5A. Use the sketch in Figure 5B to depict a three dimensional view of the solid by drawing appropriate geometric symbols on the sides. Assemble the solid by the robot.

A. B.

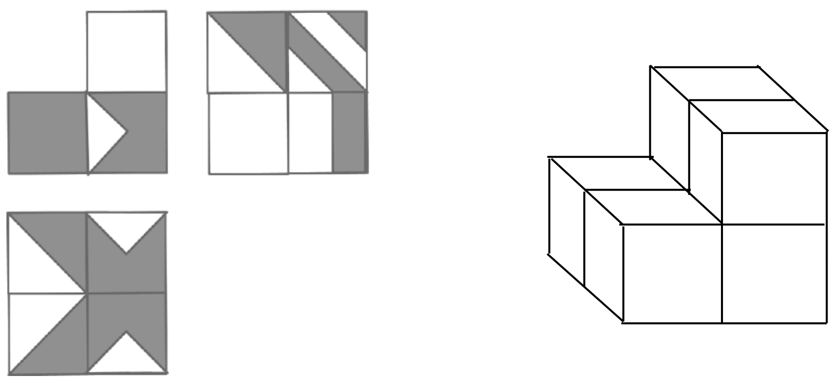

Figure 5. A. Orthographic projections; B. Solid sketch

For the third task the students used different block parts consisting of identical cubes connected together along their faces to assemble given shapes. When performing the task the students designed an assembly plan, determined destination positions of each block and operated pick and place manipulations (Figure 6).

At the beginning of the course we evaluated spatial skills of the students by means of three paper-and-pencil spatial tests: the spatial perception test, the mental rotation test, and the visualization test (Eliot & Smith, 1983, pp. 18, 290, 149).

Figure 6. Assembling a puzzle from block parts

The task of the spatial perception test was to reproduce a given pattern on the dot matrix. The test included 32 patterns to be completed in 3 minutes, and was scored as the number of correct reproductions. The mental rotation test was the same as in the Case Study 1. The task of the visualization test was to choose 2D pieces that can be put together to make a given puzzle. The test included 12 tasks to be completed in 8 minutes. The test score was the number of correct answers minus the number of wrong answers.

Outcomes of spatial learning in the course were assessed by means of interim and post-course paper-and-pencil tests. We run the spatial perception test at the end of the first part of the course and the mental rotation test at the end of the second part. The purpose of interim tests was to provide feedback for lesson planning and encouraged students' interest in the course. The post-tests at the end of the course were similar to the pre-tests. Data on students' perceptions of the course were collected by means of semi-structured interviews conducted by the school teacher. The interview questions and students' answers are presented in the next section.

Results related to spatial training can be summarized as follows:

- The pre-course tests in 2012-2013 and 2013-2014 academic years indicated that there were no significant differences in the spatial performance between experimental and control groups.
- The post-course tests showed significant advance of the students from the experimental group in the spatial perception test (19.6%), the mental rotation test (104.5%) and the visualization test (30.1%).

CONCLUSION

The update of our technology teacher education and outreach courses was achieved through development of the departmental laboratory for practice in robotics and digital design and providing the balance of learning pedagogical and engineering fundamentals with teaching practice by using the CDIO approach. The factors of this update were:

- Support of the industrial partner helped to develop the laboratory and enhance the engineering content of the course.
- Connection with a technology school enabled real teaching practice for all students in the education course.
- Purposeful productive assignments of making tangible models and using them in real practice motivate both teacher students and school pupils.
- The orientation to foster development of spatial vision skills enriched the courses and fostered motivation of the learners.
- Even basic assignments of programming and operating robots in physical and virtual environments, being focused on spatial tasks, can facilitate meaningful spatial learning of high school students.

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BIOGRAPHICAL INFORMATION

Igor M. Verner is an Associate Professor of the Department of Education in Science and Technology and Head of the Center for Robotics and Digital Technology Education at the Technion – Israel Institute of Technology. He has a secondary affiliation at the Technion Faculty of Industrial Engineering and Management. His current research focuses on design for learning in digital technology and robotic environments and new strategies for technology teacher education.

Corresponding author

A/Prof. Igor M. Verner
Dept. of Education in Technol. and Sc.
Technion - Israel Institute of Technology
Haifa, 3200003, Israel
972-48292168
ttrigor@technion.ac.il