

# Project-based High School Mechatronics Course\*

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*Mechatronics is a complex, highly technical, multidisciplinary subject that involves the design and manufacture of integrated products. In order to teach it properly in a course, student teams have to engage in designing a product. Due to the complicated nature of mechatronic products, such a project further complicates the administration of mechatronics courses. This paper presents a design of a course for non-technical high school students. The design includes elements that motivate students to devote extra hours for technology study; it leads students to successfully design products through managing a team project with little budget and scarce teaching resources. We present the structure of the course and its evaluation. We conclude that such a course can be taught to non-technical university students thus bringing them closer to understanding technology and engineering.*

## INTRODUCTION

MECHATRONICS is commonly defined as the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes [1–3]. Mechatronics is complex due to its interdisciplinary nature and its system, rather than component, orientation. Therefore, in order to understand it, one has to experience building a mechatronic product in addition to studying the relevant theoretical material. Consequently, a course on mechatronics will have to deal with complex theoretical subject matters as well as the complexity of managing a class project. The latter complexity is exacerbated due to the need to manage design teams in a tight schedule and with scarce teaching expertise.

In this paper, we describe our experience in running a mechatronics course for junior and senior high school students. We describe the course as a design problem and its solution. We elaborate the project objective with constraints and follow to articulate a course design. Next, we describe the implementation of the design and its evaluation. Most of the issues addressed in this paper are also relevant to a college-level course, in particular to non-technical students. The success of the course suggests that mechatronics could be taught to non-technical university students. The similarity between the two groups of students is that non-technical college and high school students are not necessarily motivated to learn technology, nor do they have serious technical background knowledge. Nevertheless, colleges often have

better facilities and qualified staff for teaching mechatronics.

## COURSE DESIGN AND IMPLEMENTATION

### *The foundations of the course*

The design of a mechatronics course has three foundations: theory, practice, and its dynamic nature:

- *Theory.* Mechatronics includes topics from mechanics, electronics, computers, software, and control engineering as well as system theory topics.
- *Practice.* The practice aspect of the course is divided into exercises, creative thinking tasks, laboratory experiences, and a mechatronics project. The practice learning accompanies the theoretical curriculum topics and is scheduled accordingly.
- *Dynamic nature.* Mechatronics is a dynamic, rapidly changing discipline. The real mechatronics practice requires that students have various independent learning skills. Teaching of such skills involves integrating several teaching and learning methods.

Owing to the nature of the course, project base learning (PBL) becomes the preferred teaching method, and a complex project—the thread of scarlet of the curriculum. Leifer [3] calls it product-based learning and strongly supports it as core curricula for engineering education.

### *Course goal and objectives*

The main goal of the course is a high school mechatronics study with a threaded principal idea

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of designing a mobile robot. The course objectives are:

- acquiring knowledge;
- acquiring a system thinking approach;
- improving skills of problem solving and decision making;
- developing critical and creative thinking abilities;
- developing teamwork skills;
- experiencing development of a product, with time and budget restrictions, and
- improving students' perception of technology.

Some of these objectives coincide with those of Leifer [3].

#### *Integrated curriculum*

One of the system models has been chosen as a means to design an integrated curriculum: namely 'threaded meta-curricular approach' [4]. The study of one 'principal' idea is declared as the general goal of the curriculum. In the mechatronics course, the thread of the curricula is a general cybernetics idea on universal mechanisms of control and communication in technical, biological, and social systems [5]. This idea is taught via design of a mobile robot.

The purposeful learning process includes developing of thinking skills, social skills, multiple intelligence, technology, and learning skills through various disciplines.

The course integrates not only the subject matters but also various activities including:

- frontal teaching;
- experimental laboratory;
- team and individual guidance;
- teamwork and peer learning;
- motivation exercises;
- research based on professional literature and Internet information.

Based on the above foundations, objectives, and the model, the course disciplinary and system learning subjects were developed and depicted in Table 1.

Some of these topics are taught as full-semester four-hour courses at the college level (e.g., statics or dynamics of bodies). Subjects 1.4, 2.4, 4.3, 4.4 5.3, 5.4, 6.1, and 6.2, can be considered as system topics, since they involve more than one discipline. Some additional topics are project specific:

- driving/steering mechanism;
- lit candle extinguishing;
- pyro device;
- UV controller;
- microphone driver;
- obstacle avoidance;
- sensory array;
- white line detection;
- emergency situations escape.

Prerequisites and parallel topics are derived from the course content and time limitations along with Israeli Ministry of Education requirements. Table 2 introduces the course schedule for two

Table 1. Course learning subjects

Learning subjects		Topics	
1	<i>Mechanics</i>	1.1	Materials, forces and torque
		1.2	Statics and dynamics of bodies
		1.3	Motors and gears
		1.4	Design methods
2	<i>Electronics</i>	2.1	Fundamental concepts and electronic circuits
		2.2	Components and integrated circuits
		2.3	Digital and analog electronics
		2.4	Motor control circuits
3	<i>Computers</i>	3.1	Logic and Boolean algebra
		3.2	Computer components
		3.3	Serial communication, address, data and control buses
4	<i>Assembly language and robot programming</i>	4.1	Microprocessor structure and addressing modes
		4.2	Assembly language instructions and commands, interpreter, 'high language' application
		4.3	Input/output, interrupts and communication implementation by software
		4.4	Robot control
5	<i>Control</i>	5.1	Control types
		5.2	Motor control
		5.3	Speed and distance PID control
		5.4	Robot movement closed loop control
6	<i>Robotics</i>	6.1	Robot design considerations
		6.2	Integrating hardware and software
		6.3	Sensor's types
7	<i>Laboratory</i>	7.1	Electronic PCB construction
		7.2	Designing and building a robot
		7.3	Final tests, troubleshooting, debugging and fixing
8	<i>Creative projects</i>	8.1	Practical mini project
		8.2	Theoretical mini research

Table 2. Course schedule

Week Hrs	1-4	5-6	7-9	10-12	13-14	15-19	20-24	25-32	33-35	36-37	38-39	40-43	44	45-49	50-52	53
First	2.1	1.1		1.2			5.2	5.3	6.3		6.2		6.1			8
Second	3.1		2.2			5.1	2.4	2.3			3.3	1.4		4.4		
Third	3.2					4.1	4.2			4.3						
Fourth	7.1					1.4	7.2			7.3					8	

years, four-hour weekly sessions, which is equivalent to four semester courses of four hours each.

Due to the required scientific background, the course schedule and curriculum should be planned for a period of two years including both the junior and senior high school years. This time span, which is still short, and the complexity of the project, enforces a serious time constraint. As a consequence, some of the topics that should be taught sequentially (i.e. based on prerequisites) are taught in parallel. The course complexity requires that students have self-study ability and work overtime but in a way that should not harm their other studies. These requirements mandate that the course participants are talented high school students (or non-technical college students).

In Israel, the most talented students study in general high schools rather than in vocational or technological ones. This means that such students have no technology background.

In order to convince non-technical students to take a technology-oriented course, and even to work overtime, the students' technology perception and motivation must be improved. Creative exercises and assignments related to the project and the course curriculum achieve this goal leading even to the students' demand for overtime work.

From our experience, in the last four years, students are motivated to complete their projects timely and work six to twelve extra hours per week, depending on the lab and the teacher's availability. Within very few weeks something that might be called 'a team spirit' is created, where each team member feels responsible for the success of the project and thus supports other members.

### LEARNING STRATEGY

The learning strategy is compatible with the framework of a PBL technology course [3, 6, 7] and is based on:

- Self-learning in teams and as individuals is a necessity (objectives 1–7).
- Providing the students with opportunities to apply and evaluate knowledge and methods acquired in mathematics and science (objective 2, 3, 4, and 7).
- Streamlining the learning through pragmatic activities (objective 2, 4).
- Concentrating on studies of modern technology basics, operating technological systems and design activities (objectives 1–7).

- Attracting students towards technology issues through diverse theoretical, hands-on and creative team-tasks, as in the working on the robot project for Trinity College Contest (objectives 1, 4, and 7).

### *Autonomous mobile robot project as the thread in a mechatronics design course*

An autonomous mobile robot project is a suitable platform that covers both the objectives and the curriculum. In the years 1994–1998, small groups of 2 to 3 students performed small-scale projects, like designing and implementing an interface (hardware and software) for a small vacuum cleaner, or a small manipulator.

Over the years we saw that although the students' skills and motivation improved, we still faced some difficulties. There was no common comparison scale. Some projects like a mobile manipulator were far more complicated than a robot that turned a radio transistor on and off. Other projects were small scale, so students had no opportunities for developing creativity or solving complex technology problems. Some of the projects were not close enough to real-life situations or needs and therefore missed one of the course objectives. Teams of two to three students were too small. Sometimes a mismatch between the team members could fail a project or adversely influence other team members' attitude and motivations towards technology.

A robotics contest seems to be a possible alternative for a course project. After reviewing various contests, we selected a Fire Fighting Home Robot Contest taking place at the Trinity College (<http://www.trincoll.edu/~robot>), as the preferred one for the following reasons. The students participating in teams for designing and realizing a robot face challenges of large-scale projects. This project approaches the complexity of real-world projects. Therefore, it requires a high level of mechatronics interdisciplinary integration and consequently large teams. The project gives more opportunities for creative and inventive solutions to various technological problems; it simulates a real-life situation (the robot is intended for extinguishing fires at home), and covers all objectives stated above.

We have decided not to deal with FIRST contest as it involves using non-autonomous robots with simple subsystems. This contest would be an excellent choice for the beginners level at elementary and junior high schools, as it introduces

a technology project of an intermediate level, advancing creativity.

The contest-oriented course has advantages and disadvantages, some of which are summarized below.

#### *Advantages*

- Exposing the students to a variety of technologies and solutions that they would not see otherwise and that have a great importance in mechatronics. Preliminary design steps, such as problem analysis, legal, social, economic and technological feasibility study, the problem partitioning, selection of architecture and product evolution planning require very broad socio-technical knowledge. Even traditional specialists in the mechanical or electronic engineering are not well prepared for these tasks [2].
- Expanding the students' knowledge through interaction with high level and complicated projects. Complex mechatronics projects enable the students to practice more technical problems and thus to improve their decision-making skills, conduct research; learn to work as team members, and have peer evaluation.
- The students' satisfaction is meaningful when the project is done, serving as a factor to motivate further learning.
- Strict time limits force the students to find solutions quickly, bringing out creative ideas. There are additional advantages that are not directly related to the learning process improvement, but have a positive impact on outside systems.
- Most of the students that are involved in the project intend to continue study or work in technology.
- The students improve their social acquaintance with other students dealing with similar topics.
- The students obtain access to experts and leading academic and industry specialists (advisors and observers).
- The school conducting the project gains the prestige that attracts students; even those who initially, do not intend to learn technology or science.

#### *Disadvantages*

- The students have a strong motivation to win the contest. Consequently, some other subjects can become less attractive and less worth investing for the students.
- Equipment for participating in the contest is quite expensive.
- Sometimes, during the project, the mentor or the team finds that some of the team members are not suitable professionally or socially, thus affecting the student's learning in general. While we wish to minimize this effect, sometimes it is too late to change the team.
- There is a constant shortage of teachers and tutors qualified to handle the subject matter

and teaching methods, and thus only a limited number of schools can participate in the program.

- A possible failure to complete the project or to take a reasonable place in the contest may lead to disappointment and thus to deterring students from technology.

#### *Constraints and restrictions*

After seven years of implementing the course, several limitations become apparent.

- There is a constant shortage of well-educated teachers that can handle the subject matters covered by the course.
- The interdisciplinary course requires good understanding in various engineering fields and on top of that, the ability to integrate various disciplines in one system.
- The complexity of the robotics project makes it very hard to complete without overcoming numerous failures and faulty functioning.
- A two years term is insufficient for such course; therefore extra time is needed as described before.
- High school students lack a technical background. This necessitates a conceptual cognitive change in the students' attitude, which is not easy to achieve.
- The work in the team creates a challenge to the students that are not used to share ideas and to get criticized by their own friends. They eventually have to accept at least some of their friends' ideas as solutions to specific tasks.
- Budget for the equipment is more limited in high schools, than in technological or vocational schools.
- The students participating in the course are usually advanced students, so their efforts and various time consuming activities do not affect other school assignments. Participation of regular students in the course may harm their success in other school subjects.

## COURSE EVALUATION

Nevo's [10] project evaluation structure was adopted. Pre/post attitude questionnaire results for 141 students learning at 5 high schools in the years 1997–1999 and personal interview with six matriculate students reveal the following findings [8, 9]:

- The students recognized the importance of complementary technology knowledge acquired in the course.
- The students became interested in engineering studies.
- The initial motivation factors include experimenting with creative technological activities, curiosity in a technology subject matter broadening the individual knowledge.

Table 3. Course evaluation

No	Objective summary	Degree of achievement 1 ÷ 5, 5 very good	Evaluation method
1	Acquiring knowledge	5	Average grade of more than 90 in matriculation exams.
2	Acquiring system approach thinking	4/5	Mentors' opinion and high scores in robotics contest.
3	Improving problem solving	5	Mentors' observation, students' interviews, and contest scores.
4	Developing critical and creative thinking	3	Students' reports, attitude questionnaire and mentors' observations.
5	Developing teamwork skills	4	Students' attitude questionnaire, interviews and mentors' reports.
6	Developing product with time and budget restrictions, and with 'Real-world' technological problems	5	Project restrictions; project is very close to other known commercial products like lawn-mower robot and many others.
7	Improving technology perception	5	Mentors opinion and students attitude questionnaire [8, 9].

- Among the reasons to take this course were: it is more interesting than other subjects; it is a combination of a thinking challenge and the technological creativity; watching robots created by other students; the course objectives; relevant technologies covered by the course.
- The students recognize a substantial difference between the science and technology disciplines in both the essence and the learning styles. In contrast to science, technology is more experience and practice oriented, gives satisfaction for creative tasks implementation, creates personal cooperation channels between teacher-student and student-peers, develop teamwork skills, and make students familiar with real design processes in engineering.
- The necessity to understand the system behavior and the need to complete the practical project on time motivated the students to learn theoretical subjects.
- The contest oriented mechatronics project proves to be quite efficient in increasing the motivation of non-technical students, thus preparing them to spend extra hours on the course.

Since 1999, our students participated regularly in the international Fire Fighting contest at Trinity College. They succeeded very well as reflected in the 1st, 3rd, 12th places, etc., among (approximately 40 participants) in the 2000 contest; the 2nd, 7th, 8th places, etc., among 40 participants in the 2001 contest; and the 1st, 2nd, 4th, places, etc., among 73 participants in the 2002 contest. These successes suggest that the course presented here is an excellent learning environment for studying and experiencing mechatronics.

We have stated the main goal and the derived objectives of the course. In Table 3, we summarize the students' achievements.

Table 3 shows that the course achieved most of its goals. We observed that students still make many mistakes that cause problems (which they solve eventually). There is a gap between their theoretical exam scores and their project's success in contest. Many robots do poorly or even fail to work in the contest, even though they had succeeded in several preliminary tests. This causes us to search for a method that can be helpful in avoiding the majority of these mistakes.

## CONCLUSIONS

Our experience leads to the following conclusions:

- The course presented here is a model of a mechatronics course for non-technical students. It can increase the awareness of non-technical students to technology and technology practice.
- Motivation for technical study of the participant students was increased.
- The breadth and scope of the course material cannot be covered adequately in the allocated two-year term; therefore, extra hours of work are needed.
- Contest is an important means for motivating students for extra hours of work.
- Our extended good experience shows that non-engineering major or minor students can study mechatronics if the course is properly designed and managed.
- The course improvement, as we see it for the time being, should concentrate on improving the project design and creativity thinking. One promising possibility for the project design improvement seems to be studying various creative-thinking methods.

## REFERENCES

1. A. Moshaiov and K. Okyay, Socio-mechatronics in the era of information technology, *Proc. 1st Int. Conf. Information Technology in Mechatronics (ITM01)*, Istanbul, Turkey, (2001).
2. G. Rzevski, (Ed.), *Mechatronics: Designing Intelligent Machines, Vol. 1, Perception, Cognition and Execution*, The Open University/Butterworth-Heinemann Ltd., Oxford (1995).
3. L. J. Leifer, *Evaluating Product-Based-learning Education*, Osaka '95 Conference.
4. R. Fogarty, A faculty can easily work with the 10 models over time to develop an integrated curriculum throughout the school, in: *The Mindful School: How to integrate the curricula*, Skylight Publishing Inc. (1991).
5. N. Wiener, *Cybernetics or Control and Communication in the Animal and the Machine*, Cambridge, MIT Press (1961).
6. L. Schachterle and O. Vinther, Introduction: The role of projects in engineering education, *Euro. J. Eng. Educ.*, **21**(2) 1996, pp. 115–120.
7. M. Robinson and M. S. Fadali, A model to promote the study of engineering through a capstone course for pre service secondary science and mathematics teachers, *Proc. 1998 IEEE Frontiers in Education Conf.*, Arizona, pp. 1166–1171.
8. I. Verner, S. Waks and E. Kolberg, Upgrading technology towards the status of high school matriculation subject: a case study, *J. Technology Education*, **9**, 1997, pp. 64–75.
9. I. Verner, S. Waks and E. Kolberg, Educational robotics: an insight into system engineering, *Euro. J. Eng. Educ.*, **24**(2) 1999, pp. 201–212.
10. D. Nevo, *School-Based Evaluation*, Elsevier Science (1995).

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