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DESIGING DESIGNERS

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1 Introduction

"What does it take to become a great designer?" It is difficult to answer this question. An easier task is to recognize great designers based on their past work; notable examples are Leonardo de Vinci and R. Buckminster Fuller; if we leave aside such obvious examples, the next task we could agree upon is to mutually appreciate specific design products. It is much easier, even though not simple, to appreciate specific product instances than to recognize good designers, than to know how to foster design capabilities. We address the above challenge within an educational setting by asking "What does it take to teach students to become good designers?"

Being design researchers, we addressed this question as a design problem. We first, specified from our own perspective, and after conducting a thorough review, what a good designer is; other perspectives regarding the properties of good designers could be incorporated similarly. Second, we designed a teaching process that would lead students from being design-illiterates to being capable designers. Third, we tested our process in multiple ways in a particular context and found that it led to superior results compared to other processes. In this testing we had to find ways to evaluate students as designers and evaluate design products. Our experience leads us to propose a general way to design teaching processes for different contexts. We intend to test this approach in the future.

In addition, designers do not finish learning when they graduate from school. In fact, much of the learning takes place subsequent to graduation, while practicing design. Consequently, our long-term goal is to develop methods for designing life-long learning experiences.

Figure 1 describes the roadmap of this study. It is composed of theory development and course design followed by course implementation. The results of the course feeds back into the theory development and course redesign. The theory underlying the course design is a synthesis of ideas, drown from different disciplines: design, education, cognitive psychology, systems engineering, and social science. These disciplines provide the guidance in the course design, its implementation, and testing. The course design starts from requirements that are translated into course goals to be addressed by a detailed curriculum. This curriculum is implemented and tested. The results lead to reflection that helps improve our understanding and course design.

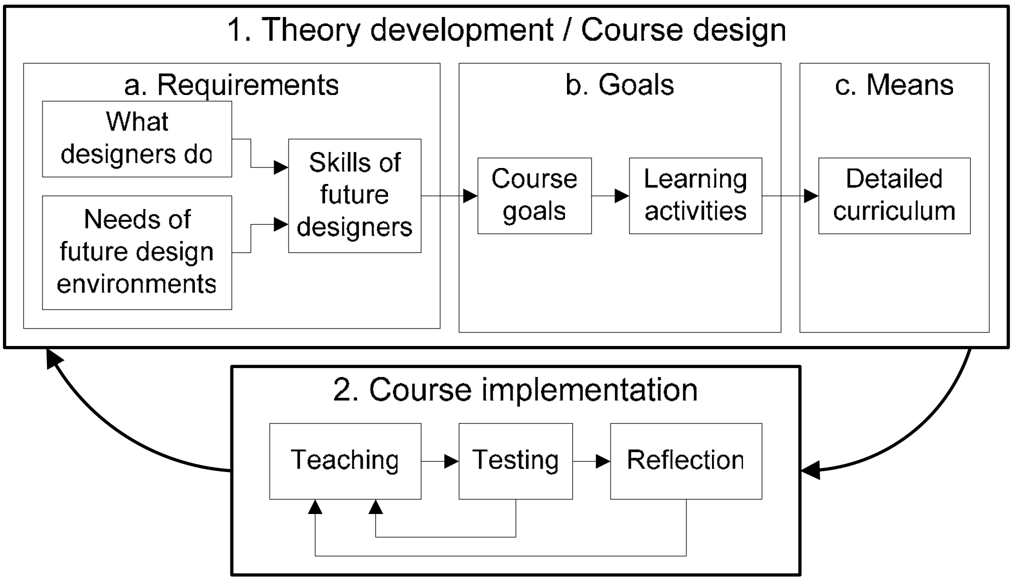

Figure 1. Roadmap for designing designers

There have been hardly any other studies in design education that used structured design methods that originate from engineering to create a curriculum (e.g., Kaminski et al., 2004; Martin and Ishii, 1998). This is unfortunate because design researchers that do not use their own methods when they could be applied to their own problems, loose the basis for asking others to use their methods (Reich *et al.*, 2005). There have also been many studies on the design of curriculum in education and other fields (e.g., Barrows, 1985; Clark, 1997; Diamond, 1998). Nevertheless, we are not aware of a single study on teaching design that was performed on a large scale, tested in a controlled experiment, and produced conclusive results as the present study. In Kolberg *et al.* (2003) we presented the previous design of the course which was done without structured design methods (see 1 in Figure 2). That design was driven by the subject matter of mechatronics and utilized a project-based learning (PBL) approach. That design was quite successful in achieving its original goals (Kolberg *et al.*, 2003). The present design (2 in Figure 2) uses structured design methods to redesign the class. Using these methods, we made choices regarding the incorporation of several design methods into the curriculum (Kolberg *et al.*, 2005). In this paper we focus on the overall course philosophy and design and provide recent analyses that support the further improvement of the present design course over the previous. Given that this improvement is an addition to the benefits of the previous course design, the results are very promising. In the future, we intend to further improve the way we design the course and test it (3 in Figure 2).

The paper follows the roadmap. We define the product of our design as student with particular design capabilities. Section 2 defines the requirements of the product and translates them to course goals. The course to be designed is a process that takes students unfamiliar with technology without engineering background and transforms them into designers. Section 3 reviews our theoretical foundation that provides the basis for the solution. Section 4 describes the solution process – the course design – and section 5 discusses its testing. Section 6 discusses designing courses for different contexts and section 7 concludes.

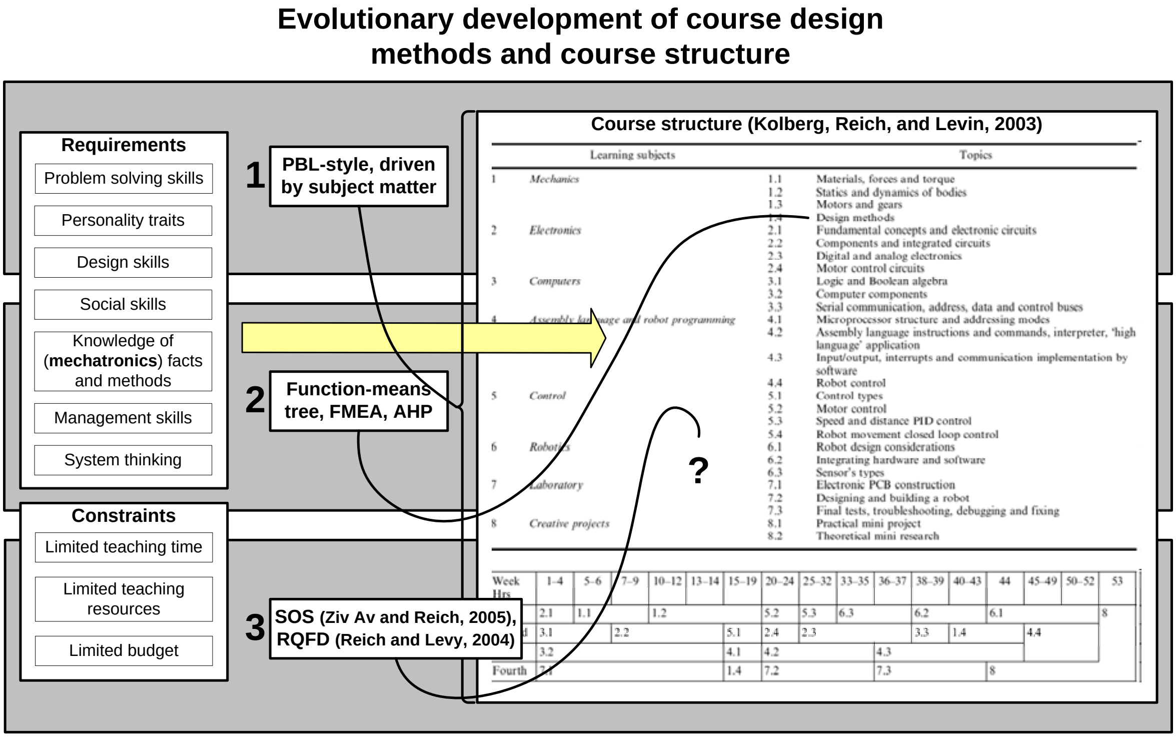

Figure 2. Evolutionary development of course design methods and course structure

2 What make a good designer?

The starting point of any solution is a well-posed problem. In design however, we know that problems are often ill defined and the solution evolves with the problem definition. Therefore, the problem defined here is as it was defined when we set to solve it in 2002. Our question was what are the important qualities of a good designer? In particular we were interested in the good qualities of mechatronic designers.

One could identify qualities of designers and establish teaching program by studying design (Cross, 1900). Cross identified four skills designers employ: solving ill-structured problems, using solution-focused strategies, employing abductive reasoning, and using non-verbal communication. These skills could be nurtured through education. Table 1 shows the differences between the traditional disciplines of art and science and design. Design is not a combination of the two but involves traits specific to it. Therefore, its teaching would be different that traditional modes of teaching and learning.

Table 1: Differing characteristics of art, science, and design (after Cross, 1990)

	Fields of knowledge	Range of values	Types of skills
Art	Human experience	Subjectivity, imagination, emotional, concern for “justice”	Criticism, analogy, evaluation
Science	Natural world	Objectivity, rationality, neutrality, concern for “truth”	Experiment, classification, analysis
Design	Artificial, human-made world	Practicality, ingenuity, empathy, concern for “appropriateness”	Modeling, synthesis, pattern forming

In a recent analysis, Cross (2001) elaborated on his observations about the nature of design by summarizing empirical studies reported during the period 1970 to 1999 in diverse disciplines. Designers seem to be “ill-behaved;” they might even treat well-structured problems as ill-defined in order to solve them. Experienced designers use solutions to guide them through the process. They constantly evolve the problem formulation with the solution progression. If necessary, they generate new problems and frame them to suite their needs. Designers behave differently when they generate solutions; some get fixated or become attached to a single solution early in the process, while others creatively generate alternative solutions. Designers are often opportunistic and change their strategies as required by the problem.

Out approach to analyze the skills of designers was similar except that we focused not on what could be learned from past empirical studies but what would be the skills required of designers in the future. These skills are derived from the nature of design as well as from the challenges that designers would increasingly face due to changes in product design practices. These new practices involve collaborative work across time and space, continuous learning due to technological advancements and system thinking. From previous studies and projecting on the future of product design, we developed a list of skills that a good designer should have:

1. General problem solving and learning skills. We expect students to have basic skills that might need improvement.
2. Basic personality traits – a designer will be mediocre without motivation or curiosity.
3. Design related skills: (a) Ability to synthesize and evaluate solutions to practical problems – this includes understanding the needs of practical situations (anticipate failure, foresee interactions and interferences, and accommodate changes); (b) Decision making (many times in uncertain situations). These skills overlap with Cross’ list of skills.
4. Social skills – Designing a real product involves a design team; each team member has to communicate with others, accept different ideas, and help and get help from teammates. The team should works like one entity for achieving the desired goal.
5. Knowledge of facts and methods relevant to the design subject matter – these could differ between different engineering disciplines even though they share much in common (Shai and Reich, 2004a,b).
6. Basic management skills (time, resources).
7. System’s thinking skills – the ability to analyze a problem as a system with environment and components and their interactions, and to adapt as the environment and the system change.

This list is expected to evolve to accommodate new perspectives of and insight about product design. A recent Delphi study that analyzed the competencies designers ought to have in the forthcoming decade (Robinson *et al*., 2005) found a similar profile consisting of 42 competencies divided into the following six competency groups (in descending order of criticality; in parentheses we list our corresponding skill category):

1. Personal attributes (2, 4);
2. Project management (6);
3. Cognitive strategies (1, 3);
4. Cognitive abilities (1, 3);
5. Technical ability (5); and

6. Communication (4)

Although the competencies are structured differently, aside from our system's thinking skills, there is significant overlap in the basic competencies and the categories. Another survey related to manufacturing engineers found similar results even if with different importance levels (Saunders and Saunders, 2004).

Our seven-item list of desired skills translates into the following course goals (in parentheses we list the designer's skill or trait that the course goal supports):

1. Acquiring technical knowledge (5);
2. Acquiring a system thinking approach (7);
3. Improving skills of problem solving, decision making, and learning (1, 3);
4. Developing critical and creative thinking abilities (1, 3);
5. Experiencing development of a product, with time and budget restrictions (3, 6, 7);
6. Developing teamwork skills (4); and
7. Improving students' perception of technology (2).

These goals are described as goals of learning activities that should be incorporated in the course. So far we did not take into account the subject of the design course: mechatronics. Fortunately, mechatronics products are classic examples of contemporary designs; therefore, the subject – mechatronics – does not change our analysis. It merely fixes the task of acquiring technical knowledge to deal with mechatronics related subjects.

3 Theoretical foundation

3.1 How people learn?

In order to address the aforementioned requirements, a learning environment must be designed. This requires intimate understanding of how people learn in general, and subsequently, how they might learn to become designers. Recent reports provide an excellent start for gaining such understanding and its consequence to education practice (Bransford *et al.*, 1999; Donovan *et al.*, 1999). People's learning rests on three foundations. First, students come to learn with preconceptions. This means that teaching must start from existing body of student knowledge and also incorporate broader issues such as the culture of students and their inclination to learn in group or individually. Correspondingly, assessment must start from the beginning in order to appreciate students existing knowledge; it must be done in a learner's friendly approach to further encourage learning.

Second, any learning must involve strong factual knowledge, within a conceptual framework that allows its organization. This requires that in-depth coverage of material be experienced rather than broad superficial coverage. It also mandates that the facts and methods be organized in a conceptual framework to assist in their integration into students existing body of knowledge. Third, metacognitive skills including self-monitoring and reflection allow students to take control over their learning experience. In addition to the three foundations, it must be acknowledged that any learning occurs within a context that includes the community around the classroom. This community establishes norms and values that shape the learning setup. For example, there could be communities that promote cooperation and others that encourage competition.

Altogether, these reports offer a pragmatic and theoretically grounded framework for designing learning environments. Notwithstanding, the list of research issues they compiled demonstrates that our understanding is far from complete and there is still a gap between the framework and education practice.

3.2 Philosophical position

A different approach for guiding practice is by adopting a philosophical position regarding knowledge. The main contesting paradigms in many disciplines including education have long been objectivism and constructivism (e.g., Guba, 1990; Reich, 1994). To illustrate these two paradigms, consider a museum as an educational environment. Most museums operate assuming the traditional objectivist mode of learning where people visit and observe exhibits. Exceptions are museums such as San Francisco's Exploratorium. These museums are founded on the constructivist philosophy. The focus is on the learner and knowledge is gained through creating meaning from experience (Hein, 1995). This example is particularly compelling since learning to design requires even greater involvement than being educated about technology. It is becoming apparent that constructivism takes a leading role in shaping education in general and design education specifically. Also, constructivism is in line with systems theory perspective of education (Banathy, 1999).

Hein (1991) provided a list of propositions related to education that underlie constructivist thinking:

1. People learn to learn in the process of learning.
2. Acting is insufficient for constructing meaning, the latter happens in the mind.
3. The language used in learning has impact on the learning activity.
4. Learning is a social activity involving students, teachers, peers, and others.
5. Learning is contextual: we learn facts, theories, and methods in relation to our existing knowledge and believes.
6. Consequently, one needs knowledge to learn.
7. Learning is an effortful activity.
8. Understanding the purpose of learning and other motivating factors are essential to learning.

This list is very much in tune with the three foundations of learning derived from "how people learn" and their consequences.

3.3 Teaching strategies

There are many teaching strategies that could be used. Donovan *et al.*, (1999) argues that there is no strategy that is better than others. This is in line with our position (Reich, 1994) to bypass the debate between different paradigm while adopting a pragmatic view that the particular context and our understanding of how people learn determine the philosophical position and the effective teaching strategy. A teaching strategy that maps directly to constructivism, system thinking perspective, and the foundations of people learning is project-based learning (PBL) (Barrows, 1985; Dym, 1999, 2004; Leifer, 1995; Leifer and Shepard, 1998; Kolberg *et al*., 2003). In particular, PBL involving multidisciplinary projects such as mobile robots shape a pedagogical environment with the following desired features (Kapila and Lee, 2004; Piepmeier *et al*., 2003; Ruiz-del-Solar and Aviles, 2004):

1. Integration and cooperation –The expectations of the students and their cooperation with their team members and teachers create highly responsible learning environment.
2. Motivation – the students are responsible for the result and not the teacher. There is not an external authority to tell them what to learn each hour. The motivation for learning can be divided into six factors:
   1. Positive attitude towards the learning, the subject and the method
   2. Awareness to the practical needs and the value of subject matters
   3. External urge factor of the learning results
   4. Positive emotions within the learning process
   5. Competitive reward achievement
   6. Strengthening of the learner abilities and skills
3. Relation and experience – real world projects make students aware of the demands in industry; through projects they gain valuable experience
4. Teamwork – it is usually impossible to execute the project with one person. The students learn to share ideas, tasks, and to accept others ideas and make compromises in order that the group will work as efficient as possible to achieve the goal
5. Open-ended problem solving – browsing in the class textbook cannot solve complex problems. Problem solving is a central issue in the evolutionary learning process. Developing the ability to identify various approaches to a problem, creating solutions and improving them with relation to multiple criteria are vital in engineering. It goes with identifying objectives from a problem specification, determining variables to be sensed and manipulated, deriving interface requirements for sensors, actuators, analog and digital electronics, and microcontroller hardware
6. Tight time restrictions – time planning and schedule design is an important issue. There is always a deadline, which no activity takes place afterwards
7. Communication skills – convincing their teammates to prefer certain solution, to argue before their friends and teachers, to get sponsors, to present the project report, and more, requires good communication skills
8. Interdisciplinary – each project, nowadays involves several engineering and science domains. The students integrate theoretical and experimental knowledge coming from various engineering fields
9. Flexibility – PBL allows internal flexibility within the curriculum. The projects allow for the students an access to the very new technologies without being dependent in the long process of redefinition of the curriculum
10. Producing artifacts, which someone will use – projects must lead to a result, a product that can be tested and that someone will want to use. The functional implementation of the robot allows for bringing the students to actual subjects they face in their life

11. Continuous active learning for a life time – the world is ever changing and there must be a continuous learning in order to be updated

It is clear that PBL is an excellent match to the aforementioned ingredients of constructivism. There are other teaching methods or learning activities that might be appropriate for different topics including:

1. Frontal teaching;
2. Experimental laboratory;
3. Team and individual guidance;
4. Teamwork and peer learning;
5. Motivation exercises; and
6. Research based on professional literature and Internet information.

4 Solution design: The design of the teaching process

If the skills we previously listed are requirements of the "product" – the designer, we should ask what would be the process by which such a product is created. Developing such a process is clearly a design problem. Therefore, we arrive at the central theme of this paper: how do we design designers?

The requirements of the design were given in Section 2. The constraints on the design were:

1. Limited teaching time
2. Limited teaching resources
3. Limited budget

In order to meet the requirements under the constraints, we used function-means trees (Hubka and Eder, 1988), FMEA (failure Mode and Effect Analysis) and AHP (Saaty, 1980) to drive the design. Figure 3 shows part of a function-means tree. The functions on the left are translated into means on the right. A more detailed analysis could be performed to do this translation by using two Houses of Quality. The first one would translate from the required designers skills to the course goals in the middle; and the second would further translate into the means.

The second method we used, FMEA, led to identify several additional methods that could have significant impact on improving the design of robots:

1. Creative inventive thinking method (ASIT; Horowitz, 1999)
2. Atomic Requirements tool (ATR; Salzer, 1999)
3. Fault tolerance design method
4. Fuzzy logic tool

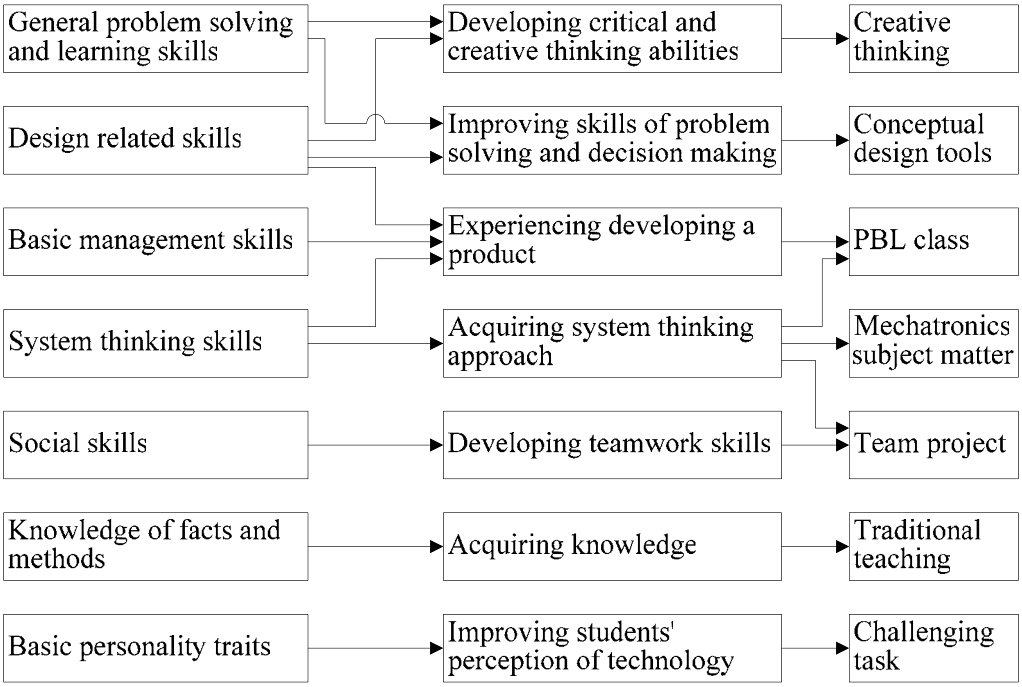

Figure 3. Course design: influence of requirements on means

Subsequent to identifying the design methods, two experts used AHP to prioritize the methods in order to allocate them the necessary teaching resources. They agreed that conceptual design is the most important method (importance 42.3% out of 100% for one expert and 34.0% for the second)**.** The method with the second importance was fault tolerance and testability (18.6% and 22.0%, respectively). The expert agreed on the following four methods but differed in the order of importance they assigned to each. Nevertheless, the expert assessment and our own judgment were quite consistent. After the relative importance evaluation, and given the stringent teaching hours limit, we decided to teach subsets of these design methods that deemed critical to the robot design or that would contribute significantly to other course goals.

All design methods and the projects help developing students’ problem solving skills:

1. Conceptual design is the basic design method; it places things into order, so problems in specific parts can be tested in relation to their position in the system.
2. ASIT creative thinking method is a systematic method for creative thinking, which is designed especially for problem solving.
3. ATR design. Dividing the requirements into atomic ones, help the students see the detailed requirements, which can show conflict requirements, similar requirements, etc. In the debugging mode, and problem solving, each requirement can be tested easily separately. That is because an atomic requirement is very simple to test.
4. Fault tolerance design introduces the students with possible faults during the design phase. That improves their ability to identify problems and overcome them.
5. Microprogramming design allow for designing the robot control by moving between two different representations that make it easy for designing, debugging, and coding, simultaneously (Levin et al., 2004).

6. Fuzzy logic helps in simplifying things related to motors control. It is more straightforward and can be checked in an easy way, compared to other control methods.

Social skills are developed within several levels. First, teammates have to discuss and change ideas between them. They have to decide upon many sub-systems after they hear each other and agree upon the chosen system or part or function or method. They also have to present their work in front of an inspector from the Ministry of education. They also work together lots of hours and help each other. The students gain their theoretical knowledge of mechatronics facts and methods by theoretical learning of technology and science subjects.

Management skills are developed when conceptual design is implemented. There are timing consideration management, task management and other management related subject within conceptual design planning. Gantt chart is an example. Each team has to manage its resources in all aspects. The contest date is known and the robot must be prepared to the contest.

The limited teaching time constraint allows only for short introduction of design methods; this is partially remedied by the use of mentors at least in the first part of the course. The time for teaching the design methods is added to the course schedule but it is not too much. Limited teaching resources can be overcome by writing a book that explains the methodology and how to implement it. Training sessions for new teachers would also minimize this constraint.

Prerequisites and parallel topics are derived from the course content and time limitations along with Israeli Ministry of Education requirements. The course schedules for two years, four hours weekly sessions, which is equivalent to four semester courses of four-hours each. This time span, which is still short, and the complexity of the project, enforces a serious time constraint. Consequently, 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). The learning strategy is compatible with the framework of a PBL (Project Based Learning) technology course

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. The robot building project approaches the complexity of real world projects. Therefore, it requires a high level of mechatronics design and interdisciplinary integration and consequently large teams. The project gives more opportunities for creative 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.

5 Testing the teaching process

We tested the process at several levels through a controlled experiment study involving 104 students in four high schools. All the students had general scientific background and they participated in a mobile robot project. Schools were located within the center of the Israel and are named A, B, C and D. Some of the teams (50 students) produced fire-fighting robots (ffr) and some (54 students) produced other mobile robot projects. Table 2 presents student numbers in each school with the relevant projects.

Table 2: Students participation in the experiment

School	Students participating in ffr	No of teams ffr teams	Students participating in other robot project	No of students in other robot projects
A	20	2	-	-
B	14	2	29	2÷4
C	6	1	25	2÷4
D	16	2	-	-

The different schools received different training:

1. School A was taught the complete suite of methods;
2. School B was not taught ASIT and microprogramming design, while ATR was taught as a regular documentation requirement;
3. School C was taught only conceptual design; and
4. School D was taught no method.

Schools that were not taught a particular subject got other material instead to balance the hours of frontal teaching. This setup allowed us to assess the impact of different course designs on the course goals. The tests were subdivides into three levels. First, at the objective general level, the scores of the students in related disciplines improved compared to those that studied part of the methods and those that did not study any design method.

We performed several statistical analyses to see the effect of the different curricula on the scores student achieved in the different science disciplines (mathematics, physics, and chemistry). We eliminated the effect of the differences in the pre-course grades. The results of a paired samples *t*-test with significance of 5% (conservative), shows that for each science subject analyzed separately (again conservative), *students that studied more design methods, improved their grades more than those who studied less design methods*. This demonstrates that the design course teaches skills that improve general academic performance and might extend to other subjects than those tested. This is a significant benefit in today’s turbulent technological world.

Second, at the objective particular level, we tested particular design skills by students’ success in a design contest, expert evaluations of the designs, design tests, peer evaluations, and attitude questionnaire. Presently we only have partial evaluation of the results. They point to the same conclusions. For example, in the international fire fighting competition held on April 2004 at Trinity College, Hartford, CT, team from school A won 1st prize, team from B, finished 6th, from C, finished 14th, and from D, finished 16th place. The second team from school A did not participate in the contest due to misunderstanding in the registration although they travel from Israel to the US to participate. Nevertheless, their robot was tested under the contest conditions in the same arena and got score that would have given it 2nd place in the contest. The other two ffr robots did not travel to the international contest due to lack of funding.

The expert evaluation was corresponding to these results. The success in the contest shows that the particular process indeed makes a difference in creating designers with an understanding of addressing real design situations with state-of-the-art design tools like microprogramming and fault tolerance methods (Levin *et al.*, 2004) along with various conceptual and detailed design methods. Initial examination of the other data suggests the same direction but we have not yet analyzed the results. Third, at the subjective level, we interviewed the students and got their opinion on the process and on their design skills improvement as they see it.

It seems that the course had a good balance between the teaching of subject matters, design activities, and product construction. It enabled students acquire the skills mentioned before. Altogether, our design, the course plan, succeeded in delivering the required results. Students improved their problem solving skills, improved their attitude toward technology and showed unsurpassed motivation. They demonstrated design skills and through extensive teamwork, improved their social skills. Students master systems view of mechatronics products and the related factual and method knowledge. They came to appreciate the importance of managing time and other resources for the successful and timely completion of the robot. To summarize, *the designers that we designed succeeded in their design tasks*.

6 Context dependent design of a teaching process

There are differences between the educational contexts of different schools. For example, some schools do not have teachers knowledgeable in all needed subject matters and some would not have a laboratory infrastructure. The available facilities and resources change the teaching activities that could be planned and therefore, impact the course results. Therefore, for each such context, a different educational process and content might be most suitable. In the future, we intend to use a general concept and configuration generation method – SOS (Ziv-Av and Reich, 2005) – together with a flexible resource allocation tool – RQFD (Reich and Levy, 2004) to set up the appropriate course structure for each context in order to maximize the course objectives.

SOS would analyze the available resources and maximize the course objectives with the available resources. This will create a list of subjects and design methods to teach in class. Subsequently, RQFD would be used to assist allocating the time for each subject in order to maximize the course objectives.

The same approach would also allow for making changes to class material while the course is running. Such unforeseen changes could result from sudden budget cuts, difficulties running laboratories or new laboratories that become available, as well as teachers leaving or joining the school system. While the focus of this paper has been on designing high school designers through designing high school curriculum, we envision that similar results would be obtained if the same methods are applied to universities or industry.

7 Future course improvements

In the future, we are considering incorporating SOS as a concept generation tool. It supports system perspective, incorporation of multiple objectives, and available technology for maximizing product goals. In preliminary exercised we conducted, we were able to converge quickly to conceptual robot designs that are known to be superior.

Other opportunities arise without planning. Any design has side effects. Some are bad and some are fortunate. Our course design has some fortunate results. These results emerge from some of the properties of the design methods we chose to teach; these methods allow appreciating issues beyond their original role. For example, fuzzy logic allows appreciating that mathematics is not always about precise numbers. In fact, much engineering reasoning is qualitative and imprecise. Fuzzy control demonstrates that imprecise concepts lead to very robust behavior in uncertain environment that is relatively easy to attain. This insight about mathematics could be a revelation for students.

Fault tolerant design brings insight into the difference between products that are designed according to requirements, and robust products that can stand faults up to a certain degree. This allows students to understand the concept of redundancy and anticipating failure since reality is so complex therefore, we are unable to foresee all potential situations.

Microprogramming design shows the students that there is a duality between two representations of control schemes and that even though it is more “natural” to use one to describe the robot operation, it is better to use another in order to be more robust and efficient. Demonstrating the multiplicity of representation or perspective and the lack of superiority of one in all situations is a very important concept. In addition, students see that it is possible to combine two or more control schemes and save resources; meaning, forming a “team” of methods could be a powerful problem-solving principle.

Presently, the students experience these additional insights but they are not being tied into a general framework to allow their full appreciation. An addition of such topic is also considered for the course.

8 Conclusions

Key to designing designers is a good understanding of what design practice is and would be in the future, in order to prepare designers to participate effectively in it. Based on our own design and teaching experience, we derived a list of skills designers should have. We then used the most recent thinking about human learning, teaching methods, and other related disciplines as the basis for designing a course that would take high school, design-illiterate students and transform them into capable designers. This transformation had positive effect on general academic skills of the students.

The design of the course used several structured design methods. Their use in the design process allowed us to go from course goals in a systematic manner to the means to attain these goals. We further discussed the future improvement of this course design method to further improve the course.

We discussed the implementation of the course design and the results demonstrating its significant impact (e.g., improved academic performance, winning first and other good places in an international robot contest, and improved technology perception). Since design is context dependent, our study should be considered in its context, namely, designing mechatronics designers who are high-school students that are expected to design, produce, and operate a mobile robot in robot competitions. Nevertheless, we contend that the same approach would work for other design disciplines and for universities as well as industry.

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