A NEW PERSPECTIVE TO DESIGN EDUCATION IN INDUSTRIAL ENGINEERING: PRODUCT DESIGN PROJECTS AT FRESHMAN

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ABSTRACT

This paper describes an introductory project-based engineering design course for the industrial engineering freshman students. An innovative approach is preferred in this course and students in the form of design teams are required to design and construct working prototypes for predefined "physical products". This course brings a new perspective to the industrial engineering education, which is mainly focused on designing "systems" rather than "physical products". It is argued that this "product design" experience improves understanding of the industrial engineering students "systems approach" at an early level and provides students with a strong foundation on designing systems in the future.

Keywords: Design education, industrial engineering, product design

ENDÜSTRİ MÜHENDİSLİĞİNDE TASARIM EĞİTİMİ İÇİN YENİ BİR YAKLAŞIM: BİRİNCİ SINIFLAR İÇİN ÜRÜN TASARIM PROJELERİ

ÖZET

Tasarım felsefesinin mühendislik eğitiminin ilk yıllarında verilmesi, öğrencilerin lisans programında gördükleri çeşitli kavramların/yöntemlerin mühendislik tasarımı ile ilgili problemlere nasıl çözüm getirdiğini anlamaları bakımından büyük önem taşımaktadır. Bir sistem ve insan mühendisliği olan endüstri mühendisliği, profesyonel anlamda fiziksel ürün tasarımından çok sistem tasarımına yönelik çalışmalar yapmaktadır. Bu nedenle endüstri mühendisliğinde tasarım eğitimi daha çok sistem tasarımına yönelik projeler/uygulamalar ile gerçekleştirilmektedir. Bu makalede yenilikçi bir yaklaşımla geliştirilen ve endüstri mühendisliği bölümü birinci sınıf öğrencilerinin ürün tasarımına yönelik açık uçlu projeler yaptığı tasarım dersi anlatılmakta ve bu dersin yedi yıllık uygulaması ile ilgili değerlendirmeler sunulmaktadır.

Anahtar kelimeler: Tasarım eğitimi, endüstri mühendisliği, ürün tasarımı

INTRODUCTION

Engineering design is a systematic, intelligent process in which designers generate, evaluate and specify concepts for devices, systems or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints (Dym et al. 2005). Since design is central to most of the engineering activities, engineering design courses are generally one of the leading courses in many of the engineering curricula. In addition, valuable research is also performed on the theoretical foundation for design education (Eder and Hubka 2005).

The importance of engineering design education is also reinforced by the professionals which are responsible for accreditation of engineering programs at international level. ABET (Accreditation Board for Engineering and Technology) (ABET 2007) have emphasized importance of design courses promptly at all levels in engineering curriculum. According to ABET "Engineering design is the process of devising a system, component or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics and the engineering science are applied to convert resources optimally to meet these needs. Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints." With the strong encouragement of ABET accreditation criteria capstone design courses became almost standard in engineering curricula (Dym et al. 2005), even with multidisciplinary collaboration at international level (Erden et al. 2000). Capstone design in senior-level courses requires students to apply the basic knowledge they have acquired over the course of their degree programs to a large scale, comprehensive engineering design project. A recent objective on design education (Noble 1998; Dym 2004; Hyman 2001) considers design as the "cornerstone" of the engineering curriculum rather than just being its "capstone". Cornerstone design courses at freshman and/or sophomore levels of the engineering curricula were also motivated and emerged starting from 1990s (Dym et al. 2005). The use of both freshman and upper-division project-based learning has been characterized as a cornerstone/capstone approach and associated methods and experiences form the foundation for subsequent engineering education (Little and King 2001). It was indicated that design experience in freshman engineering design courses enhances the intellectual development of students, since first-year design courses use several instructional methods including an emphasis on hands-on design activities, oral and written forms of communication, teamwork, in-class discussions and solving ill-structured problems (Marra et al. 2000).

This paper describes a freshman engineering design course offered as a cornerstone design component for an Industrial Engineering curriculum. The course exposes students to the design process in the first year and actively engages students in this process. This course brings a new perspective as "physical product design" to the industrial engineering education which is mainly devoted to "system or process design". The paper discusses seven years of experience in teaching engineering design methodology to industrial engineering freshman through their involvement in hands-on experience in product design projects. Project topics, project progress, evaluation and grading are explained. The paper discusses how the "product design" experience of first-year industrial engineering students affects their understanding of "system design" and design related issues in industrial engineering practice.

WHY PRODUCT DESIGN FOR INDUSTRIAL ENGINEERING FRESHMAN?

Industrial engineering is a discipline concerned with the design, improvement and the installation of the systems of people, materials, equipment, energy and information to produce goods and/or services (Turner et al. 1993). Industrial engineers are mainly concerned with system design rather than physical product design. They focus on the interactions between various components that comprise integrated systems as represented in Figure 1 (Noble 1998).

Therefore, the design education in most of the industrial engineering curricula is maintained via concepts and applications towards system design. System design courses generally serve as capstone design for the application of industrial engineering techniques to solve complex real life problems in either a manufacturing or service enterprise. The system design perspective for a manufacturing enterprise makes it necessary to consider all factors of the organization within the product design task and the viewpoints of research, purchasing, marketing, development, manufacturing, finance and sales are all considered as part of the product design process in the "business design activity model" (Noble 1998; Pugh 1991). Starting system design and systems engineering concepts at the freshman level is of great importance in terms of vertical integration for engineering design education (Dym 1994).

A system is a collection of parts and/or subsystems integrated to accomplish an overall goal (McNamara 1997). Systems have input(s), processes, output(s) and outcomes, with ongoing feedback among these various parts. Systems engineering is related to the systems engineering process (Asbjornsen and Hamann 2000) which starts with a definition of the stakeholders and their involvement in the system design and operation. Once the functional and operational needs

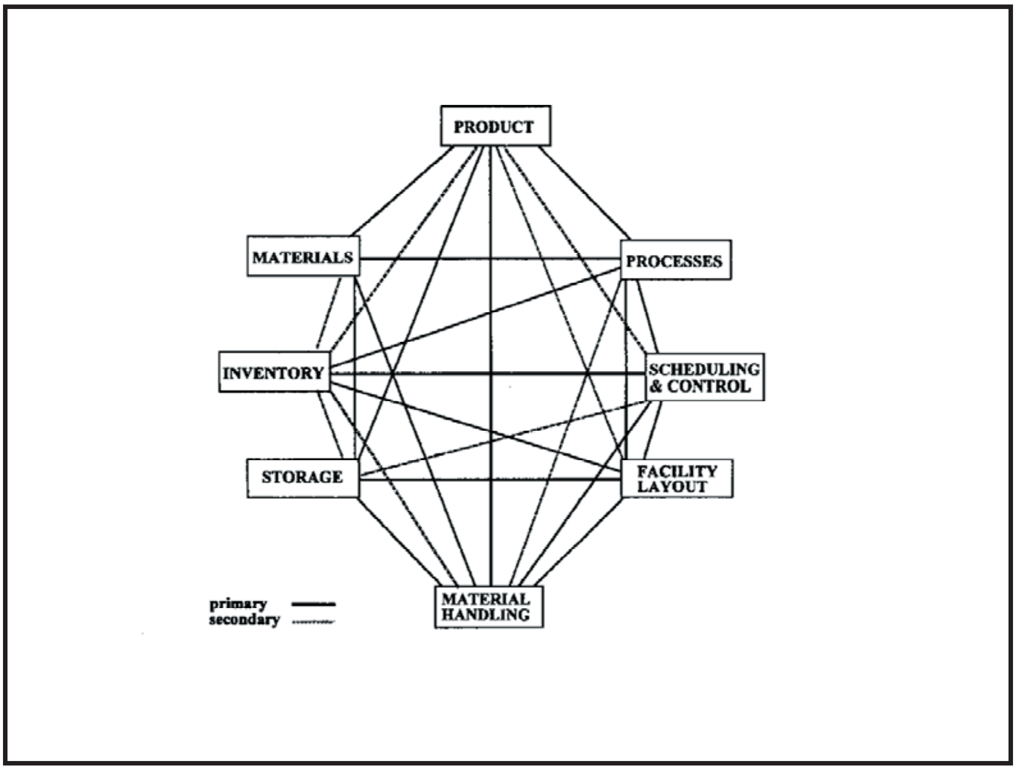

Figure 1. *Interactions Between Manufacturing System Components (Noble 1998)*

are analyzed and the mission, objective or purpose of the system is agreed upon, the requirements to the system performance over its mission or lifetime are defined. This part of systems engineering is closely related to the general engineering design process, such as a product design or a production plant design. The "system" concept can be taught to freshman students via physical products easily. Freshman students are able to develop mental visualization skills by examination of the design and manufacture of physical products and/or simple machines, the way in which these products and machines work; their physical operation, the manner in which they are constructed. By means of such an examination they develop a basic aptitude for engineering and engineering design from systems perspective.

With this motivation, a cornerstone engineering design course IE 101 was first introduced to the industrial engineering freshmen of Atılım University, Turkey in September 2000 to improve student retention and to provide design experiences across the entire curriculum. IE 101 was a 2-credit course with 2 lecture hours per week. This one-semester course was offered with the name "Concepts of Industrial Engineering" between 2000 and 2003. During that period the course content covered an introduction to engineering profession in general and industrial engineering in particular with special emphasise on engineering design process. The content has a wide spectrum such that a single textbook would not be sufficient to follow up. Thus, various reference books are used for this course and they are listed in Table 1.

Some revisions have been done to the course since its first introduction and the course has been given the name "Introduction to Engineering" starting from

Table 1. Reference Books for the IE 101 Course

AUTHOR(S)	TEXT	PUBLISHER
Turner, W.C., Mize, J.H., Case, K.E. and Nazametz, J.W.	*Introduction to Industrial & Systems Engineering*	Prentice Hall
Hicks, P.E	*Industrial Engineering & Management*	McGraw-Hill
Wright, P.H	*Introduction to Engineering*	John Wiley and Sons
Voland, G.	*Engineering by Design*	Addison-Wesley
Eide, A.R., Jenison, R.D., Mashaw, L.H. and Northup, L.L.	*Introduction to Engineering Design*	McGraw-Hill
Howell, S.K.,	*Engineering Design & Problem Solving*	Addison-Wesley
Mitcham, C. and Duvall, R.S.	*Engineering Ethics*	Prentice Hall
Fleddermann, C.B.	*Engineering Ethics*	Prentice Hall
Schiavone, P.	*Engineering Success*	Prentice Hall
Holtzapple, M.T. and Reece, W.D.	*Concepts in Engineering*	McGraw Hill
Dominick, P.G. et al.	*Tools and Tactics of Design*	John Wiley and Sons

September 2003. The focus of IE 101 course is on the design process within the context of an engineering product development. The major course concepts within this framework include;

1. Definition of engineering,
2. Definition and characteristics of the engineering design process,
3. Needs assessment and problem definition,
4. Concept generation,
5. Concept evaluation and selection,
6. Modelling in engineering design,
7. Implementation of engineering design,
8. Written and oral communication skills (both individual and team),
9. Team management and team dynamics in engineering design,
10. Ethical and legal considerations in engineering and design.

The course brought a new perspective to the industrial engineering curriculum as an open-ended product design experience in teamwork at freshman level. This course is designed to help freshman students gain a better perspective on engineering, particularly on the creative aspects of engineering design. The following are the objectives of the IE 101 course;

- To provide students with insight into the nature of engineering,
- To help students gain experience on design through a design project,
- To help students gain experience working in teams,
- To help students learn ethical and legal issues in engineering,
- To make students develop communication skills through written and oral presentation of their design work.

One of the most important objectives of the IE 101 course with design projects is to enhance students' creative skills. It is commonly accepted that upper level students have more and stronger analytical skills than first year students, but the lower level students can be learning and practicing the creative skills (Dekker 1995). Although first year students are not prepared to complete technically complex engineering designs, they can learn to apply the basic techniques associated with the engineering design process. Thus, the purpose of the freshman design project in IE 101 course is to introduce students to a real design problem, to encourage them to explore different ways of meeting the stated objectives while having to consider the advantages and disadvantages of different possible solutions or alternatives to meet the design criteria and constraints.

SELECTING PROJECT TOPICS

Project progress in the IE 101 course is organized as parallel to the lecture topics which are based on the discussion of methodology and systematic of the engineering design process given in Figure 2. Therefore the course is designed such that students are expected to implement the methodology given in the lectures in their hands-on project work.

Project work is conducted as a teamwork and it is known that the topic of engineering project is critical for team motivation, because the team will not be motivated unless the students see "a specific performance challenge that is clear and compelling to all team members" (Delson 2001). Since freshman students do not yet have the fundamental engineering background to make professional designs, the following criteria are considered in selecting the project topics:

1. Project topics should not require considerable background knowledge on engineering sciences; instead topics that encourage students' creativity are selected,

2. The design projects should be affordable financially by the students,
3. The size and volume of the products must be small enough to carry anywhere (home or machine shop easily), but large enough to have a feeling of producing a real size product,
4. Amusing topics are selected to make students work on their projects throughout the semester without getting bored (Figure 3, Figure 4),
5. Manufacturing of the projects should be easy such that even students can produce the prototypes at home.

The design project topics with explanations and related design criteria during the period 2000-2007 are given in Table 2.

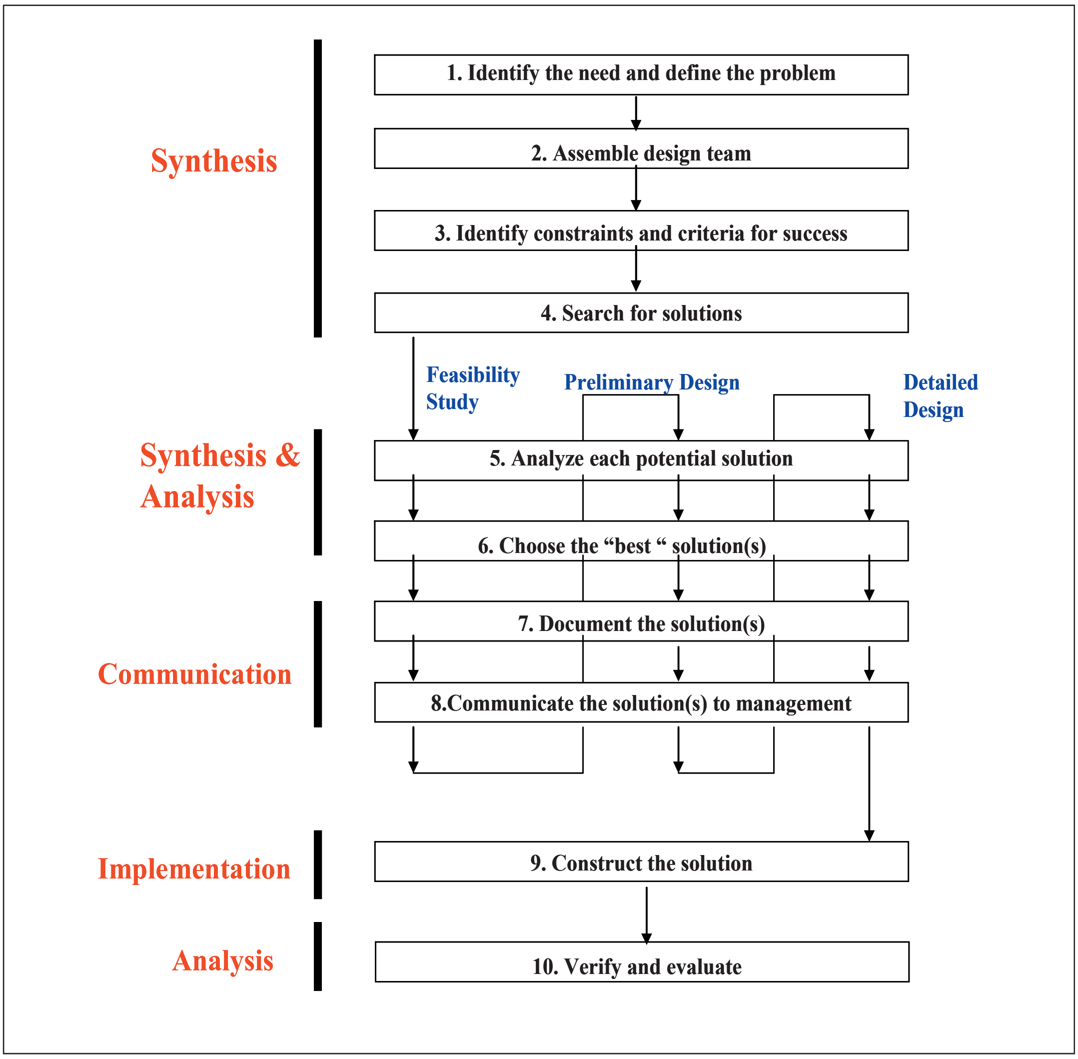

Figure 2. *Methodology of the Engineering Design Process*

Figure 3. *Competition Day (2002-2003 Academic Year)*

Figure 4. *Spaghetti Bridge Project (2003-2004 Academic Year)*

Table 2. IE 101 Project Topics Between 2000 – 2007 Period

Academic Year	Project Topic	Design criteria
2000 – 2001	**Egg-drop structure** Design and construction of a protective impact mitigation structure to protect raw eggs from damage when dropped from a 2.5 m height	▪ Number of eggs that are not damaged (to be maximized) ▪ Weight of the structure (to be minimized)
2001 – 2002	**Recycling container for disposable household waste** Design and construction of a recycling container to accommodate 4 types of recycling materials (beverage can, plastic water bottle, glass bottle and milk carton) collected at home	▪ The number of recycling materials per unit container volume (to be maximized) ▪ Weight of the container (to be minimized)
2002 – 2003	**Cardboard vehicle** Design and construction of a model vehicle, using cardboard only and any type of glue/tape. The vehicle should be able to carry one of the team members while another team member may pull or push the vehicle.	▪ Weight of the person carried by the cardboard vehicle for 5 m (to be maximized) ▪ Weight of the vehicle (to be minimized)
2003 – 2004	**Spaghetti bridge** Design and construction of a model bridge which is constructed only from spaghetti and glue to carry 2 kg load.	▪ Load carried by the bridge for one meter bridge length (to be maximized) ▪ Bridge length to carry 2 kg load. (to be maximized)
2004 - 2005	**Canwood transportation structure** Design and construction of a structure made of wood and beverage cans only to carry 5 kg weight for 3 m horizontal distance.	▪ Number of cans used (to be minimized) ▪ Time to carry the load (to be minimized)
2005 - 2006	*Design project was not given*	
2006 -2007	**Catapult for a target** Design and construction of a catapult to hit a target.	▪ Score obtained from 3 m distance (to be maximized) ▪ Distance between the launch position and the target to hit any score (to be maximized) ▪ Originality of the design and aesthetics

PROJECT PROGRESS, EVALUATION AND COMPETITION

In the IE 101 course, student teams tackle open-ended design problems, design and construct working prototypes. The course content guides the students through the design process and addresses topics such as problem definition, concept generation, concept selection, project management and embodiment design. The design project topic is announced at the beginning of each semester and students are asked to form design teams with 3-4 members. There are 15-20 teams per semester as an average number. Design teams have official project meetings with their project assistants every week during the semester. Time reserved for the weekly project meetings is one hour per design team. Teams are expected to work on their projects 4-5 hours per week except the official project meetings and they are free to ask any questions and/or discuss their design with the project assistants and/or course instructors any time other than the project meetings. During the regular project meetings, teams present and discuss the progress of their designs, and submit two to three pages "short report" explaining what they have done during that week. Each team member is responsible for a specific section in the short reports. These reports are evaluated by the project assistants and necessary feedback is given to the design teams and to the individual members. The individual team members' contribution and progress is evaluated and graded based on the short reports and their performance throughout the entire design activity. Short reports form the skeleton of the "Final Design Report" that each team should submit at the end of the semester. Some useful guidelines for preparing all reports are provided and teams are expected to prepare "professional" reports.

Time spent for the design projects is largely dependent on the individuals' performances. It is observed that success of the design teams is usually proportional to their effort and time spent on the design project. Few students are observed with no intend to involve in the ongoing design activity. The assistants and faculty do not evaluate the design ideas during the term as good or poor design, but instead, they guide organizing a proper schedule to complete the project within the assigned time period. Assistants are told not to make any suggestion on the design, but only to observe and guide the design teams during the project meetings and throughout their project work.

A competition is carried out in the department's exhibition hall before the final examinations in each term as shown in Figure 5. Alumni and parents are also invited to the competition. The stress observed on the students prior to the competition is very high. To relieve high tension, students are asked to prepare any humorous posters, paintings and jokes for the day of competition. Popular music is played at the hall during the competition. The hall is usually full of students making their last experiments and fine adjustments and repairs (Figure 6), through several days and nights before the day of competition.

Each design team is required to present their design with an official oral presentation in 10 minutes prior to the competition day (Figure 7). In this oral presentation, all team members are expected to contribute and oral presentation grades are given individually. During the competition, each team presents how well their structure meets the design criteria. Except the examinations, individual progress grade and oral presentation grade, other grades are given to the team as a whole and thus, all team members have the same grade. Although minor changes may be done each semester, grading policy is such that about 40-45% of the total course grade is given to the design project. A typical course grading is as follows:

• Midterm Examination*	25%
• Design Project	45%
Final Design Report	12%
Competition Grade	18%
Oral Presentation*	7%
Individual Progress*	8%
• Final Examination*	30%

* Individual grades

Figure 5. *Competition Day (2006-2007 Academic Year)*

Figure 6. *Adjustments and Repair Prior to the Competition (2006-2007 Academic Year)*

Figure 7. *Design Presentation (2001-2002 Academic Year)*

The competition grade is determined by evaluating each design based on the design criteria which are given at the beginning of the project work. The design criteria for the project topics since 2000-2001 academic year are listed in Table 1. Every design is evaluated based on each of the criteria for the related project topic. The best design for each criterion is graded as x/x and the worst is graded as 1/x, where x = 18 / (number of design criteria). Other designs are assigned grades determined by linear interpolation between 1/x to x/x. Any failure is given 0/x.

REMARKS AND DISCUSSION

The product design projects conducted as the hands-on experience for the industrial engineering freshman challenges students to integrate the engineering design methodology covered in the lectures with their creativity in a teamwork environment. The requirements for the design projects were decided based on the skills of industrial engineering freshman and structured such that meaningful results in the form of working prototypes can be obtained within one semester time period. Students learn teamwork, importance of meeting deadlines and the basic engineering design as a process.

Since the course is offered for freshmen who do not have engineering knowledge, selecting the project topic is of great importance. Projects must be matched to the skill level of the students. For example in the cardboard vehicle project we accepted manually driven vehicles as shown in Figure 8, since students might not be able to use any other type of power source in their designs. Since most students in the course have not yet been exposed to analytical courses in engineering at this point in their education, the project is purposely defined to allow freedom of creativity in determining a suitable design alternative. When choosing a possible project topic, it is better to keep balance between “too easy” and “too difficult”. Projects must be simple enough so that they can be completed within the time period of the course and with the level of skill and knowledge of

Figure 8. *Cardboard Vehicle Project (2002-2003 Academic Year)*

the freshman students. However, project must also be complex enough such that each member of the team has a chance to make a significant contribution. There may be some unexpected negative results of selecting a wrong project topic. The production cost may be too high to be affordable by the students. A very simple design may be developed without any engineering design insight. Some ready made devices may be available for a very similar function, which may discourage students from any innovative work but use the available devices. There may be one unique solution, so that groups will be doing the same design.

The course instructor and the project assistants need to monitor the progress of the design teams and individual team members throughout the design process carefully. Design teams are required to go through the entire design process. Students are encouraged to develop and assess a variety of solution alternatives before they begin building the prototypes. Since engineering design is an iterative process, re-design at any stage is possible, provided that the design teams must be aware of and apply time management issues. Weekly project meetings and discussion sessions with each group are necessary to prevent students developing unnecessarily sophisticated designs, or getting stuck to infeasible solutions. A progress grade is given for individual works. Weekly meetings and time management issues are important concepts that industrial engineering freshmen should understand, because they will be involved in planning and scheduling the key activities of integrated systems in their professional life.

Evaluating the performance of designs in a competition enhances the quality of the design effort. The competition approach has several positive effects. Students are able to compare their designs with those of the other design teams, observing design alternatives that they did not think of before. Knowing that they would compete with the other design teams, students tend to put more effort into the design and construction of the prototype. Engineering faculty and administrators not directly involved in the course have an opportunity to examine the projects. On the negative side, the decision to hold a competition at the end of the term makes it more difficult to find project topics appropriate for a competition. Some students work with high enthusiasm and emotions, so that a natural competition for self proving is observed. This leads to unexpectedly successful designs. Immediate intelligent solutions are found for any failed designs at the day of competition.

Some assistant/student/alumni evaluations about the IE 101 design projects are as follows:

Many students state that `*we built our self-esteem as engineers while designing the products in IE101 project*`. I think, this sentence is a kind of proof that students really enjoy the project work and in the future they will understand the objectives of the IE 101 course better." *Merve Hande Ergin (IE 101 Project Assistant, 2002-2005)*

"I'm happy to work for a design project at freshman, because I learned and experienced the steps of an engineering design process in my project work. Finding solutions for a design problem based on design criteria and constraints was the main purpose of the project work. Although some of these constraints were not much realistic, I understand the meaning of engineering by conducting this project work." *Emrah Demiralp (3rd year IE student)*

"IE 101 project was a very important experience for me such that I still keep a copy of our design report. This experience made me feel self confident and satisfaction about my education. The project taught us how to start problem solving in a systematic manner. During my 3rd year and 4th year summer practice studies, I realized that IE 101 project was also an important experience to develop teamwork, time management, and communication-presentation skills which are necessary for a successful engineering career. As a suggestion for the conduct of the project work, the design teams may be formed based on the academic success of the students. In addition to the first year, such a design project should continue in the 2nd and 3rd years with a different format." *Ahmet Çayhan Günay (IE Graduate-2006)*

"System approach is a method that we use for solving problems in industrial engineering. Solving a design problem using our own ideas in the first year of education made me feel self confident that affects my professional life. In my opinion, oral presentations and encouragement of creativity are the most important aspects of the IE 101 course because they play important roles in the professional development. I think the design criteria should be determined such that students are as free as possible in developing any alternative solution. The teamwork experience was very useful because I understand the importance of sharing both risk and success." *Mustafa Yazıcı (IE Graduate-2006)*

"It was quite difficult for our team to design and construct an impact mitigation structure to protect eggs from damage when dropped from a given height, because we performed such a project for the first time. But we studied a lot and we were successful. This project study was very useful in my professional life particularly in the design and installation of systems. An important contribution of the IE 101 project to my profession was the preparation of written reports and oral presentations in the first year of the university education." *Elif Öziskender (IE Graduate-2004)*

Common undesirable results where new rules are set to prevent their effect are as follows. Majority of the groups tend to produce similar designs based on an idea which seems to be most reasonable design at first sight. Teams are encouraged to develop unique designs and bonus credit is given for the unique designs. Most of the groups have tendency to produce designs with average performance. Desire for high competition performance is not achieved for all groups. Innovative designs are considered to have high risk; therefore they are not much preferred by the students.

CONCLUSIONS

When different issues and their interactions in the engineering design process are considered, it is understood that a systems perspective is required by the nature of design. Systems approach is also necessary for solving problems in industrial engineering which provides the perfect blend of technical skills and people orientation. Industrial engineering addresses the overall system performance and productivity, responsiveness to customer needs, and the quality of the products or services produced by an enterprise.

The IE 101 course with design projects forces such a systems-perspective for the industrial engineering freshmen by using a "complete" product development process, i.e., the students must take a product from its imagination to a manufactured physical product. Students no longer focus on individual parts at the expense of the entire system.

Growing global collaboration as well as competition and the explosion of information technology has changed the way that organizations operate. As a result companies, require engineers not only with technical skills but with a skill set that includes communication, teamwork and global, economic, social and environmental awareness as well. The IE 101 course with hands-on design projects provides the industrial engineering freshman students a knowledge and insight to design a real system (as a physical product). After this course, we observed that our students move through the rest of the curriculum with a greater understanding of the importance of creativity, systematic methodology and teamwork in design and therefore are better motivated for the core curriculum that adds critical technical competencies to their basic understanding of the engineering design process. The course gives students an opportunity to learn about the process of design as well as the art of working together in a team and learn project/ time management issues. This course also provides freshman students an opportunity for developing their oral and written communication skills. The freshman design course helps students to see that engineering can be fun as well as challenging.

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