

Redesign of a Toy Project for First Year Engineering Courses

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ABSTRACT

Many students decide to study engineering because they like to design and build things or they like the hands-on work. However, most of the engineering programs devote the first two years of the engineering curriculum to theoretical foundations in math and science with little or no connection with the engineering majors. As a result, a big number of students are stepping out of engineering due to a lack of design and hands on experience during the first two years. This paper reports the implementation of a redesign project in two freshman engineering courses. The purpose of this project is not only to introduce the design process and professional skills such as teamwork and communication among others, but also to serve as a means to connect the students with the engineering field from the very beginning and motivate them to stay in a technical career.

Keywords: Redesign, toys, reverse engineering

1. INTRODUCTION

There is a clear need to attract more students to science, technology, engineering and math (STEM) disciplines and retain them in the engineering and engineering technology fields. In average the engineering students' retention rate varies, depending on different institutions, between 37 to 66 %; but some might argue that the real challenge is in the recruitment of students for engineering majors (Ford, 2009). According to Ford, the interest in engineering majors should be cultivated before students reach the college age (Ford, 2009); otherwise, it is difficult to awake their curiosity in technical majors. Once the interest in engineering is created, a transition plan is needed to retain the students in the field. A search in the literature shows that many retention issues have been identified and, among the most common reasons for the students to leave engineering, it is important to highlight the followings: misconception of engineering, other majors are more interesting, too much fundamentals concepts in basic sciences during the first year and no engineering connection, engineering curriculum is very demanding, and there is no fun in engineering (Anderson-Rowland, 1997). Many students decide to study engineering because they like to design and build things or they like the hands-on work. However, most of the engineering programs devote the first two years of the engineering curriculum to theoretical foundations in math and science. As a result, a big number of students are stepping out of engineering due to a lack of design and hands on experience during the first two years.

There is a general consensus that the first year is critical in retaining engineering students in the field, and this has been the focus of many institutions. They are incorporating courses not only to help in the transition from high school to the rigorous curriculum of a technical career, but also to develop technical and professional skills (Kotys-Schwartz, et.al, 2008) and to make engineering appealing and interesting to the students. The effectiveness of first year engineering courses including projects and hands-on activities has been reported in the literature showing an increase in the retention rate of 16% on average (Knight et. al., 2003, and Richardson. and Dantzler, 2002). This paper describe the modification of two first year engineering courses to incorporate redesign projects with the aim of exposing engineering students to an academic experience that combines fundamental concepts of engineering design, practical experience, and teamwork and problem solving skills early in their careers.

2. BACKGROUND

Design is considered the creative, decision-making and problem-solving essence of engineering. It is a fundamental component of engineering and introducing it properly in the first year has the potential to have a positive impact on students and to contribute to retain them in the field (Vetltman, and Rosehart, 2010). In the Penn State system, the course Introduction to Engineering Design (EDSGN) is required by all engineering majors during the first year with the aim of start preparing the students in the engineering design methodology, teamwork, communication and problem solving skills, and the course First Year Seminar (FYS) is required also by all engineering majors to help the students in the transition from the High School to the university environment. This course is very flexible in terms of the content but the overall goal must be the same across the college: to help students get connected with the engineering field and faculty, and become familiar with the university resources and expectations.

In our campus, both courses were modified with the purpose of incorporating a redesign project of a toy to provide a project-based experience in the first year. In both courses, teams are formed and a toy is given to each team for its dissection and redesign. Teams have to go through the design process to gather information and generate ideas for the new conceptual design of the toy. Teams are required to write a report documenting the entire process and are also required to make an oral presentation in front of their peers. The project is explained in more details in another section of this paper.

3. REVERSE ENGINEERING AND REDESIGN CONCEPTS

Reverse engineering or product dissection is the process of teardown a product to understand how the product works as a system and the interaction of all its components. It also provides information about the architecture of the product and the technology used to manufacture and operate the product (Otto and Wood, 2001). Reverse engineering starts with an existing product and by taking it apart, it gives inside information about how designers develop the product to satisfy customer requirements (Dieter and Schmidt, 2009).

From the professional perspective, traditionally, reverse engineering is used by industries for external and internal benchmarking not with the intention of copying the product but with the idea of exploring opportunities for improvement (Otto and Wood, 2001). However, from the academic perspective, it is an excellent means to provide a hands-on experience to the students and let them to discover how the products work, how systems interact, how artifacts are assembled, what materials are used, what manufacturing processes are required, how different engineering disciplines complement each other in putting together a product, and other engineering questions that might arise from students' curiosity.

On the other hand, redesign is the process of modifying an existing product with the aim of improving the product by fixing existing problems, migrating to new technology, satisfying new requirements, and/or enhancing specific attributes and/or specifications. Commonly, the redesign takes place after the reverse engineering since the product dissection might open opportunities for improvement. From the academic perspective, the redesign process provides a great opportunity for students to start developing creative thinking while they develop ideas to create the next generation of the product.

The idea of developing a hands-on project including reverse engineering and redesign process appears to be the appropriate option to reach the desire goal for the academic experience.

4. ACADEMIC COURSES

The main purpose of introducing a redesign project into first year engineering courses is to motivate students to study engineering by exposing them to an academic experience that combines fundamental concepts of

engineering design, practical experience, and problem solving skills early in their careers by means of hands-on design projects. This hand on project will facilitate the teaching/learning experience of engineering by creating a dynamic and active participation environment. The main goal of this initiative will be attain by fulfilling the following objectives:

Teaching Objectives:

- To provide an active-learning environment in the classroom
- To demonstrate the utility of the design process in finding solutions to engineering problems
- To enhance students' ability to work in teams in a collaborative context
- To enhance students' ability to develop skills in the acquisition, evaluation and use of information
- To enhance students' ability to develop oral, and written communication skills

Learning Objectives

- To define engineering design and explain the basic design process
- To apply effectively problem solving and design processes in the creation of a toy or a machine
- To summarize and communicate effectively the results of the design project results by means of oral and written engineering presentations
- To develop teamwork and leadership skills by means of an active and positive participation as a team member
- To demonstrate professionalism in the interaction with colleagues, faculty and staff.

As mentioned before, the redesign project was introduced in two different first year courses, EDSGN and FYS. For the EDSGN, the project is one module of the course, weights the 20% of the final grade for this course and it last for seven weeks; while for the FYS, the project is for the entire semester and weights 100% of the final grade for this course. Table 1 summarizes the activities done in this project in EDSGN, while Table 2 summarizes the activities done in FYS to enhance the student learning.

Table 1 Learning activities for the project in the EDSGN course

Activities	Learning
Teamwork	• Participate as an effective team member • Manage conflicts effectively • Work effectively with peers • Accept and give constructive criticism
Patent search and Benchmarking	• Use the library and the internet to conduct searches and document the results • Gather and evaluate data obtained by searching public access catalogs, on-line databases, and government documents
Dissection	• Identify mechanical and electric components in a product • Analyze logic systems based on mechanical and electric components • Determine the interaction of mechanical and electrical components in the operation of a product • Identify potential opportunities for product improvement
Conceptual design	• Plan and schedule project work with consideration for budgeting and time efforts to meet customer requirements • Prepare product design objectives form customers' description of need • Apply design methodology to redesign a toy

Written reports	• Convey ideas and facts by composing, revising and editing reports • Determine the form, length, content and style of a written report for presenting material to an intended audience • Use proper grammar, syntax, punctuation and spelling in Standard American English written report
Final prototype	• Modify, manufacture and assembly a product (toy) based on customers' requirements
Oral presentation	• Determine the form, length, content and style of an oral report for presenting material to an intended audience • Plan, organize, rehearse, and make effective oral presentations • Prepare visual materials for oral presentation

Table 2 Learning activities for the project in the FYS course

Activities	Learning
Teamwork	• Participate as an effective team member • Manage conflicts effectively • Work effectively with peers • Accept and give constructive criticism
Machines and Mechanism	• Recognize different types of basic mechanism
Dissection	• Identify mechanical and electric components in a product • Analyze logic systems based on mechanical and electric components • Determine the interaction of mechanical and electrical components in the operation of a product • Identify potential opportunities for product improvement
Conceptual design	• Plan and schedule project work with consideration for budgeting and time efforts to meet customer requirements • Prepare product design objectives form customers' description of need • Apply design methodology to redesign a toy
Written reports	• Convey ideas and facts by composing, revising and editing reports • Determine the form, length, content and style of a written report for presenting material to an intended audience • Use proper grammar, syntax, punctuation and spelling in Standard American English written report
Final prototype	• Modify, manufacture and assembly a product (toy) based on customers' requirements
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Even though the project is similar and the learning objectives are the same, each course has its own identity and makes emphasis in specific areas. This differences in the approach and expected deliverables are reflected in the evaluation system develop for each course as shown in Tables 3 and 4. Additionally, the FYS course includes an

additional activity related to the study of basic machines and mechanism that allow the students to better understand how mechanical devices work. It is important to highlight that some students take both courses simultaneously or take FYS during the fall and EDSGN during the spring. That means that they are exposed to the experience twice which allows them to learn from both courses and to reinforce the concepts. Some of the first year engineering students might be exposed to a robotics project during the FYS course and then to the redesign project in the EDSGN course. At the end, all incoming freshman engineering students are exposed to a hands-on project two times during the first year.

Table 3 Evaluation system for the redesign project in EDSGN

Concept	Weight
Progress Report • Dissection • Customer requirements • Functional analysis • Revise problem statement • Patent search • Benchmarking	20
Final Report • Dissection • Customer requirements • Functional analysis • Patent search • Benchmarking • Concept generation • Concept selection • References	40
Prototype	10
Oral presentation	20
Team assessment	10
Total	100
Overall course	20%

Table 4 Evaluation system for the redesign project in FYS

Concept	Weight
Class attendance	5
Team participation	5
Written assignments • Machines & mechanism • Product dissection • Conceptual design • Prototype plan and bill of materials	10 15 10 10
Prototype	25
Oral presentations	20
Total	100

5. REDESIGN OF A TOY PROJECT

This section describes in details all the activities related to the redesign project as they are presented to the students on each course. The projects are presented in a general form that can be adopted and adapted in any engineering course related to introduction to engineering or introduction to engineering design.

5.1 TOY REDESIGN PROJECT IN FYS

In the FYS the first three weeks of classes are used to lecture about teamwork and basic machines and mechanics. Teams are formed during week one and the toy redesign project is assigned to the students in the third week of classes. Teams have two weeks for the dissection process, two weeks for concept generation and selection, one week to create the prototype plan and bill of materials, and four more weeks to finalize the project. The details of the project as given to the students are shown below.

Title

Redesign of a toy

Description

Your team is in charge of redesigning and manufacturing a toy. The new toy should have moving parts and either lights or sound (or both!). The project is divided into four parts that will be evaluated independently but they must be consistent through the entire process:

Part I: Product dissection

Part II: Conceptual design

Part III: Prototype plan and bill of materials (BOM)

Part IV: Model or prototype

Part I: Product Dissection

Definition

Your team will disassemble a toy to its essential components

Activities

1. Identify the toy: type, manufacturer, model number, performance specifications (use the owner's manual for this)
2. Operate the toy. Describe how the toy works including your perception of how it runs (sound, lights, touch feeling, motion, etc...). Your senses are useful qualitative measure of the toy.
3. Before you dissemble the toy, list all of the functional requirements (what the toy has to do) that the apparatus must satisfy.
4. Disassemble the toy as far as possible (do this in order and put all the parts in a bin). Spread the parts and take pictures of the exploded elements.
5. Review your functional requirements. After disassembling the apparatus to its basic components, you may find out that didn't list all functions; therefore, add more functions if needed.
6. List all the physical parts (components) of the toy.
7. Identify the parts that satisfy each function. Make a table showing the functions and the corresponding parts or assemblies that satisfy the function.
8. Identify the machine elements used in the apparatus (level, pulleys, wedges, screws, gears, cams, chains, belts, etc...).
9. Identify electric components and its characteristics (electric motors, sensors, switches, etc..)
10. Make a bill of materials (BOM) (part list) of your apparatus.
11. What is the total number of parts for your toy?

Deliverables

Written report

Part II: Conceptual Design

Definition

Your team will analyze current offerings in the market of similar toys and will generate a conceptual design.

Activities

1. Identify the market for your toy (age range, gender, etc..)
2. Perform a customer needs analysis and create a vision (the desire object)
3. Make a list of attributes and constraints for your desired toy
4. Explain the functions of your toy (what the toy does)
5. Have brainstorming sessions and generate a list of ideas and alternatives concepts for your toy
6. Select the conceptual design that you will move forward for details and manufacturing
7. Clearly explain your conceptual toys (main features, mechanisms, electrical components, materials, how it works, etc..)

Deliverables

Written report

Part III: Prototype Plan and Bill of Materials (BOM)

Definition

Based on your conceptual design of the toy, your team will prepare a prototype plan and a bill of materials (list of parts including a budget) for manufacturing the toy.

Activities

1. Make a list of all activities and resources that you will need to manufacture the prototype of your toy (take into account the class time that you can use for the development of your toy)
2. Make a list of all the parts and materials that you will need to manufacture the toy (estimate cost for the parts)

Deliverables

Written report

Part IV: Model or Prototype

Definition

Based on your conceptual design, your team will create a model or prototype (physical model or 3D concept model)

Activities

1. Build your prototype or create your model based on your concept developed in Part II and using the parts described in Part III.

Deliverables

Written report

Oral presentation

Physical prototype (or 3D model)

5.2 TOY REDESIGN PROJECT IN EDSGN

In the EDSGN course the first two weeks are used to lecture about teamwork, the design process, and literature search including patents and benchmarking. Teams are formed during week one and the toy redesign project is assigned to the students in the third week of classes. Teams have five weeks to complete the project. The details of the project as given to the students are shown below.

Title

Toy Redesign

Background

Your team is working in the product design and engineering department of a company, which specializes in toys. During the last strategic meeting, the board of directors recognized the market potential and approved research and development (R&D) funding for a newly designed toy. Your team is charged with the redesign assignment.

Description

Your team will receive a toy and your task is to analyze the toy, the current offerings in the market of similar products, and redesign the toy that will better meet needs of the targeted population.

Activities

1. Dissection: *You will take apart a toy to learn about their parts and functions, and you will analyze the current status of the toy to look for opportunities for improvement.*
2. Analysis of customer needs: *Gather information using surveys, focus groups, interviews to potential customers, and by dissecting or taking a part a similar existing product.*
 - a. List of design objectives (*objectives are expressions of the desires attributes and behavior that the client of potential user would like to see in the designed object. What the design will be.*) (At least 20)
 - b. List of constraints (*constraints are restrictions or limitations on a behavior or a value or some other aspect of a designed object's performance.*)
 - c. Hierarchy list of design objectives (*set priorities on what the client can have*)
3. Functional analysis: *Functions express what the designed object must do to realize the stated objectives. You have to specify which functions have to be performed.*
 - a. List of functions (*functions are the things the design is suppose to do.*)
 - i. State the main function
 - ii. Decompose the overall function into sub-functions
 - iii. Identify all the objects used and defend their inclusion in the functional model
 - iv. Which sub-function(s) must remain unchanged during the redesign? Why
 - v. Which sub-function(s) must be changed to meet new requirements? Why
4. External and Internal search for concept generation: *Look for information that will help you to develop a set of alternatives solution to the redesign problem using external information and internal information by means of a brainstorming process.*
 - a. External search
 - i. Literature search (with at least 4 non-internet sources),
 - ii. Benchmarking,
 - iii. Product dissection (*Dissect the toy*)
 - b. Internal search
 - i. Brainstorming
5. Concept selection: *Provide the description and sketches of your redesign product explaining the main features and how they satisfy the design objectives and the customers' needs.*
6. Redesign prototype: *Redesign the toy and built a prototype using your original toy as a starting toy.*

Deliverables

Written progress report
Written final report
Oral presentation
Prototype and/or 3D model
Self and peer teamwork assessment

6. FINAL REMARKS AND CONCLUSIONS

This redesign project has the potential of having long-term impact in recruitment and retention of engineering students and in changing the learning model of engineering.

Respect recruitment and retention, there is a clear need to attract more students to STEM disciplines and retain them in the engineering and engineering technology fields. A search in the literature shows that many retention issues have been identified and, among the most common reasons for the students to leave engineering, it is important to highlight the followings: misconception of engineering, other majors are more interesting, too much fundamentals concepts in basic sciences during the first year and no engineering connection, engineering curriculum is very demanding, and there is no fun in engineering. Many students decide to study engineering because they like to design and build things or they like the hands-on work. However, most of the engineering programs devote the first two years of the engineering curriculum to theoretical foundations in math and science. As a result, a big number of students are stepping out of engineering due to a lack of design and hands on experience during the first two years. It is expected that incorporating this fun and hands-on experience in the freshman year might help in getting more students interested in entering and staying in the engineering field. Besides, students feel connected with engineering from the very beginning in their careers and start understanding the application of engineering in the development of objects and machines, and the impact of engineering in transforming the society by advancing technology and bring new and innovative products to the market.

About the learning model, traditionally engineering is taught from the basic principles to the engineering concepts and from the design of individual parts to the integration as a system. The total integration of components for a machine or system is only done at the capstone project or senior project level at the end of the engineering program. As a result, students spent four or five years dealing with single elements and just at the end are asked to integrate them in a system which causes students to be well trained in designing or calculating parts but ill prepared to put together them as part of a device or machine. This project has a different approach: first, it starts from a product already existing and working as a system and students start discovering how the system works and how the different parts are interrelated to accomplish the functions; then, they start proposing changes, conceptual design, to modify the product and make it more attractive and marketable; finally, students put together a solution for the product without major calculations. This reverses the learning process creating a new way to teach and learn engineering. Now the students start studying how a system (product) works and as they progress in their studies they start understanding the basic and engineering concepts as they know how they are related to a product as they see it the first year. It is a matter of awaking interest first so students can grasp the knowledge better and move to the application stage during the capstone project and beyond. Additionally, this approach fosters creativity and innovation in engineering, as well as the development of professional skills such as communication and teamwork which are important abilities to be competitive in the global economy.

The first year seminar course is directed to incoming freshman engineering students. In Penn State, engineering students declare their major and enter into a specific discipline after the fourth semester; therefore, there is a mixing of engineering students with different discipline interest in the first year seminar course. As a result, this course is not designed for specific majors. The course goal is to provide a first year hands-on experience where engineering students recognize the role of the design process in the solution of engineering problems independently of the discipline. Additionally, this experience gives students an overall view of how systems work and how different engineering disciplines play a fundamental role in the production of a simple product such as a toy.

Toys are used for this initiative because they are popular and relatively inexpensive products that still can have certain grade of complexity and the involvement of many engineering disciplines. Consequently, toys are selected to ensure that mechanical, electrical and computer systems are part integral of the toy. The most common toys used in the first year seminar course are the learning and educational toys with moving parts and electronics components. This allows reaching the desire goals stated above.

This project was developed as part of the Toys'n MORE project sponsored by the National Science Foundation (NSF) in the US. The final assessment of this initiative and its effectiveness will be reported in other papers. This manuscript is reporting the structure and methodology developed for the redesign project to be incorporated in the first year of the engineering curriculum.

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