Teaching Design to First Year Engineering and Engineering Technology Students: A Case Study

by

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Abstract:

This paper describes the instructional approach used to teach engineering design and invention process to freshman baccalaureate engineering and engineering technology students at The Pennsylvania State University – Altoona College. Students are taught engineering design in a 3 credit-hour course titled Introduction to Engineering Design and Graphics (EDSGN 100). The goal of this course is for students to learn the fundamentals of engineering design by using contemporary methods and tools on actual design problems. Students also develop supporting skills such as teamwork, communication methods (graphical, oral, and written), and computer-aided engineering analysis. The paper provides details of how engineering design and invention process is taught to students in EDSGN 100. Information regarding course assessment techniques used in EDSGN 100 is also presented.

I. Introduction

Engineering design is the communication of a set of rational decisions obtained with creative problem solving for achieving certain stated objectives within prescribed constraints (Anwar, et. al., 2002). The importance of incorporating design skills in undergraduate engineering programs is widely recognized (Bullen, et. al., 2004). The methods faculty choose to teach engineering design process relate to the skills they want their students to develop (Davis, et. al., 1996). As a result, over the past several years, the first-year engineering courses have evolved from standard problem solving, graphics, and computer programming courses to a format that emphasizes an early realization of engineering design, collaborative learning, and highly interactive environment (Anwar & McClure, 2006).

Developing design skills in professional engineering programs allows students to learn through active engagement and team work. Ideally, design should cross discipline boundaries for any potential engineer to truly understand how design process occurs in the real world (Bullen, et. al., 2004). Many educational institutions throughout the nation are currently making an effort to provide effective multidisciplinary design experiences to their engineering students. Walter (2003) describes a 3-semester, team-oriented, industry-funded interdisciplinary design sequence taught at Texas Christian University. Mountain (2001) describes freshman multidisciplinary engineering design projects conducted by the freshman engineering students at The University of Texas at Tyler. Christensen et. al. (2006) describes an effort to integrate engineering design in the first-year courses across the curricula of multiple departments at the Southern Methodist University. Other papers describing multidisciplinary freshman engineering design experiences are listed by Libii (2004).

This paper describes the instructional approach used in EDSGN 100, a 3 credit-hour freshman engineering design course, to teach multidisciplinary engineering design and invention process to the first year engineering and engineering technology students at The Pennsylvania State University-Altoona College. This course provides an opportunity to the freshman engineering students to learn and practice engineering design process, write and present technical reports, and use appropriate computer software packages.

II. EDSGN 100 Course Structure

Introduction to Engineering Design is a required 3 credit-hour first-year course for all engineering students who enter the baccalaureate engineering degree programs (with the exception of Architectural and Computer Engineering majors) at The Pennsylvania State University. It is also a requirement for all the first year BSEMET (B. S. in Electromechanical Engineering Technology), a four-year engineering technology degree offered by The Pennsylvania State University. This course provides direct support to the ABET Engineering Criteria 2000 Program Outcomes (Bilén et. al., 2002). Upon completion of this course, students should be able to:

- Conceptually design a system, component, product, service, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- Conduct basic experiments, as well as analyze and interpret data
- Function more effectively in small teams
- Identify, formulate, and solve engineering problems
- Communicate more effectively in oral, written, and graphical media
- Use CAD, spreadsheet, and internet application tools relevant to engineering practice

Introduction to Engineering Design (EDSGN 100) consists of three components with each component meeting for a single two-hour period every week (Anwar & McClure, 2006). This gives a total class meeting time of six hours per week for fifteen weeks. The first component of EDSGN 100 introduces students to computer application skills using CAD. It also develops student design competencies in the topical area of communication. Topics covered include Internet navigation, website design, word processing, presentation software, and computer aided design and drafting using AutoCAD.

The second component of the course deals with manual graphic and drafting skills. Students are introduced to the fundamentals of orthographic projection. The topics covered include multiview projection, dimensioning, lettering, oblique and isometric projection, sectional views, tolerances, scales, and selected topics in descriptive geometry.

The third component of EDSGN 100 focuses on team-based engineering design projects. Working together in teams, students work on design projects selected from various disciplines of engineering. This component of the course introduces students to principles of engineering design practice while developing design competencies in problem definition, idea generation, evaluation and decision making, implementation of teamwork, and process improvement.

It is the intent of EDSGN 100 course to increase students’ interest in engineering with the hope of reducing the transfer rate of students who leave engineering for other academic majors at The Pennsylvania State University. This course is one of a few engineering courses taken by students during their first two years. The majority of courses taken by students during the first two years of any baccalaureate degree engineering program at The Pennsylvania State University consist of mathematics, physics, chemistry, English, arts, social sciences, and humanities.

At The Pennsylvania State University-Altoona College, the first task assigned to students in the engineering design component of EDSGN 100 is to develop a new product, process, or material that could be marketed. Students may also choose to develop a modification of an existing product, material, or process. Examples of past patented ideas are provided to EDSGN 100 students. Detailed information regarding engineering design and manufacturing processes is provided to students using class lectures, handouts, and notes. All this information helps students develop an understanding of the steps involved in engineering design process and the factors they need to consider when designing and manufacturing a product. Students are then asked to present their design ideas in the form of a one-page proposal using MS Word. The proposal is graded for market feasibility and grammar. Some examples of student product ideas include liquid dispensers, electronic shower temperature control, focusable automobile headlights, remote entry system for houses, disposable travel toothbrush, portable campfire ring, disposable cellular phone, microwave inside a standard oven, 9-1-1 button on remote car door opener, and varying intensity automobile break lights.

During the Fall 2002 semester, the instructor for the design component of EDSGN 100 course decided to use NYSCATE module titled *Design for Manufacture*.

III. NYSCATE Module

The New York State Curriculum for Advanced Technology Education (NYSCATE), a consortium of two-year and four-year institutions (Finger Lakes Community College, Fulton Montgomery Community College, New York City Technical College, and Hofstra University), has recently developed fourteen grade 9-14 advanced technological education curriculum modules. The modules represent three areas of technology: bio/chemical, information, and physical sciences. Each module features the integration of mathematics and science principles through informed design.

In the NYSCATE module *Design for Manufacture* students work in groups to:

- Understand and investigate possible solutions to a given problem;
- Investigate the problem by completing Knowledge and Skill Builder (KSB) activities, and by using information resources that they identify;
- Prepare a report showing how they considered important factors in making their design decisions;
- Base their design and redesign upon technological, scientific, and mathematical concepts;
- See that their design meets specifications and constraints;
- Use appropriate tools and materials to build a model of their design, which is useful in illustrating, analyzing, and defending their design decisions;
- Develop and use a repeatable and reliable method for testing their design; and
- Make or propose improvements to their design on the basis of their analysis and testing.

The NYSCATE module *Design for Manufacture* features a design challenge, which consists of designing a desktop CD holder, taking into account factors to optimize its manufacture. The CD holder must have the capacity to hold at least 20 standard-sized CDs on a desktop. Students do not need to overly concern themselves with features of the CD holder. It is to be assumed that there is a large demand for CD holders and any reasonable features chosen by students will sell in the marketplace. The holder can be a drawer style, stackable, open style, flip style, etc. The following steps are involved in this design challenge

(1) Student teams are established and charged with designing a desktop CD holder according to the above-mentioned specifications. Each team consists of 3-4 students.

(2) The challenge faced by students involves designing a CD holder that optimizes its potential for manufacturing. Many students would like to proceed with the design challenge by trial and error. To prevent this, they must be convinced that they need to find out what they now know as a group and what they will need to know about the process of design, and about design for manufacturing, in order to complete the challenge properly. The Knowledge and Skill Builders (KSBs) activities are meant to help students become more informed about the process of design and about design for manufacturing. All of the following KSBs include the following topics:
    - KSB T-1 The Informed Design Cycle
    - KSB T-2 Product Design Considerations

- KSB T-3 Manufacturing Methods-Materials
- KSB T-4 Manufacturing Methods-Construction Elements
- KSB T-5 Manufacturing Methods-Assembly Techniques
- KSB T-6 Manufacturing Methods-Coating
- KSB T-7 Manufacturing Methods-Packaging
- KSB T-8 Manufacturing Methods-Automation
- KSB T-9 Reverse Engineer a Product
- KSB T-10 Find a Good Example of Designing for Manufacture
- KSB T-11 Estimate/Calculate Materials Required

(3) Every student team is required to maintain either a design folio or a design journal in which team members gather and record information as they complete the design challenge.

(4) Every student team is required to prepare a final design report in which team members' work and findings are summarized. The final design report is a written report in which at least two product styles are compared. For example, a team might look at a drawer-type CD holder versus a flip-lid type. The report should include an evaluation of possibilities presented by various manufacturing methodologies studied in this course. In addition, the design decisions made by the student team must be justified in the report.

(5) The student team is required to build a model of one of the styles analyzed in the written report. The model does not have to be made of the same material or use the same methodologies recommended in the written report, but it should illustrate some of the major design decisions made by the student team. This model can be a physical model or a 3-D virtual model constructed using CAD.

(6) Every team is required to develop a group presentation to explain how the team members met the design challenge.

(7) All the student teams are assessed on the quality of their work on Knowledge and Skill Builders (KSBs), design journal or design folio, final design report, model, and group presentation.

IV. Use of NYSCATE Module Design for Manufacture in EDSGN 100

As stated above, the design project for EDSGN 100 was based on a NYSCATE Module entitled *Design for Manufacture*. The purpose of the module is to provide a teaching tool for faculty to be used in teaching not only the engineering design process but also the manufacturing processes and materials that are used in producing a product. The students were asked to consider the materials, construction methods, and manufacturing techniques that would be used in mass-producing their design. Students were guided through the design and manufacturing processes by completing a series of Knowledge and Skill Builder (KSBs) exercises. Some of the KSBs provide background information related to design for manufacture while others apply that information. The total time needed to complete the module consisted of six two-hour periods. While the *Design for Manufacture* module made up only part of the total activities related to engineering design in EDSGN 100, it was by far the largest single activity completed by EDSGN 100 students. Most of the students were first semester freshman engineering students with a few sophomores. What follows is a narrative of authors' experiences with the Design for Manufacture

Module as taught at The Pennsylvania State University - Altoona College during the Fall 2002 semester.

The first activity completed by students consisted of a pre-assessment exam to measure their knowledge of design for manufacture. The exam was made up of 10 questions related to the design cycle, manufacturing processes, materials selection, fasteners, coatings, and reverse engineering. At the completion of the module, the students again took the same assessment exam. Their scores were recorded and it was found that 77% of the students improved their assessment test scores significantly. Some of the questions from the assessment exam are listed below in Table 1.

Table 1

Selected questions from the Pre-Assessment Exam

1. What best describes the concept of "design for manufacture?"
    - A) Designing a product that can be manufactured as quickly as possible.
    - B) Considering the best materials and assembly techniques to use in a product.
    - C) Considering the cost of components in an item to be manufactured.
    - D) Designing a product that can be taken apart if re-work is required.

2. Which of the following metal items would best be manufactured through extruding?
    - A) Car body panels.
    - B) Door handles.
    - C) Tubing.
    - D) Aluminum foil.

3. Which of the following plastic items would best be manufactured through injection molding?
    - A) Drinking straws.
    - B) Plastic bags.
    - C) Wheels for gar grills.
    - D) Computer monitor housings.

4. Without the requirements or use of a product, which fastening method would lend itself best to mass production?
    - A) Use of adhesives.
    - B) Snap-together.
    - C) Screw fasteners.
    - D) Welding.

5. The informed design cycle is:
    - A) A process by which a design decision is made and carried out.
    - B) A process by which two wheeled vehicles are designed with computers.
    - C) A process by which a design decision is tested, reevaluated and possibly redesigned.
    - D) A process by which design documents are inspected.

6. Reverse engineering is:
   A) The process of analyzing a product to identify the product's components and operational relationships.
   B) The process of studying how engineers think and design products.
   C) The process of hiring an outside team of consultants to design a product based on an idea already conceived.
   D) The process of using previously published design diagrams to enhance a product under development.

As explained earlier, the students were divided into design teams of three to four students resulting in a total of twelve design teams. The students were given complete freedom in choosing their team partners. The teams elected a group leader or contact person for each design team. Every student was given a three-ring notebook with paper to be used as a Design Journal. The students also received a Design Folio giving them a basic outline that guided them through the initial design process, alternative designs, selecting an optimal design, constructing a working model or prototype, evaluating the design and presentation of their design to the class. The grading policy for the module was that all team members received the same grade which team earned on its final design report and presentation.

The first KSB covered by EDSGN 100 students was KSB T-1, The Informed Design Cycle. Students were provided information regarding various steps in the informed design cycle model. The steps are: Clarify Design; Research and Investigate; Generate Alternative Designs; Choose Optimal Design; Develop a Prototype; and Test, and Redesign.

The Informed Design Cycle is shown in Figure 1.

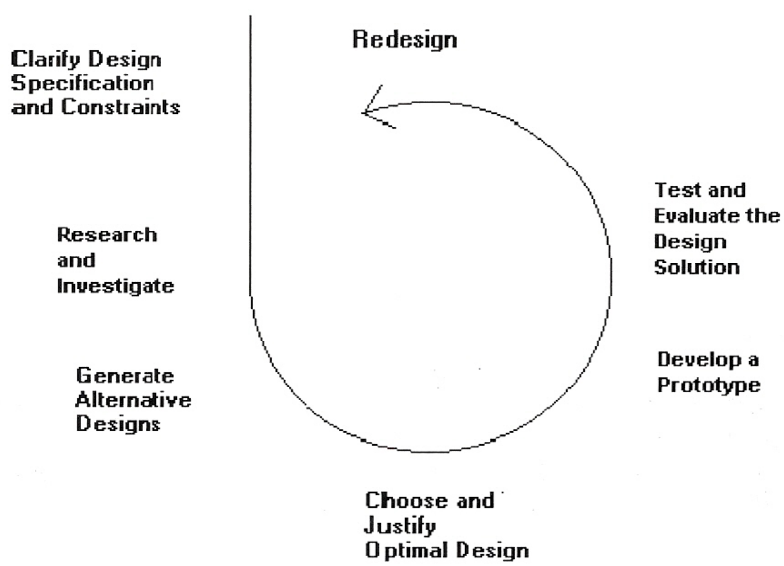

Figure #1

Students were asked to create some hand sketches or CAD drawings of their own possible designs and share them with the rest of the design team for consideration. KSB T-2, Product Design Considerations, helped to further define and clarify the designs by asking students to focus on topics such as intended customer, overall cost, service life, style, environmental considerations. At this point in the module it was found that most of the design teams had decided on one of the team members' designs to be used as final design for the CD holder. Interestingly, some of the design teams employed certain features of several of their team member's designs in developing a final design for the CD holder. Another observation was that none of the teams used the same basic storage concepts and so the CD holders varied widely in type and features. Normally, assigning student teams the same problem would result in similar solutions to the problem. Moreover, it was interesting to watch dynamics of the students trying to sell their own design to the rest of the team.

KSB T-3, Manufacturing Methods and Materials, asked design teams to find and list examples of products using the plastic manufacturing methods and processes of injection molding, blow molding, vacuum forming, extruding and forming sheets. The EDSGN 100 students also had to find and list examples of metal products manufactured using casting, machining, extruding, stamping and bending techniques. Products made from wood, glass and cloth were also sought and listed in the assignment. To help students in understanding the course material, they were shown two films related to design and manufacture of products using plastic materials. These films also helped students in understanding the material covered in KSB T-8 Automation.

Another activity completed by the EDSGN 100 students was borrowed from a short engineering course that has been taught at the Altoona College to young children ages 8-10 related to engineering called Dismantle and Discover. In this activity, the EDG 100 students were required to disassemble everyday items to their most elemental parts, using simple hand tools. The items used for this activity included two stroke chain saw engines, four stroke lawn mower engines, electric drills, VCR's, record players, personal CD players, toasters, toys of all types, electric motors, telephones, keyboards, stereos, speakers, radios, etc. All of the items were obsolete or discarded products and were obtained at a very little cost. After disassembling the items, the students were required to lay out the parts in an organized fashion and explain the products operation to the rest of their classmates, along with the materials and possible manufacturing techniques used for the product. The students conducted this activity with great enthusiasm.

KSB T-7, Packaging, was demonstrated with actual product samples. It was shown how various products were packaged and displayed in stores. Lastly, KSB T-11, Calculation of Material Required and Cost, was developed by having the student teams make rough calculation of material needs based on volumes and areas of materials of their CD holder design. This led to simple calculations needed to find total estimated material costs.

As a part of the *Design for Manufacture* module, student design teams were required to build an actual prototype of their CD holder. Most groups used materials supplied in class such as foam backed poster board, balsa wood, duct tape, hot glue, etc. The students were told that they did not have to build their prototypes to actual scale. They needed to build just enough of the prototype to demonstrate the principles of operation and features of their CD holder.
The design teams were also required to use their graphic skills and produce a set of working drawings of their prototype using manual drafting tools. Later in the course, after completing their CAD training, the teams were required to complete their final design drawings using the AutoCAD. These CAD drawings were included in their final report. A final report covering all aspects of the design process was collected for each design team. These reports summarized the steps and reasoning the teams followed in developing and selecting their best design for the CD holder. Cost and material estimates were also included in the report. The report was required to be completed in MS Word, a skill that the students were taught in the computer skills portion of the course. The report also included imported CAD drawings and the digital photos of their prototypes. The authors found that the reports varied greatly in content and quality. As no special care was taken in forming the student design teams, a possible reason for the variation on the quality of the reports may be due in part to some of the groups being filled with academically better students than other groups.

V. Assessment

In an effort to improve the NYSCATE module *Design for Manufacture,* EDSGN 100 instructors were asked to distribute and collect Student Reaction Form. The results of the Student Reaction Form indicate that the students in general, reacted to the module in a favorable way. The break down of the ratings is as follows: 12.5% of the students found the module to be excellent, 62.5% found the module to be good, 20% found the module to be fair and 5% found the module to be poor.

It should be noted that the EDSGN 100 students come from all the engineering majors that The Pennsylvania State University offers and one could postulate that some of the students just are not interested in the topic of design for manufacture. In response to the question of what was the most important thing the students learned from the module, the greatest number of students responded with statements related to learning about the design process and manufacturing techniques used to produce products.

These results seem to show that the students in general were less satisfied with their individual group's performance than with the module as a whole. Therefore, it is the authors' suggestion that care be taken in assigning students to design teams in order to balance the weaker students with stronger students academically, thus increasing the chance of a successful design team and a good learning experience for all the students. Constant monitoring of the design teams progress is also suggested to avoid any delays in completion of assigned tasks.

The concluding activity of the module was a brief classroom presentation of CD holder designs by the student teams using a Power Point presentation created by the teams. The teams also showed their actual prototypes during their presentations.

VI. Conclusion

The authors found the instructional module titled *Design for Manufacture* developed by The New York State Curriculum for Advanced Technology Education (NYSCATE), to be very complete and useful in teaching concepts of design for manufacture to freshman engineering students. The module made use of a project-based learning approach to enhance student participation in the learning process, increase communication skills, address a wider set of learning styles, and promote critical thinking. The authors feel that the module was effective in achieving its goals related to knowledge of the design for manufacture process as evidenced by a significant improvement in post assessment exam scores for 77% of the students. The module was also very flexible. The faculty members using the module had the freedom to emphasize areas they thought were important. The authors are planning to use this module in the future offerings of EDSGN 100 and in an associate degree Industrial Engineering Technology course. A suggestion by the authors is that care be taken in assigning students to design teams to balance the weaker students with stronger students academically in order to produce a successful design team.

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