Enhancing a Freshman Level Engineering Design Course Through Project Based Learning

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Abstract

The use of engineering design projects provides students with a broad context related to the material presented in the lectures. Through the use of project based learning, students are encouraged to assume responsibility for their learning experience and to shift from passive to more active learning pattern. This is likely to improve the knowledge retention as well as the ability to integrate material from several different courses.

Engineering Design and Graphics 100 (ED&G 100) is an introduction to engineering design course for all freshman baccalaureate engineering students at the Altoona College of the Pennsylvania State University. In this three credit-hour course, engineering design process is taught through team oriented design projects supported by communication skills: graphical and written. Implementation of project-based learning in ED&G 100 course is achieved by assigning a comprehensive project designed to encompass all the fundamental engineering principles covered in the course and to complement the projects conducted in the associated design laboratory. The capstone project requires students to design a product to be mass produced. To solve this design challenge, students learn about manufacturing methods. They evaluate design options and make decisions based on information regarding engineering design process, manufacturing methods, and various economic considerations.

Introduction

In recent years, the engineering education community has shown increasing interest in project-based learning approaches. The benefits of project-based learning include enhanced student participation in the learning process, enhanced communication skills, addressing of a wider set of learning styles, and promotion of critical thinking.[1] The use of engineering design projects provides students with a broad context to the material presented in the lectures. A thorough literature survey provides information regarding implementation of project-based instruction into several freshman engineering/engineering technology courses.[2,3,4,5,6]

Engineering Design and Graphics (ED&G 100) is an introduction to engineering design course for all freshman baccalaureate-engineering students at the Altoona College of the

Pennsylvania State University. In this three credit-hour course, engineering design and principles are taught through team-oriented design projects supported by communication skills: graphical, oral, and written. The course is made up of three components with each component meeting for a single two-hour period once a week. This gives a total class meeting time of six hours per week for fifteen weeks.

The first component of the course 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, MS Power Point presentations, 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 multi-view projection, dimensioning, lettering, oblique and isometric projection, sectional views, tolerances, scales, and selected topics in descriptive geometry.

The third component of ED&G 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 the ED&G 100 to increase students' interest in the field of engineering with the hope of reducing the transfer rate of students who leave the engineering major. This course is one of only three engineering courses taken by students during their first two years at the Pennsylvania State University. The majority of the courses taken by students during the first two years of any engineering program consists of mathematics, physics, chemistry, English, arts, social sciences, and humanities.

This paper focuses on the backbone of the ED&G 100, that is, its engineering design component. During the Fall 2002 semester, the primary vehicle used for the engineering design component of ED&G 100 was an instructional module titled *Design for Manufacture* developed by The New York State Curriculum for Advanced Technology Education (NYSCATE). The paper will outline the NYSCATE *Design for Manufacture* module, discuss the use of the module, and present assessment results.

Pedagogical Framework of NYSCATE Module

The New York State Consortium for Advanced Technology Education (NYSCATE) is a consortium of two-year and four-year institutions in New York state. These institutions include Finger Lakes Community College, Fulton Montgomery Community College, New York City Technical College, and Hofstra University. NYSCATE is currently developing, field testing, and preparing for distribution, fourteen grade 9-14 advanced technological education curriculum modules. These modules represent three areas of technology:

bio/chemical, information, and manufacturing. Each module features the integration of mathematics and science principles through informed design process.

It is expected that after completing the NYSCATE *Design for Manufacture* module students will:

- be familiar with a variety of manufacturing methodologies such as injection molding, blow molding, metal casting and sheet stamping and bending, assembly techniques and automation, surface finishing, and packaging techniques;
- understand each methodology's applicable materials, and advantages and disadvantages including relative costs and effects;
- be familiar with a variety of materials used to manufacture and package products; and
- understand the advantages and disadvantages of the materials in the design, manufacturing, and packaging of products.

In this module the teacher is expected to:

- prompt acquisition of mathematical analysis, scientific inquiry, and informed design processes;
- foster cooperative learning as students work in design teams;
- provide opportunities for improving communication skills through the use of the Design Journal or Design Folio, Design Report, and group presentation;
- introduce students to the design process through an engaging Design Challenge;
- involve individuals and groups as they compose, construct, test, improve, and present their design solutions;
- help students refine what they already know about informed design and, more specifically, designing for manufacturing;
- guide students as they identify and investigate factors relevant to design for manufacturing decisions.

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 containers 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) are meant to help students become more informed about the process of design and about design for manufacturing. The KSBs are on 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.

Use of NYSCATE Module Design for Manufacture in ED&G 100

As stated above, the design project for EDG 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 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 course time to complete the module was approximately six two-hour periods. Please note that while the *Design for Manufacture* module made up only part of the total activities related to engineering design in ED&G 100 it was by far the largest single activity we completed in the engineering design component of ED&G 100. Most of the students were first semester freshman engineering students with a few sophomore students. What follows is a narrative of our experiences with the Design for Manufacture Module as taught at the Penn State Altoona College Fall semester 2002.

The first activity completed by students was to take 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.

As explained earlier, the students were divided into design teams of three to four students giving a total of twelve design teams. The students were given complete freedom in choosing their team members. The teams elected a group leader or contact person for each design team. Each 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 as the team earned on its final design report and presentation.

The first KSB that the students covered was KSB T-1, The Informed Design Cycle.

Students were given the steps in the informed design cycle model which included: Clarify Design, Research and Investigate, Generate Alternative Designs, Choose Optimal Design, Develop a Prototype, Test and Evaluate and Redesign. At this point the 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. The KSBT-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 we found most of the design teams had decided on one of the their 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 that was made 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 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 in their understanding students were shown two films related to design and manufacture of products using plastic materials. These films also helped students to some extent in understanding the material covered in KSB T-8, Automation.

An activity that the students completed is called Dismantle and Discover. In this activity the 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 stroked 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 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 received this activity with great enthusiasm.

KSB T-7, Packaging, was demonstrated with actual product samples. As a class we discussed and showed 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 lead to simple calculations to find total estimated material costs.

Another activity to further reinforce the design for manufacture process was a guest speaker visit by Mr. Edward Kopp of State College, Pennsylvania. Mr. Kopp is a consulting engineer who gave a Power Point presentation to the entire class on a four-wheeled utility cart project that he was developing. Mr. Kopp explained how he was brought into the project to develop a computer solid model of the original prototype utility cart. Mr. Kopp used Solid Works software in developing his model. Mr. William Groove of Creative Solutions Incorporated, located in Center Hall, Pennsylvania developed the original prototype for the utility cart under contract from the Flexible Flyer Corporation located in Mississippi. He explained that Southern Comfort Corporation located in Mississippi is responsible for manufacturing the plastic body parts for the utility cart and explained the vacuum molding technique that was used to form the body components. He also showed an actual plastic fuel tank to the students and explained how it was manufactured using a rotor molding process. Mr. Kopp showed the students how the prototype and solid model of the cart were developed and how various manufacturing techniques for both steel and plastics components were considered in the final production design. He also addressed cost considerations, as the target cost for the completed cart was to be under $5000 and explained to the students that most of actual production of the cart takes place in China because of reduced manufacturing costs. Marketing of the cart is to be done by Sam's Club stores across the country with a first run of 10000 units. Photos of the manufacturing site in China were also shown to the students. Mr. Kopp's presentation was very well received by the students. Many of the students stayed after the presentation for a short demonstration given by Mr. Kopp on the Solid Works software package.

Several articles related to design and innovation, design for manufacture and assembly, design for disposability were distributed to the students for reading. Articles of past successful designs and their impact on society such as the Phillips Screw, the stapler and the paper clip were also given as readings. Students were given a short quiz with questions pulled from the all the readings. It was the intent of the quiz to make sure that the students read the articles.

As 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 prototype to actual scale or build a complete prototype if their design was very complex. 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 developing 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 CAD software 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 of their prototype along with imported digital photos of their prototypes. The authors found that the reports varied greatly in content and quality. As no special care was taken in the forming of 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 than others groups.

Assessment of the NYSCATE Module

In an effort to improve the NYSCATE module *Design for Manufacture* we were asked to distribute and collect Student Reaction Forms and Student Group Assessment Forms. The results of the Student Reaction Forms 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 is the opinion of the authors that should we elect to teach the module a second time, these scores would improve as our proficiency in teaching the module improves from experience. It should be noted that the students are made up of all the engineering majors that Penn 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. What the authors found interesting was the second most common response, which related to working together in design groups and the teamwork necessary to complete an assigned task. The results of the Student Group Assessment Forms are as follows; 10% of the students gave their group a success rating of A, 37.5% of the students gave their group a success rating of B, 35% of the students gave their group a success rating of C, 12.5% of the students gave their group a success rating of D and 5% of the students gave their group a success rating of F. 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 author's suggestion that care be given 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 prototype during their presentations.

Conclusion

We 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. We feel 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 ED&G 100.

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Biography

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