Project-Based Learning in Engineering Design and Graphical Communication

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Abstract – Retention of engineering students from the freshmen year to the sophomore year is a concern of many engineering institutions. Also of concern is the ability of students to take knowledge learned in one application and transfer it to another application. To address these issues the Engineering program at the University of Tennessee at Chattanooga (UTC) has recently redesigned its freshmen Introduction to Engineering Design course (IED) to excite students to independently learn, to create an environment for peer learning, to increase student in-class and out of class participation, and to emphasize and connect the role of graphical communication in the design process. It is believed that these objectives are instrumental for exciting students about engineering, for increasing student retention, for motivating learning, and for improving students’ knowledge transfer capabilities especially in the application of engineering design.

This paper provides an overview of the UTC IED course, its objectives and project structure and how students use projects and technology, specifically, computer-based systems such as SolidWorks software to enhance learning.

Keywords: Design, PBL, 3D Modeling, Freshman Design

INTRODUCTION

Figure 1: UTC IED Student Project – Welding Jig

Figure 1 above illustrates a solid model of one of eight student final projects from the Fall 2005 semester of the Introduction to Engineering Design (IED) course at the University of Tennessee at Chattanooga (UTC). IED is offered during the freshman year and introduces the design process to the students. The students experience

- the role of design in engineering.
- the application of the engineering design process including: problem definition; objective, function and constraint definition; standards/codes identification; idea generation; and simple decision-making.

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- the role and function of design teams.
- the fundamentals of graphical representation in design including sketching and 2-D and 3-D computer modeling.
- the role of graphical communication in defining and communicating a design
- the use and practice of oral and written reports in design including reporting on status and design proposals.
- the role of ethics in design.

The theory and practices introduced in this course are reiterated, applied, and expanded in three other courses traversing the remaining three years of the curriculum (see Figure 2).

Figure 2: The Engineering Design and Communication Emphasis (EDC) Structure

As shown in Figure 2 at least ten credit hours are devoted to teaching (to all engineering majors) design and communication concepts in an applied, interdisciplinary setting. At the freshmen level the students are introduced to the foundations of design and communications. At the sophomore level the students use design concepts to design and build small structural and mechanical projects and communicate weekly activity. The students also emphasize testing of the devices. At the junior and senior level the students use design and communications concepts to solve and communicate findings of real-life and open-ended interdisciplinary industry-based problems provided by industrial sponsors.

The goal of the engineering design and communication (EDC) curriculum is to graduate students who can apply the steps of the design process to various interdisciplinary and discipline-based applications, use solid modeling to visualize designs and aid in prototyping designs, and use various techniques and practices to communicate final designs to the customer. The first step toward meeting these goals is to introduce solid modeling and the steps of the design and communication processes in UTC’s 3 credit hour IED freshman level course. The design process introduced during IED and emphasized throughout the 4 year curriculum is shown in Figure 3.
This paper describes the goals of the freshman *Introduction to Engineering Design* course, its objectives and project structure and how students use projects and technology, specifically, computer-based systems such as SolidWorks software to enhance learning.

**Course Goals and Objectives**

UTC’s IED course has three primary goals: (1) to expose students to the process of engineering design, (2) to expose students to the techniques of technical communication, and (3) to instill in students an excitement for participating in an engineering curriculum. The above is accomplished in the context of three projects of which two require customer contact. The three projects are designed to introduce design concepts, solid modeling techniques, drawing and sketching basics, technical writing practices, and prototyping experiences.

After completing the IED course, the students should know how to

- formulate a problem statement
- create project objectives
- distinguish between functions and specifications
- use idea generation exercises to generate alternative solutions to a problem
- use at least one proven means for deciding between design alternatives
- recognize and apply ethical decision-making practices.
- organize, participate in, and document team meetings
- participate as a contributing team member in the design and problem solving processes
- apply graphical 2-D and 3-D drawing principles
- use a 3-D modeling software package
- use the principles of good oral communications to effectively communicate major ideas
- use Microsoft PowerPoint software to aid oral presentations
• use Microsoft Project for creating a simple Gantt Chart
• use principles of good technical writing (emphasizing minimizing wordiness and improving formatting and use of headings) to effectively communicate major ideas

Course Structure
IED introduces 3D modeling, 2D sketching, and graphics concepts in the context of individual, class, and team projects as well as individual (supplemental) exercises. IED meets for four hours each week – evenly split between lecture time and lab time. A fifth hour emphasizing individual coaching is offered for any students wishing additional instruction. Class size is limited to 24 students. Two sections are offered each semester.

IED learning focuses on three projects – an introductory individual project, a class project, and team project. The time requirements and learning expectations are summarized in Table 1.

Table 1: IED Project Structure

<table>
<thead>
<tr>
<th>Project</th>
<th>Length (weeks)</th>
<th>Learning Expectations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introductory</td>
<td>2</td>
<td>(a) Sketching; dimensioning; solid modeling; rapid prototyping</td>
</tr>
<tr>
<td>Class</td>
<td>5</td>
<td>(a) and (b) design process; customer needs; defining objectives, functions, constraints, standards; concept generation; technical writing; oral presentations</td>
</tr>
<tr>
<td>Team</td>
<td>8</td>
<td>(a) and (b) and (c) decision making; prototyping; testing,</td>
</tr>
</tbody>
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The Introductory Project
The introductory project requires each student to sketch, model, and build a puzzle cube of five parts (see Figures 4 and 5). Each part is made from four to six one-inch cubes. Each part must have 3 axis so they interlock.

![Figure 4: Puzzle Cube](image1)

![Figure 5: Exploded Puzzle Cube](image2)

Upon completion of the project, each student provides the instructor original hand sketched drawings of 10 possible parts. Using SolidWorks, the students must also provide
• a 3 view drawing of each final puzzle part with an isometric view on an A size sheet. Parts should be completely dimensioned.
• all 5 parts in 3 views with an isometric view and 2 isometric views of the assembled part on a C size sheet.
• an exploded isometric drawing with parts list and ballooning on an A size sheet.
• a fabricated puzzle created from a rapid prototype machine

If a student has previous 3D modeling or CAD experience and completes this assignment quickly the student may use the SolidWorks software to cut the cube puzzle to another shape and create new individual
puzzle parts. The student can then fabricate the new puzzle on the rapid prototyping machine and repeat the deliverables for the new puzzle (except for hand sketches).

The Class Project
The class project is a large design project somehow associated with the College of Engineering and Computer Science or its building such as the fall 2005 project – a recycling center. This project requires teams of students to investigate or research user and customer needs, historical context and present designs, locations and use options, process of use options, and substantiation of need. The students must learn to recognize credible sources and determine how to gather credible information. Books, journals, the internet, students, faculty, and staff are often used as sources.

Following the research stage the students summarize their findings in a short paper and share this paper with the other students using the course website. The teams of students also present a summary of their findings to the class in a short presentation.

As a class, the students then brainstorm project objectives, functions, and constraints. Class instruction introduces the students to objective trees and input/output functional block diagrams to help them clarify and document their understanding of the project device. They submit individual understanding of the objectives and functions as trees and diagrams to the instructor for feedback. A sample student generated objective tree is shown in Figure 6.

Figure 6: Sample Student Generated Objective Tree for Recycle Center

Each student then creates a project solution (design) using SolidWorks based on their understanding of the project problem statement and related important device functions, customer and user objectives, and project constraints (including standards requirements). Figure 7 illustrates one such student design. The exercise concludes, following a lecture on technical writing, with each student creating a proposal of their design complete with definition of problem, objectives, functions, and constraints, as well as drawings (part and assembly) with dimensions. The students also present their designs to their peers and interested faculty in individual presentations.
The Team Project

The goal of the team project is to provide the students the opportunity to use what they learned in the class project in a team setting and for a real customer. Project proposals are requested of faculty, staff, and students. Each proposal states a brief statement of the problem the students should address which should not include any consideration of AC power. The problem is constrained so that the students can complete the project in 7 weeks. The problem requires the students to investigate the device and device applications, understand and define customer needs, and identify device objectives, constraints, functions, and code/standards requirements. The problem is also complex enough to have a variety of solutions so the students participate in decision making to choose the design that best meets the device objectives. The problem requires the students to create a 3D model as well as a prototype of the device.

The proposals are provided to the instructor who selects four to five proposals for each section. The students read each proposal and select which project they want to work on. Ideally there are four or five students for each project.

Using the team project the students learn to manage a team, brainstorm ideas, generate alternatives, decide between alternatives to best meet developed criteria, and generate test procedures. Before initiating project activity, however, the students are introduced to concepts of group dynamics, personality styles, and team problem solving. They then must learn about their project and device and begin defining customer needs, objectives, functions, and constraints using the tools learned earlier in the semester.

The students are also introduced to concept generation and creative thinking practices. Brainstorming and Mind Mapping are discussed and practiced in the team environment. The students then generate at least 10 possible solutions for their device and problem statement. Students are also introduced to the concepts of morphological charts. The students use this tool to break the possible solutions into components and to recombine them to develop additional possible solutions.

Once the 10 possible solutions are generated, the students are asked to select 3 to 5 they believe to be the “best” solutions based on ability to create a prototype and to meet the customer criteria. This is a “we think” selection with no basis in decision theory. Then the students are introduced to several
concepts of decision-making including pair-wise and weighted comparisons. They select the best of the 3 to 5 solutions using these tools and the customer criteria outlined in their objective trees. The decision on how to weight the criteria is sometimes based on the clients’ needs; other times based on a vote of opinion of the team members, depending on the project.

Each team is required to develop and test a prototype of the solution. Some monetary support is provided the teams depending on the proposal origin (some are supported by Grants). The teams develop procedures to test selected device functions to determine whether they meet the customers’ criteria. The test procedures, collected data, and analysis are included in the team final report.

The team final report is a compilation of team exercises (such as defining objectives and creating test procedures) assigned throughout the last half of the semester. Each of the team exercises are posted on the teams’ websites and reviewed by the instructor. Instructor comments are posted on the websites prior to the submission date of the report so the students can revise and improve their work. The students must present their report in writing as well as orally. The oral presentation includes a demonstration of the prototype.

**DISCUSSION**

IED has been offered since August 2001 but was revised the fall of 2005 semester in two ways – (1) to use 3D solid modeling instead of a 2D software package as the drawing learning tool and (2) to use project-based-learning to teach the 3D solid modeling package. The student outcomes of the fall 2005 semester far exceeded expectations of the instructor and produced excellent reviews from the College faculty. Of specific interest was how quickly students learned the modeling package, how well the students learned drawing concepts, and how the use of the 3D modeling software affected the outcome of the team project.

**Using SolidWorks**

Students quickly learned how to use the SolidWorks software and to create simple as well as complex parts. One student, who had a semester of Autodesk Inventor software instruction commented that the other students were able to do in three weeks what he learned to do in one semester (using traditional means of instruction). The initial puzzle cube project was instrumental in this instruction. The instructor provided an overview of how to use SolidWorks to build parts, how to mate parts, showed some examples, and then let the students experience and practice on their own. The students were also assigned various software tutorials to complete. The structure of the course allowed the instructor to roam the room to respond to individual questions and then stop class work when a question prompted a response addressed to the entire class.

The class project initiated instruction in more advanced solid modeling concepts such as sheet metal use, revolving, engraving, and referencing geometry. Again, the instructor introduced the topics as they became relevant to a student’s or students’ design. Thus the students would learn the application and immediately apply it.

Supplemental exercises using the SolidWorks software were also assigned to the students to give them practice on solid modeling applications not introduced in the first two projects. These supplemental exercises provided more practice in creating parts, referencing geometry to extrude and cut, dimensioning parts, creating holes and hole callouts, and using special features such as shelling, lofting, sweeping, and ribbing. The students also created their own title blocks taking into account information needed on a drawing. These assignments were reviewed by the instructor during class. Thus, students were provided immediate verbal feedback so they could use these techniques for their team project.

Most students were successful with the project-based learning approach. They succeeded through spending much time using the software and working with their peers. Aside from office hours and classroom hours, the instructor supported a one hour open lab time to help with individual software use
issues. The sessions were attended by no more than 7 students each week (there were initially a total of 41 students in the course).

**Learning Drawing Concepts**

Each of the three projects required completely dimensioned 3 view plus isometric view drawings as a part of the deliverable package. Thus all students were required to learn how to dimension, to view a part from various views, to create specialty views for appropriate dimensioning, to create assembly drawings, and to create exploded view drawings. The difficulty of the drawings progressed as the difficulty of the projects progressed. The students were provided short lectures on how to dimension and create appropriate drawings and were allowed to practice in class. The students did not have a text that provided any instruction on how to dimension and create drawings.

Most students were successful at learning the basics of dimensioning and creating part drawings. However, those students who had no previous drafting or drawing experience did lag behind those who did. A few of these students, even at the end of the semester, were not able to identify when they were over dimensioning a part. However, most students could identify an incorrectly dimensioned part and know how to correct it. The supplemental exercises were important to many of the students in giving them more practice at dimensioning.

**Team Project Outcomes**

The fall 2005 semester resulted in eight completed projects:

- Shower Curtain Hanger
- Tubing Jig for MiniBaja Project
- Welding Jig for MiniBaja Project
- Car Jack Handle
- Pilot Cockpit Knee Board
- Mobility Tricycle for Child with Disabilities
- Communication Mount for Child with Disabilities
- Remote Switch for Child with Disabilities

The team projects greatly benefited from the use of the 3D software package especially for providing 3D models of the projects as well as complete drawing packages for the prototype builds. The models also aided communication with the customers for discussion functions and features and manufacturing. For example, Figure 1.0 illustrates the finished 3D model of the Welding Jig for the MiniBaja project. When first completed the students envisioned the major parts of the jig being sculptured from a solid block of metal. When they showed the model to the customer (a student in the senior design course) they realized that the jig needs to be constructed of many pieces cut from a sheet of metal. The result is a jig composed of over 20 parts (see Figure 8).

![Figure 8: Exploded View of Welding Jig](image_url)
Other students learned that even though they designed their device one way, the prototype may not, due to constraints, exactly meet the design portrayed in the 3D model. For example, one team developed a tricycle for a child with Prader–Willi Syndrome. This child can not yet walk and has difficulty keeping his body upright in a seated position. However, he gains weight easily and must exercise. The original design is as shown in Figure 9. It has a particular geometry and seat style that could not be duplicated due to time and budget constraints. The resulting prototype is shown in Figure 10. The prototype was tested with the child as the rider and was found to fit well except for the reach to the pedal.

The learning opportunities from the projects appeared to occur no matter if the project involved many parts or few parts. For example, some teams used sketching as well as 3D modeling to help them visualize their designs. The Shower Curtain Hanger team designed a hanger that holds both a shower curtain and a shower liner and allows one to be removed without removing the other. The team created a design on paper and thought it was their final design and would work, so they also created a 3D model (see Figure 11). It was not until they created the 3D model that they determined that the design would not work – the hangers are 90 degrees out of line with the ring and can not hang the curtains! Figure 12 shows the final design they proposed and prototyped.

CONCLUSIONS

The IED course has a history of introducing student projects that emphasize improving devices. However, the Fall 2005 semester was the first semester in which students created complete drawings of their designs and operable and usable prototypes. In addition, most of the report packages were complete and explained the device functions and functions as well as design constraints. The reports discussed proposed tests for the manufactured device as well as performed tests and results for the prototype. But what stood out most for those faculty observing the presentations or reading the reports was the ability of freshmen students to communicate their designs using 2D and 3D techniques. The descriptions of the designs as well as the drawing packages were thorough.
What is also of interest is that much of what the students used to present their designs in their presentations was not taught by the course instructors. The students taught themselves. They found the SolidWorks software package fun to work with and generally easy to understand. They became fully engrossed in using the software to help ensure that their design was functioning as designed (using the 3D animation) and thus could be produced as a working prototype. Thus, they put in the time and effort to learn what was needed to succeed.

At the end of the semester when the designs were complete and the prototypes presented, the students were proud of their products. They stated they enjoyed the course even though it was “a lot of work for 3 credit hours!” It appeared that the addition of a client made the projects more real especially for those working with the children with disabilities. They learned that what they do as engineers, even freshmen students in an engineering program, can have a long lasting positive effect on someone’s life.

**FUTURE WORK**

At first glance the results of the end of the semester student survey used to indicate how well the course meets its objectives does not differ from those of previous semesters. However, a more statistically rooted analysis is in progress that will provide more conclusive evidence of any differences. It is hoped that the course has created more excitement for commencing an engineering career.

It is also hoped that the addition of 3D modeling to the IED course will help students visualize in 3 axis. An instructor of a sophomore level course found in the past that many students, even those with traditional CAD experience have difficulty visualizing 3D placements. A survey tool is being developed to measure student’s ability to visualize in 3D. Sophomore students who participated in the revised IED course as well as those who participated in the original IED course will take this survey. The results of the surveys will be compared and analyzed to determine whether a difference in visualization capabilities exists between the two populations.

Some small changes will be made to the Spring 2006 IED course. For one, a simple text on engineering graphics concepts will be a required resource. This text is necessary to provide students visual support when learning dimensioning as well as tolerancing which was not successfully covered during the Fall 2005 semester. Also, a second instructor will support the course. During the active learning portions of the course it was difficult for the one instructor to meet with all students. The second instructor will provide more one-on-one time with the students which is important in project-based learning.

**REFERENCES**


**Cecelia M. Wigal**

Cecelia M. Wigal received her Ph.D. in 1998 from Northwestern University and is presently an associate professor of engineering at the University of Tennessee at Chattanooga (UTC). Her primary areas of interest and expertise include complex process and system analysis, quality process analysis with respect to nontraditional applications such as patient safety, and information system analysis with respect to usability and effectivity.