Freshman Engineering Design in the Design4Practice Program

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Abstract

The award winning Design4Practice program (1999 Boeing Outstanding Educator Award) incorporates a design experience into each of the four years of the engineering programs at Northern Arizona University. This paper describes the experience that new engineering students receive in the freshman course titled "Introduction to Engineering Design". This multi-purpose course serves to provide experiences in the engineering design process, working in teams, introduction to the engineering professions, planning for success, development of communication skills, and an introduction to mathematical modeling. The course has been designed to articulate with the other schools in Arizona, and a matrix of the outcomes that all the Arizona universities and community colleges are expected to achieve is included in the paper.

I. Introduction

Many freshman students opting to study engineering are not sure if they really should and, if so, do not know which field of engineering to select as a major. In the typical engineering curriculum, most of the freshman year is spent studying mathematics, chemistry, and physics courses with little or no exposure to engineering. The course, *Introduction to Engineering Design*, was developed to bring these freshmen into the College of Engineering and Technology, expose them to the various engineering programs available at Northern Arizona University, and to develop their skills as problem solvers and communicators. Other important objectives for the course are to develop teaming skills, to provide exposure to ethical issues, and to initiate the development of skills that will be used in the subsequent three engineering design courses. This course is the initial step in the *Design4Practice*[1] curriculum, first described in 1995[2], and which won the 1999 Boeing Outstanding Educator Award.[3]

II. Background

The first engineering design course developed and offered at Northern Arizona University was a capstone course which integrates content from many of the previous engineering courses into a team-oriented, senior-level design experience. After several years of successful capstone courses, the faculty determined that the senior course could be much more effective if students learned to use some of the so-called "soft" skills earlier in their educational experiences. Subsequently a sophomore-level course, *Engineering Design: The Process*, was developed and offered, followed

by a junior-level course, *Engineering Design: The Methods*. The senior capstone course is called *Engineering Design: The Practice*.

The freshman course was developed with the intent of introducing necessary skills that require no technical background while exposing the students to the excitement of engineering, and introducing them to the various engineering fields they might elect to pursue. The course was taught initially as a two-semester sequence with no prerequisites and was offered to students who were deficient in their mathematics and science preparation. The philosophy was to provide students with some exposure to the engineering field, some simple team-oriented design, and strong support for academic success. The present course is a one-semester, three-hour course with a minimum mathematics proficiency of algebra and trigonometry (pre-calculus). Team-oriented problem solving has become the major focus of the course.

III. Course Description

Multiple sections of the course are offered in both the fall and the spring semesters. A typical section has an enrollment of from thirty to thirty-five students most of whom are designated as pre-engineering majors; some are designated as undecided, and use this course to see if they would be interested in engineering. Each section holds two 2-hour meetings per week. Two textbooks are required. One text treats the engineering design process[4] and the other is a guide for spreadsheet use.[5] The information in the textbooks is supplemented with handouts developed by the instructors.

The course is structured to provide experiences in: (1) the engineering design process, (2) working in teams, (3) engineering as a profession, (4) planning for success, (5) written and oral communications, and (6) mathematical modeling using spreadsheets. These six learning objectives evolved from a series of meetings attended by representatives of Northern Arizona University, The University of Arizona, Arizona State University, and several of the Arizona community colleges where pre-engineering courses are offered. The purpose of the meetings was to develop a framework for the introductory course so that the course, when offered at one State educational institution, would articulate at any of the others. Articulation is discussed in more detail in Section IV of this paper.

Major development of the course has occurred through the cooperative efforts of the three faculty members who co-author this paper. The teaching team has worked effectively together, bringing backgrounds and experiences from an accumulation of approximately sixty-five years of teaching and from professional design in the disciplines of civil, mechanical, and electrical engineering. The faculty teaching team meets weekly to plan activities with focus on the six learning objectives mentioned above. The following discussion describes a typical semester of *Introduction to Engineering Design*, and the activities used to address the six learning objectives.

III.1 The Engineering Design Process

Three major team-oriented design projects are assigned each semester. Each project emphasizes a different engineering discipline and relies on the students' creative abilities rather than upon their limited technical abilities. In the usual semester the three projects assigned could be:

1. Build a paper bridge that spans a minimum of thirty inches while maximizing strength and minimizing cost. The student teams are provided a kit of bridge building materials consisting of a pad of paper, a tube of glue, a roll of tape, a spool of sewing thread, and some straight pins. There is a cost associated with each item in the kit. Each team is required to sketch and submit four alternative designs developed during a brainstorming session prior to building the bridge.
2. Build a toy that is powered by a mousetrap spring. Each team is supplied with two mousetraps to be used in their design. The toys are required to be safe, reliable, rugged, aesthetically pleasing, easily packaged, and have a high excitement level. Each team is required to generate at least four concepts for their design and to use a decision matrix to select the concept from which the prototype is developed.
3. Develop an electrical device that will alert drowsy drivers. Each team is given information concerning the frequency of automobile accidents related to sleepy drivers. They are asked to develop a detailed problem statement and to do Web research to determine the availability of existing products. They generate several solutions, select the one they determine to be the best solution, and develop a prototype. Each team is allowed to spend a limited amount of money and they are reimbursed for expenses not exceeding that limit.

Testing a Paper Bridge

Testing a Marshmallow Launcher

All assignments are given in a memorandum format. The students submit progress reports in a memorandum format. Each team with all team members participating makes oral presentations, and the prototypes are demonstrated and tested. All members of the class submit written critiques of the designs. Final written summary reports are presented which, along with peer reviews of team members' performance, are used to develop a grade for each team member. The grades on the three team projects represent forty percent of the total grade for the course.

New design projects are used each semester. Some of the other design projects assigned include a paper tower, a child's electric multiple choice testing machine, an edible scale, a household device that incorporates a thermostat, and a marshmallow launcher.

Before the first design project is assigned, students are prepared with several activities. They are introduced to the five-step design process discussed in Howell's *Engineering Design and Problem Solving*.[3] The five steps are: (1) Define the problem, (2) Gather pertinent information, (3) Generate multiple solutions, (4) Analyze and select a solution, and (5) Test and implement the solution.

To help the students understand the process of accurately defining a problem, a team exercise, inspired by a Motorola University activity[6], is conducted to build a Tinkertoy® tower. The tower's construction is limited by several parameters, but the students have to frame appropriate questions in order to discover those parameters. The exercise is followed by an assignment to write a complete problem statement that provides all the information needed to build the tower.

To help them open up their thinking to facilitate the generation of design ideas, the students are required to view the Joel Barker videotape, *The Business of Paradigms*[7] and to prepare a two-page paper commenting on the video. As part of the paper, they discuss why it is important to recognize paradigms, how to use them successfully, and how to avoid paradigm paralysis.

III.2 Working in Teams

After a brief introduction at the first class meeting, students are divided into groups of six or seven. They then spend a few minutes getting acquainted with one another. Each student is then asked to stand and introduce all of the other students at his/her table. At subsequent class meetings during the first three weeks of the semester, new groups are formed at the beginning of the class period and the exercise is repeated. After the first three weeks most of the students know one another and, because of their familiarity, are more comfortable when assigned to a team. Faculty participate in this process and get on a first-name basis with the students.

Team problem solving exercises are used throughout the semester. An attempt is made to provide new team members for each exercise. Brainstorming techniques are discussed and used in classroom problem solving. At the beginning of each of the three major design projects, each team is asked to develop team rules and team member roles. The written reports for each project contain those rules and roles, and each team member is required to provide a confidential written evaluation of all other team members based on those rules and role assignments.

Numerous puzzles and mathematical problems are solved in teams. One exercise used early in the semester is to develop a peg that can be used to completely fill and pass through a circular hole one inch in diameter, a one-inch square hole, and a triangular hole with a one-inch altitude.[8] The teams brainstorm solutions, evaluate them, and report their solution at the next class meeting. This exercise helps the students overcome the "square peg, round hole" paradigm.

III.3 Engineering as a Profession

To introduce students to the available engineering majors at Northern Arizona University, teams are formed and one copy of each of the programs of study for each of the five majors is provided to each team. Each team then discovers common courses among the various programs, and also

courses that are unique to each program. This leads to a discussion of ABET requirements and to the types of activities performed in each engineering discipline.

Videotape presentations and visits from officers of student organizations are also used to inform students of the various engineering disciplines. Petroski's *To Engineer is Human*[9] videotape is used to illustrate the lessons that can be learned from errors made in the engineering design process.

Ethical issues are introduced in two formats. The team board game, *The Ethics Challenge*[10], provides an opportunity for serious discussion of workplace ethical decision-making. Scenarios for academic ethics and how they relate to engineering are discussed using the video, *Academic Integrity: The Bridge to Professional Ethics*[11]. A writing exercise is assigned that requires individual consideration of these ethics discussions.

III.4 Planning for Success

Activities are developed to introduce the freshmen engineering students to the support resources provided at Northern Arizona University. A short paper is assigned which, when coupled with a self-guided tour of the two Learning Assistance Centers, helps them identify resources for successful note taking, tutoring, overcoming test anxiety, developing effective study methods, and time management. A tour of the Centers also helps the students identify computer labs available for their use.

Teams are formed and a scavenger hunt of the library is conducted. The teams identify and report back in writing such things as authors of specified books, availability of videotapes, and Internet access through the library's computers. Successful completion of the scavenger hunt helps the students familiarize themselves with the resources available in the library and how to use them successfully. This assignment is made one week before the instructors assign a major technical report that requires identification and use of at least three reference sources.

Students are provided a time log for recording how they use their time for a one-week period. Upon completion of the log they submit a memo reporting on their time management. They are then given a follow-up assignment to prepare and report a time budget showing how they could be more efficient in their time management. To stress the importance of attitude and the need for a vision the videotape, *The Power of Vision*[12], is shown. A segment from a second video, *Effective Technical Communications*[13], addresses the necessity of goals and planning. Students are then asked to discuss their vision and identify short- and long-term goals, and a plan for reaching those goals as part of their time management report.

III.5 Written and Oral Communication Skills

In addition to the many memoranda and short reports required of the students, each of the three team-oriented design projects requires a team written report. Students are thus given experience with individual written reports, and the cooperative effort required to produce team reports. The team reports also contain graphical representations of their designs.

All three design projects also contain an oral presentation component. The teams are asked to make those presentations as teams, with each team member contributing a part of that

presentation. The video *Effective Technical Communications* provides help in planning and delivering an oral presentation.

An activity that promotes careful consideration of the development of written instruction is a focus of this component of the course. Teams of two students are formed. Each team is given a lunch bag containing a unique "device" which is an assembly of nine Erector Set® parts and ten sets of nuts and bolts. Also included in the bag are two photographs showing the front and back views of the assemblage. Each team is to study the photos and the assemblage, produce a set of instructions for its production, disassemble it, and pass the bag of parts and the assembly instructions to another team. The other team, who had also completed this activity for a different "device", is asked to assemble the "device" using only the set of instructions provided with the parts. After completing the assembly, they request the photographs for comparison and provide criticism of the instructions they are given. Their critique is then returned to the team that had originated the assembly instructions.

A major technical paper is a requirement of the course. Immediately before the paper is assigned the students complete the library scavenger hunt and a representative of the NAU Writers' Workshop makes a short presentation. The presentation notifies students of the location of the Workshop, times when help is available, and how the Workshop functions to help students improve their written presentations. The technical report writing assignment identifies several deliverables and due dates for those deliverables. The students are to respond in memorandum format on sequential due dates providing the topic for the report and the references that would be researched in writing the report. They are also given a due date for submitting a rough draft and the due date for the final report. Students are also required to give a brief (five to seven minute) oral presentation summarizing the report or detailing some interesting item they had discovered in writing it. Bonus points are awarded if students produce evidence that they used the Writers' Workshop and if they obtained peer reviews of the rough draft of their written report. This paper typically constitutes 10% of their grade.

III.6 Mathematical Models

There are numerous, short, team-oriented problems which provide for student solution. These problems are of varying degrees of mathematical and reasoning difficulty. More lengthy problems, which require reasoning and mathematical skills, are extracted from TEAMS[14] competitions. This competition, which is designed for high school students in higher-level mathematics and science courses, contains problems that are team-solved. Engineers from numerous engineering companies throughout the country contribute the problems. All of the problems are engineering-oriented and are relatively challenging.

Several exercises of increasing difficulty are assigned using the Excel® spreadsheet. These exercises include basic knowledge of the spreadsheet program, using data to develop graphical presentations, solving simultaneous equations, plotting functions and solving for roots, financial analysis, and solving a temperature distribution problem using finite differences. Handouts and discussions are provided on algorithm development in preparation for some of the Excel® exercises. Excel® is also used to plot histograms for a probability analysis associated with repetitive rolling of two dice and three dice. Most of the students have already had some introduction to Excel® before this course.

IV. Articulation

The three State universities collaborated in establishing the learning objectives for this freshman experience. The results of that collaboration are shown in the attached chart, "Arizona Articulation Matrix for an *'Introduction to Engineering Design'* Course." The chart has been filled out to indicate how the Northern Arizona University course meets the learning objectives. Each university, and the community colleges, uses this matrix to develop their local courses independent of each other, while still achieving the same objectives. This allows complete articulation for this course among all of these educational institutions.

Student Presentation of Design Project

V. Conclusion

As a component of the final exam, students are asked to complete a survey identifying the activities they felt were most useful and/or enjoyable. Typically the three major design projects rank as the three most enjoyable components of the course, closely followed by the Tinkertoy® tower exercise. Even the technical report ranks fairly high in the opinion of the students. Very few activities are rated below three on a scale of one to five, with five being the highest. Those activities that rank lowest are typically the time management exercise, the Excel® exercises, and the library scavenger hunt. When asked what they perceive as the major purpose of the course, the response is almost unanimously: "the five-step design process."

The authors feel that the course provides valuable experience in team-oriented problem solving which the students further develop as they continue through the Design4Practice curriculum. Over the past several years the authors have observed progressive improvement in written and oral presentations. Many of these freshman students are making formal oral presentations enhanced by PowerPoint® slides, even though they have not received training in using this tool as part of the course. The course encourages experimentation and exploration and students are taking advantage of opportunities to self-learn.

Arizona Articulation Matrix for an "*Introduction to Engineering Design*" Course

Learning Objectives	Level of Learning	Course Activities	The Name Game	Paradigm video and peg exercise	The Seven Habits	Self-guided tour of Learning Asst. C	Build a Tower of Tinkertoys	Brainstorm a problem solution	The Power of Vision	Solving short problems	Learning Styles	Time log, planning	Library tour	NSPE videos - goals & comm.	Paper bridge design	Technical Report	Excel exercises	NAU Engineering programs/ABET	Dice Activity	Electrical Design Project	Ethics game/video	To Engineer is Human	Mechanical Design Project	TEAMS Exercises	Engineering Concepts
1. Engineering Design Process	**A**																								
1.1 formulating the problem				A			A	C		K					A		K			A			A		C
1.2 solving a problem				A			A			C					A		C			A			A	C	A
1.3 implementing a solution							A								A					A			A		A
1.4 documenting the process								C							A					A			A	K	A
1.5 using engineering/physical principles							C								A					A			A	K	C
1.6 using quality principles							K	K	C					C	A					A			A		
2 Working in Teams	**C**																								
2.1 team dynamics			K	C	K		A	A		C					A			A	A	A			A	A	A
2.2 team communication				C	K		A	A		C	C				A			A	A	A			A	A	A
2.3 social norms			K	C	K		A	A			C				A					A			A	A	A
2.4 conflict management					K		A	A			C				A					A			A	A	A
3 Engineering As A Profession	**K**																								
3.1 the profession																C		K		K		K	K		
3.2 selection of a major																		K							
3.3 professional ethics																					C	K			
4 Planning For Success	**C**																								
4.1 personal career planning					K	C			A					C				K				K			
4.2 learning to learn						C					C		C												
4.3 assessment of progress									K		C	C		K	C	A				A			A		
4.4 time management												A		C	C	A				A			A		
5 Written / Oral Communication $ A																									
5.1 organize / present oral / written reports				A			C			C		A	C	A	A	A			A	A	A		A		A
5.2 graphical representations															A		A		A	A			A		A
5.3 information media / access													C			A									A
6 Mathematical Models	**C**																								
6.1 problem solving techniques										C							C		C	A			A	C	C
6.2 implementation with spreadsheets algorithms																	A		A						A

Level of Learning Legend K **Knowledge** C **Comprehension** A **Application**

The instructors' basic philosophy is that very, very little time is spent in lecturing. Most of the learning is hands-on, and through exploration and interaction with other students. The students are developing confidence in their abilities to solve problems, to be independent learners, and to work as effective team members.

End Notes

[1] Hartman, David E., and Debra Larson, "Design4Practice", Proceedings of the 28th Israel Conference on Mechanical Engineering, Beersheva, Israel, June 2000.

[2] Howell, S., D. Larson, J. Hatfield, K. Collier, G. Hoyle, and G. Thomas, "An Integrated Engineering Design Experience: Freshman to Senior Level", *Proceedings*, ASEE Annual Conference, Anaheim, California, 1995.

[3] http://www.boeing.com/companyoffices/pwu/educator/objective.html

[4] Howell, Steven K., "Engineering Design and Problem Solving," *Engineer's Toolkit*, A Benjamin/Cummings Select™ Edition, The Benjamin/Cummings Publishing Company, Inc., Redwood City, California, 1995.

[5] Gottfried, Byron S., *Spreadsheet Tools for Engineers*, Excel 97 Version, McGraw-Hill's ***BEST*-B**asic **E**ngineering **S**eries and **T**ools, WCB/McGraw-Hill, Boston, Massachusetts, 1998.

[6] Motorola University, "Design for Manufacturability" Workshop, The University of AZ, Tucson, AZ, 1992.

[7] Barker, Joel A., "The Business of Paradigms," Charthouse Learning Corporation, 1989.

[8] Nierenberg, *The Art of Creative Thinking*, Simon & Schuster, New York, 1982.

[9] Petroski, Henry, "To Engineer is Human," Films Incorporated, Chicago, Illinois, 1987.

[10] Lockheed Martin, *The Ethics Challenge*, Featuring Dilbert and Dogbert, Ethics.Challenge@lmco.com, 1997.

[11] *Academic Integrity: The Bridge to Professional Ethics*, videotape and instructor's manual, The Center for Applied Ethics, Duke University (Funded through a grant from the National Science Foundation, Curriculum and Course Development, award number 9354670).

[12] Barker, Joel A., "The Power of Vision," Charthouse Learning Corporation, 1990.

[13] Bennett, A. Wayne, "Effective Technical Communications," Modules 1 and 2, National Society of Professional Engineers, 1988.

[14] *TEAMS Competition*, Junior Engineering Technical Society, lyoderjets@nae.edu, 1994, 1995, 1996, 1997.

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