Design Case Studies: A Practical Approach for Teaching Machine Design

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Abstract - Design Case Studies is one of the new courses that has been developed through the National Science Foundation Coalition, SYNTHESIS, to initiate systemic reform of undergraduate engineering education. The course is designed to update and enhance the design content of the current mechanical engineering curriculum at Tuskegee University. These extensive case studies cover all aspects of the life cycle of selected engineered products in which exemplary design practices have been followed. They provide useful examples of design synthesis, interplay between technical and societal factors, industrial practice, multiple engineering disciplines and business considerations. Moreover, they provide a variety of design experiences, illustrate examples of good and bad engineering, and offer an opportunity to raise questions and discuss solutions. Study issues in reliability, maintenance, marketing, and design for easy assembly and manufacturing are highlighted. Since cases are about real engineering activities, students can compare their judgement and decisions with those made by the professionals and explore the differences and the reasons.

The Design Case Studies course has been taught at Tuskegee University as a design elective course since Fall 1993. This paper addresses the course development, implementation, current syllabus, and assessment.

Introduction

For about two decades following the celebrated landing on the moon, engineering education in the United States remained insensitive to the multifaceted requirements of the growing world industry. Engineering curriculum reform in United States universities is desired to meet the objectives of enhancing acceptability of US industrial products in the international market and generating national engineering manpower from the rich diversity of the US population. These two important reform objectives have been highlighted in an announcement by the National Science Foundation Engineering Education Coalitions Program. This program has triggered national efforts toward maintaining an educational and industrial environment for specialized accomplishments together with continued synthesis of those accomplishments. Such an environment will have visibility as both cause and effect for our engineering graduates’ superior performance in research, design, manufacturing, and management.

According to Leland Nicolai [1], the consensus in industry, engineering societies, the federal government, and even academia itself is that our engineering schools are producing great scientists but mediocre engineers. United States industries are being beaten to the marketplace by foreign competitors with superior products. Cameron Fincher[2] refers to contemporary survey reports to provide a dominant theme that the quality of undergraduate education has declined over the past two decades. In addition to the decline in the quality of education, the Engineering Manpower Commission’s data [3] reveals alarming high attrition rates for undergraduate students especially for minority students.

Recognition of present deficiencies in engineering education invites the engineering faculty to devote themselves to devise and implement engineering education reforms. The elements to devise the reforms have been identified by several authors. Leland Nicolai [1] suggests that more open-end problems be injected into engineering science courses with frequent and spirited discussions on the design process. Fromm and Quinn [4] obtained opinions from faculty representatives of all engineering disciplines at Drexel University. Among other things, they emphasize unifying interdisciplinary aspects of engineering, use of experimental methods, and use of oral and written communication. Jan Roskam [5] says, it would be very helpful if academia would place priority on enhancing the design competence of its product.

According to Roland Jenisen [6], the National Science Foundation Engineering Coalitions seem to agree that a design experience, reinforced and expanded throughout the entire curriculum, is a necessary component of engineering education. Teamwork, multidisciplinary activity, and open-end problem solving experience are considered major needs within all courses. The presence of a design component vertically throughout a curriculum provides the vehicle to satisfy these needs.

Under sponsorship of the coalition, Tuskegee University has developed and implemented a new set of courses and course modules that address some of the deficiencies in engineering education by incorporating a design component vertically throughout the undergraduate curriculum. The courses expose students to hands-on experience, multidisciplinary and open-end problems, communication methods, and teamwork. Enhancement in teaching and learning is also addressed by encouraging the use of databases such as the National Engineering Educational Delivery System (NEEDS) developed by the Synthesis coalition schools. It is also anticipated that these new areas of emphasis will encourage motivation and thus retention.
The new set consists of one hour of Freshman Engineering Design that is offered as part of Freshmen Engineering Graphics and Design, a new two credit hour Mechanical Dissection course, a three credit hour Mechatronics course and a three credit hour Design Case Studies course. Freshman Engineering Design and Mechanical Dissection courses essentially augment the breadth component of the engineering curriculum, whereas Mechatronics and Design Case Studies contribute to both the breadth and depth components. The Mechanical Engineering Department requires its undergraduate students to take the complete new set as part of their curriculum. The Aerospace Science Engineering Department allows its undergraduate students to take the Design course as an elective course.

This paper presents the development, implementation, assessment, and possible transportation to K-12 of one of these newly developed courses, Design Case Studies.

**Course Development**

Students will learn how to design if they are involved in a number of real projects from start to finish. These projects can be current and real if they are provided by industry. Since industry does not expect useful results from student’s work, available projects are often of low priority or are tailored for student use. Real projects require intensive labor and too much time and have high priority.

In the educational process, neither the students nor the faculty can find time for enough projects to develop the design experience [8].

Design cases can be offered as an alternative or supplement to design projects since they can provide a broad perspective in less time and a realistic context for learning the design process [8, 11]. These cases cover all aspects of the life cycle of selected engineered products in which exemplary design practices have been followed. They provide a variety of design experiences, illustrate examples of good and bad engineering, and offer an opportunity to raise questions and discuss solutions. Since cases are about real engineering activities, students can compare their judgement and decisions with those made by the professionals and explore the differences and the reasons.

At the undergraduate level most students never have the opportunity to apply engineering concepts to real world applications. In order to alleviate this problem, undergraduate students need the exposure to already developed concepts used today in industry. Through the use of advanced technology applied from various sources, the material could be presented in a manner that the student can understand.

Multimedia computing has created an exciting tool for educational purposes. Computing in multiple media (taking advantage of the unique message-carrying ability of video, audio, text, animation, and graphics) is vastly expanding the usefulness of computers as repositories and disseminators of information. The potential uses of multimedia material in engineering education are numerous. Recently, "Courseware" has employed multimedia to incorporate elements such as footage of industrial examples, experimental results, biographical and historical information, and computer simulations. In addition, students are exposed to hardware and software applications that stimulate their intelligence and challenge their imagination. By illustrating the relevance and importance of all types of information, multimedia can add depth and interest to classroom lectures. Furthermore, students enjoy the ease of operation of the applications and the independence they promote. In these ways, multimedia can play a major role in enriching the educational experience of engineering students.

Multimedia case studies of design practices in industry play a major role in boosting students’ retention rate, stimulating their creativity, and increasing the depth and width of their understanding. By incorporating video, sound, animation, and interaction, multimedia adds exciting new dimensions to classical paper case studies and illustrates that design is an interdisciplinary, cooperative, and dynamic process.

The Design Case Studies course is developed to enhance the core curriculum on the undergraduate level at the Mechanical Engineering Department at Tuskegee University. Its purpose is to give the undergraduate some insight into how exemplary products are conceived, how products are designed for easy manufacturing and assembly, as well as study issues in reliability and maintenance. The examples in this course are taken from available industrial sources. The cases are interactive with the user and contain sound, graphics, text, and animation. The use of this technology is aimed to stimulate the minds and creativity of young engineers and facilitate their retention rate in mechanical engineering.

**Implementation**

Design Case Studies, MENG 493b, is a three credit hour course and has been offered to seniors in Mechanical Engineering Department at Tuskegee University as a design elective class. The course covers ten different cases. Some of these cases are developed at UC Berkeley under the supervision of Dr. A. Agogino [9, 11]. By the end of the semester, each student is required to develop his own case study. These cases cover different aspects of engineering and provide most of the rules the designer must follow to create a reliable mechanical device. The purpose of this course is to give the undergraduate some insight into basic engineering concepts and techniques. Students interact with the cases by answering questions and choosing their own navigational paths to points of interest. The cases are taken from available industrial sources and most of them are based on the experience of generations of engineers. Hence, these cases are valuable in helping young engineers to avoid some of the pitfalls they will encounter in their practicing careers. Table 1 shows the course outlines in more details.
Table 1. Course Outlines for Design Case Studies Course
MENG 493b

<table>
<thead>
<tr>
<th>Week #</th>
<th>Topics (Subject to Minor Changes)</th>
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| Week 1 | - Project design; Organization and Structure  
- Problem Definition and Creativity |
| Week 2 | - Product Realization Project  
- Open-ended Problems (Loading Mechanisms, Oscillatory Motion) |
| Week 3 | - Case Study #1 (The Role of a Design Engineer in Industry)  
- Individual Oral Presentation of Individual Problem Statements |
| Week 4 | - Case Study #2 (Rules in Design - Multimedia Case Study) |
| Week 5 | - Design Optimization, Competing Objectives  
- Case Study #3 (Optimization of a Crimping Tool)  
- Making Decisions |
| Week 6 | - System Modeling and System Simulation  
- Case Study #4 (Dynamic Modeling of Governor Mechanism) |
| Week 7 | - Design Reviews  
- Individual Oral Presentation |
| Week 8 | - System Performance  
- Case Study #5 (A surgical Implant) |
| Week 9 | - Effect of Manufacturing Processes on Design  
- Case Study #6 (Analysis of the Requirements and Selection of Materials for Tennis Rackets) |
| Week 10 | - Case Study #7 (Solution and Working Methods in Industrial Aerodynamics)  
- Group Conferences |
| Week 11 | - Case Study #8 (Jigs and Fixtures Design)  
- Case Study #9 (Design for Assembly - The IBM Proprinter case study) |
| Week 12 | - Case Study #10 (Dimensions and Tolerances)  
- Cost estimation; Bill of materials |
| Week 13 | - Professional Ethics  
- Group Conferences |
| Week 14-15 | - Presentation of Final Report by Project Groups |

Assessment

In collaboration with faculty in the School of Education at Stanford, social scientists at Institute for Research in Learning (IRL), and support in part by literature from the international design research community, a four part assessment program has been developed and carried all over the Synthesis coalition. The following four assessment methodologies have been adopted and offered Coalition-wide service in support of these methods [12]:
1. Synthesis Questionnaire
2. Multimedia Forum Kiosk Analysis
3. Video Interaction Analysis
4. Portfolio Development and Analysis

Each case study has been tested in the classroom and evaluated from responses from students and instructors at the coalition schools. Participating companies have been given the opportunity to review and evaluate the cases. The questionnaires have been designed to test student’s sensitivity to life cycle design issues before and after being exposed to the case studies.

The usability and adoption rates of the case study methods for a range of engineering courses have been important factors. The timeline has been arranged so as to allow sufficient time for this evaluation, feedback, and revision.

Students find that the material in this course is relevant in professional work. Responses from the students on the practicality and use of the multimedia cases are very favorable. Figure 1 shows the response of the students to questions 10 and 11 of the Synthesis Questionnaire. Students are impressed by the fact that the computer can tell them verbally whether they are correct or incorrect. In addition, all of the students who tried the cases were either reminded of something they had forgotten or learned something new. This gives the students a practical understanding and helps them building confidence and motivation.

K-12 Linkage

One of the important objectives in engineering curriculum reform is the need for increasing the technical awareness in K-12 education. This is in order to attract pre-college students to the engineering profession. Real world artifacts raise the interest of K-12 students since most of the students have heard of, seen, or used them in their daily life. During the last four years, linkage has been accomplished through the followings:
- Selected modules have been made downward extensible for use in high school and pre-college programs.
- Three school systems, one rural and two urban, have been chosen to participate in this effort.
- Selected teachers from these school systems have been invited for summer workshop to initiate the development effort, in downward extensible modules.
Conclusions

The Design Case Studies course illustrates that design is an interdisciplinary, cooperative, and dynamic process. The cases provide examples of design synthesis and interplay between technical, social, and business factors, industrial practice and multiple engineering disciplines. In these cases, students can review how exemplary products are conceived, how products are designed for easy manufacturing and assembly, as well as study issues in reliability and maintenance. They express their creative thoughts through open-ended interdisciplinary and multidisciplinary design problems and teamwork.

The use of multimedia technology is aimed at stimulating the minds and creativity of the young engineers. Multimedia case studies of design practices in industry play a major role in boosting students’ retention rate and broadening their understanding. The interactive formats of multimedia engage students in active thought while exploring the design case study. Video, sound, animation, graphics, and text are integrated to provide an ideal medium for exploring engineering disciplines. The perception of the students to these cases has been favorable and encouraging to develop more.

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References