Integration of Design Throughout the Curriculum of a BSE Program

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Introduction

Although fundamental to the engineering profession, design is one of the more difficult subjects to teach. Design by its very nature is broad in scope and draws on the creative talents, management skills, and engineering knowledge of those involved. Design problems are typically open ended, have multiple solutions, and require decisions based on incomplete information. Engineering analysis is a fundamental part of the design process. Analyses are frequently required as part of the design process to size or select components or to verify that design requirements have been met. However, if there is nothing to design, no failure to investigate, or process to improve, there is no need for the engineering analysis skills that are a major component of the traditional engineering education. Thus, engineering design and its supporting management, analysis, communications, and interpersonal skills should be the backbone of an engineering education.

Engineering educators are recognizing that it is not possible to teach design in a single course or Capstone design project. Lovas[1] developed workshops that focused on integrating design into the engineering curriculum. Fronczak and Webster[2] and Thompkins[3] describe a sequence of six design courses that biomedical engineering students start taking during their first semester sophomore year and finish in their last semester senior year. This design course sequence is intended to provide the students a sustained opportunity to develop their creativity and judgment. Sheppard and Gallois[4] describe a "design spine" of eight design courses that run through all eight semesters of a student's education. The goal of these eight courses is to achieve greater integration of design with the science and engineering science courses. Brousseau, etal[5], describes a similar approach in which students participate in a series of eight design workshops, one per semester. Kartam[6] approaches the problem somewhat differently, and describes how design content is integrated into traditional courses that are most geared towards design.

This paper discusses how design content has been integrated into the curriculum of a Bachelor of Science in Engineering (BSE) program at the University of Tennessee at Martin. Due to the mixture of core and specialty courses in the BSE curriculum, the approach taken to integrate design throughout the curriculum is a mixture of dedicated courses[2-5] and design content in traditional courses[6].

The UT Martin BSE Program

The University of Tennessee at Martin is a small rural university located in the northwest corner of the state. Total student population is approximately 6,000 students. The university is organized into five colleges, and the Department of Engineering is part of the College of Engineering and Natural Science. The Engineering Department has an enrollment of slightly less than 300 students. The Department offers a Bachelor of Science in Engineering Degree. Within this degree, students may take course concentrations that permit them to specialize in one or more specialty areas. The four specialty areas are civil engineering, electrical engineering, industrial engineering, and mechanical engineering. All students take 54 semester hours of core engineering courses and 24 semester hours of courses in one of the specialty areas.

Design Specific Courses

Table 1 summarizes those courses that address traditional design material. Students are first introduced to design during their first semester in a course on Engineering Methods. This course serves as an introduction to the design process, engineering graphics (sketching), technical report writing, and oral presentations. Students working in teams are required to design, build, and test a simple device that meets a set of performance requirements. At this stage, the creativity and innate ingenuity are the student's primary design tools. Students are led through any analysis that might be required to optimize the design. Projects have included scales that must measure a weight with specified accuracy, linearity, and repeatability (Figure 1), tennis ball launchers that are optimized for distance, accuracy, and repeatability (Figure 2), mousetrap powered cars, and balsa wood structures. Buyck and Sterrett[7] and Sterrett and Helgeson[8] provide additional information on the approach used in this course.

Figure 1. Electronic Scale Designed in Engineering Methods I Course

Figure 2. Tennis Ball Launcher Designed in Engineering Methods I Course

The second course in the design sequence exposes students to computer-aided-design (CAD). The course consists of two labs each week. One lab is dedicated to instruction in AutoCAD and drafting standards, while the second lab provides instruction on MATLAB. A two-dimensional version of AutoCAD is used in this course.

Table 1
Summary of Design Specific Courses

1st Semester ***Engineering Methods I (2 hrs)*** Introduction to the design process and engineering sketching. Requires design and fabrication of hardware to meet a specific set of requirements. Heavy emphasis on creativity, ingenuity, and testing. Limited fabrication skills required of students.	2nd Semester ***Engineering Methods II (2 hrs)*** Introduction design and analysis tools - AutoCAD and MATLAB.
3rd Semester – 2hrs ***Engineering Design (2 hrs)*** Introduction to solid model based CAD. Course mimics how a design project is conducted in industry and requires development of project plans, schedules, tracking of resources, activity reports, patent searches, development of 3D CAD component and assembly models, and component and assembly drawings. Oral and written communication.	4th Semester Core engineering courses with design projects integrated into the course.
5th Semester Core and specialty engineering courses with design projects integrated into the course.	6th Semester Core and specialty engineering courses with design projects integrated into the course.
7th Semester ***Sr. Research I (1 hr)*** Initiate Capstone project. Emphasis is on project definition, project planning, cost estimating, conceptual and preliminary design. Core and specialty engineering courses with design projects integrated into the course.	8th Semester ***Sr. Research II (3 hrs)*** Completion of Capstone project. Emphasis is on tracking and monitoring resources, detailed design, fabrication, testing, documentation, and oral presentation. Core and specialty engineering courses with design projects integrated into the course.

The third course in the design sequence is a formal course on Engineering Design. This project-oriented course builds on previous courses, and provides instruction on 3D CAD, project management, and communication of design information. In this course, students working in teams complete a design in which the outputs are project plans and schedules, status reports, 3D CAD models, assembly drawings, part drawings, specifications, presentations, memos, and reports. Students track the number of man-hours spent on the project versus those estimated. They are not penalized for having poor estimates. However, it does open their eyes as to how difficult it is to estimate how many man-hours it will take to accomplish something that you have never done before. The intent of this course is to mimic the steps and outputs used in industry to complete a design project. A common comment received by students about this course is that it is a lot of work. Examples of projects for this course are the design of an egg holder used by artists painting Easter eggs (Figure 3), and a device for filling a bladder with “Magic Gel” that glows when the ball impacts a surface (Figure 4). Figure 5 shows the charts used by students to track and monitor resources.

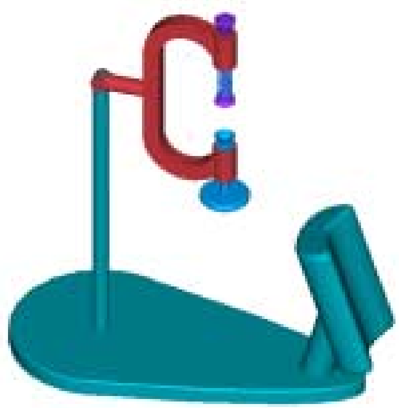

Figure 3. An Artist's Articulated Easter-Egg Holder Designed in Engineering Design Course

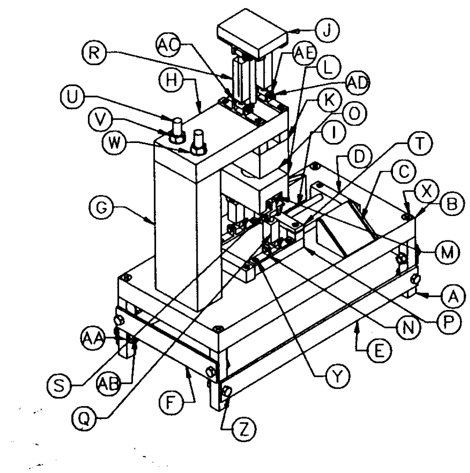

Figure 4. A Device that Fills Bladders with "Magic Gel" Designed in Engineering Design Course

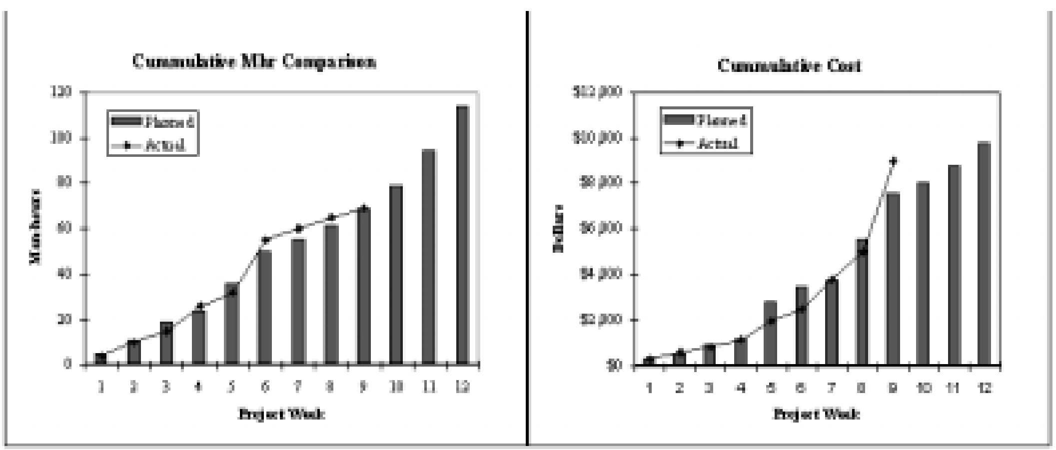

Figure 5. Charts Used to Track Resources in Engineering Design Course

As seen in Table 1, the next design course does not occur until the last year when a Capstone project is completed. Capstone projects present an opportunity for students to independently complete a significant project. Projects originate from a variety of sources. Projects have been completed for industry, municipalities, lab development, and professional society competitions.

Courses with Integrated Design Content

During semesters four through eight (Table 1), students take traditional engineering courses that have a design project integrated into the course. These projects are coupled to the objectives of the course and require students to use knowledge gained during the course to complete the project. For the most part, these courses require the students to work in small teams to complete the project.

Figure 6. Concrete structure designed and tested in Reinforced Concrete Course

For example, students taking the reinforced concrete design course in the civil engineering specialty are required as part of the course laboratory to design a concrete structure to meet a set of performance requirements, including various loads and load conditions, maximum cross sectional area, reinforcement constraints, and the code requirements of the American Concrete Institute[9]. Students must make written requests to deviate from any code requirement. After determining the required mix and reinforcement to carry the loads, each team must build, cure, and test their structure. Each team must demonstrate that their structure can carry the required load, and the structure is then loaded to failure. Teams are penalized if the failure load exceeds the design load by a prescribed amount. Figure 6 shows a concrete frame structure being loaded in a test frame.

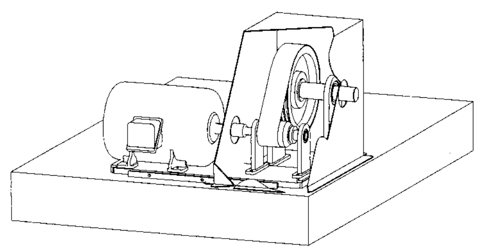

Figure 7. Speed Reduction System Designed in Machine Design Course

As another example, students taking machine design are required to design a machine (Figure 7) that meets a set of performance requirements. Students working as a team must develop concepts for meeting the requirements, select the best concept, develop a 3D CAD model that shows all of the parts and how they interact, perform all of the calculations necessary to show that all components meet the strength and life requirements, document their design and calculations in a technical report, and make a presentation on their design. The instructor considers the overall functionality, producability, and cost effectiveness of the design in assigning project grades.

Students taking a course in Kinematics and Dynamics of Machines must design a mechanism and compute the torque required to drive the mechanism. The purpose of this project is to let students encounter first hand the practical issues encountered in designing mechanisms that have real geometries. During a significant portion of the course students use mechanism analysis methods that would tend to make them think of mechanisms only in terms of a series of lines on a page. The process of developing a realistic mechanism forces them to think about clearances and interferences, mass properties, and how to avoid eccentric joint loads. Figure 8 shows a cutter mechanism designed and simulated during this course. This particular mechanism is described by Huag[10].

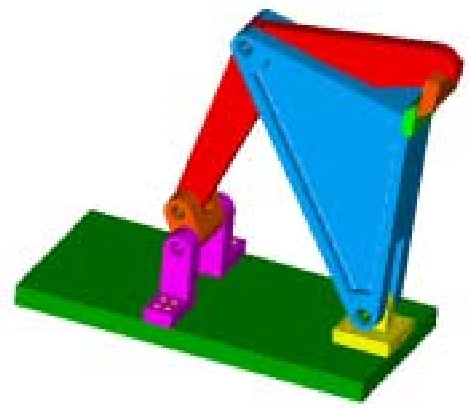

Figure 8. Cutter Mechanism Designed in Kinematics/Dynamics of Machines Course

Each student taking the course in steel design is required in the second half of the semester to design a single story hospital following a set of specifications which include minimum and maximum square footage, building height, number of bays, required member connection types, and following the LRFD Steel Code[11]. Each student is assigned a different geographical location to allow for different earthquake and wind loading conditions, and must follow all ASCE 7-98[12] loading requirements and load combinations. During the course of the eight-week project, students submit preliminary analysis and design reports, which are reviewed and returned. After all the structural members have been designed using manual analytical techniques, the students are required to perform the final analysis and code compliance checking using a commercial structural analysis package[13] and modify the design as required. The students then submit a formal report, including a written section describing the project, CAD drawings, analyses, code checks, and a summary comparing specifications to finished structure.

Conclusion

This paper has presented an approach used at the University of Tennessee at Martin to integrate design content throughout the curriculum. "Formal" design courses are used to convey information about the design process, project management, patents, ethics, and engineering graphics. Design projects are incorporated into traditional courses with the intent of showing students how the material presented in the course is used during the design of specific types of hardware. This approach has the advantage of being able to cover topics of a general nature in dedicated courses, and also providing detailed design experience in specific disciplines and specialties. Another advantage of this approach is that it can be implemented by adjusting course content without completely revamping the overall curriculum.

Bibliography

1. Lovas, C.M, *Integrating Design Into the Engineering Curriculum*, Short Course Notes, Southern Methodist University, March 1995.
2. Fronczak, F.J., and J.G. Webster, "A Series of Design Courses in Biomedical Engineering," Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition.
3. Tompkins, W.J., "Using Design as the Backbone of a BME Curriculum", Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.
4. Sheppard, K., and B. Gallois, "The Design Spine: Revision of the Engineering Curriculum to Include a Design Experience each Semester," Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition.
5. Brousseau, J., et al, "A New Engineering Program that Introduces Design Workshop Courses," Proceedings of the 2000 American Society for Engineering Education Annual Conference & Exposition.
6. Kartam, N., "Total Design Experience in Civil Engineering Education," Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition.
7. Buyck, W.J., and J.D. Sterrett, "Engineering Design Methodology Through Stimulating Freshman Project Competitions," Proceedings of ASEE Southeastern Region Conference, Atlanta, GA, April 1994.
8. Sterrett, J.D., and R.J. Helgeson, "Improving the Content of Freshman Design Course Through Computer Modeling, Experimentation, and Error Analysis," Proceedings of 1999 ASEE Annual Conference, Charlotte, NC, June 1999.
9. *Building Code Requirements for Structural Concrete (318-99)*, American Concrete Institute, Farmington Hills, Michigan, 1999
10. Huag, E.J., Computer Aided Kinematics and Dynamics of Mechanical Systems, Allyn and Bacon, 1989, pg197.
11. Manual of Steel Construction, Load and Resistance Factor Design, 2nd Edition, American Institute of Steel Construction, 1993.
12. *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers, Reston, VA, 2000.
13. *RISA-2D*, RISA Technologies, Lake Forrest, CA.

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