A Model for Teaching Multidisciplinary Capstone Design In Mechanical Engineering

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Abstract - **This paper describes a model for a multidisciplinary approach to teaching capstone design in mechanical engineering. The multidisciplinary approach described in this paper includes the involvement of four departments that have not traditionally collaborated effectively in providing capstone design experiences for students. Students in the mechanical engineering department work in teams with students from the departments of electrical engineering, marketing in the school of Business, and art in the Division of Fine Arts of the College of Arts and Sciences to complete an industry sponsored capstone design project. The level of involvement of the industrial partner and the process of defining meaningful design projects that meet the goals of the mechanical engineering curriculum are described. Examples of student team solutions to design problems from the automotive industry are presented to demonstrate the multidisciplinary nature of the design projects in meeting the goals and objectives of the mechanical engineering program. The roles played by faculty from the four collaborating departments, the grading process, resource requirements, and the summative evaluation process of the educational experience are described. Finally, the paper concludes with a discussion of challenges involved in carrying out capstone design projects with multidisciplinary teams and suggestions for overcoming such obstacles.**

INTRODUCTION

The current guidelines for accreditation of engineering programs (by ABET) require that each program must demonstrate the ability of its graduates to work professionally in both thermal and mechanical systems to include the design and realization of such systems. Engineering design in this instance is defined as a decision making process of devising a system or component to meet desired needs through the iterative application of the basic sciences, mathematics and engineering sciences. Additionally, the accreditation process requires that each program demonstrate that their graduates have the ability to function on multi-disciplinary teams. The intent of this paper is to report on a two-year experience on a multi-disciplinary approach to teaching design in the mechanical engineering department at Howard University.

As documented in [1], capstone design courses in which students work in teams on a project are an integral part of most accredited engineering programs. In earlier papers on mechanical engineering capstone design, [2-7] described the successful involvement of industry in defining and coordinating capstone design projects at Howard University. Beginning in 1989, the mechanical engineering department at Howard, in collaboration with the Sundstrand Corporation of Rockford, Ill. transitioned into a period in which senior year students were involved in the design of a product to meet a desired need in the aerospace industry. Student teams worked competitively to properly define the assigned problem, generate concepts, produce concept models, perform analyses in order to verify problem constraints and specifications, and finally produce full-scale models of their designs. This approach to the capstone design was followed by a similar collaborative partnership with Boeing Helicopters of Philadelphia for another six years until 2002. Titles of design projects proposed by the sponsors and completed by the students during the period 1989-2003 are presented in Table 1.

In most instances the capstone design course is defined as a multi- disciplinary problem but conducted in a single engineering discipline or inter-disciplines involving multiple engineering departments. The paper by Ellis [8] provides a review of teaching and student learning in a multi-disciplinary capstone design project involving students from mechanical engineering, architecture, industrial design and building construction.

In this present paper, however, the authors describe a multidisciplinary approach to the capstone design among departments, namely, mechanical engineering, electrical engineering, marketing and art that have traditionally not collaborated effectively in providing educational experiences to students. The authors describe the process of defining a meaningful design problem that meets or exceeds requirements for accreditation. Examples of students' design projects from the automotive industry are presented to demonstrate the multidisciplinary nature of the design projects in meeting the goals and objectives of the department. The roles played by faculty from the four departments, the grading process, and resource requirements for such projects, and the summative evaluation process of the educational experience are described and included in the paper. Finally, the paper concludes with a discussion of a few challenges in the conduct

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of multidisciplinary projects and suggestions for overcoming such obstacles that are for the most part non-technical.

THE MECHANICAL ENGINEERING CURRICULUM

The College of Engineering, Architecture and Computer Sciences (CEACS) recently completed a multi-year grant from the National Science Foundation to develop strategies to encourage and institutionalize design across the curriculum. As a result of this and other efforts, engineering departments at Howard University now have curricula that emphasize vertical integration of design into the curricula.

TABLE I
PAST AND CURRENT DESIGN PROJECTS

Academic Year	Project Title	Sponsoring Organization
1989-1990	The Ram Air Turbine Deployment Actuator	Sundstrand
1990-1991	Design of Leading Edge Slat Actuator	Sundstrand
1991-1992	Design of an Electromechanical Linear Actuator	Sundstrand
1992-1993	Design of an Auxiliary Power Unit Gearbox for 737 Aircraft	Sundstrand
1993-1994	Design of F-22 Asymmetry Brake	Sundstrand
1994-1995	Design of F-22 Power Drive Unit	Sundstrand
1995-1996	Global Express Wing Tip Brake	Sundstrand
1996-1997	Design of Localized Flow Spoilers on Rotor Blades	Boeing Helicopters
1997-1998	A Fuselage Mounted Main Landing Gear Design for a Tilt rotor Aircraft	Boeing Helicopters
1998-1999	Design of an Active Aircraft Landing Gear for the Chinook CH-47 Tandem Rotor	Boeing Helicopters
1999-2000	Design of a Main Landing Gear Forward Panel Folding Strut	Boeing Helicopters
2000-2001	Design of Human Powered Helicopter	Boeing Helicopters
2001-2002	Design of Human Powered Helicopter	Boeing Helicopters
2002-2003	Design of a Tailgating Accessory Package for the Saturn VUE	General Motors
2003-2004	Create an Option Package which will Increase the Appeal and Sales of the Saturn Ion Quad Coupe to the Typical Generation Y (GenY) Buyer	General Motors

As part of the institutional effort to continuously improve curricula offerings, the Department of Mechanical Engineering instituted a new curriculum with a strong emphasis on a core product realization stem, effective fall 2002 semester in order to meet the needs of industry and prepare students for advanced studies. Students who entered the program in fall 2002 will graduate from Howard under this new curriculum. In summary, the new curriculum, which reduces the total number of credit hours from a maximum of 141 to 128, includes a sequence of 10 courses (25 credit hours) that proceeds vertically down the curriculum, forms the core courses in the product realization stem. Beginning with Engineering Graphics in the first semester, the curriculum concludes with a two-semester capstone design project course sequence. CAD/CAM/CAE tools are used to integrate all courses in the product realization stem.

In concert with Mechanical Engineering and Howard University's Strategic Framework for Action, the Department of Art has also instituted a new curriculum for its studio program, entitled Visual Information Design Arts (VIDA). Implemented in the fall 2001 semester, VIDA offers students a flexible technology driven curricula in both its major and minor concentrations. VIDA students are expected to tailor a cross-disciplinary departmental and college wide program of study, reflective of current realities in the arts and material culture. It is the Art Department's mission to graduate multifaceted, socially conscious professional artists/designers who are empowered by their knowledge of the arts, humanities, and sciences; and who are articulate in the language of current electronic technologies. Available tools offered in the fine arts program will play a vital role towards the development of the electronic studio, three-dimensional modeling and animation, and will serve to lay the electronic language that connects the various disciplines within and outside the department, and especially between Design, Sculpture (Modeling and Surface Development), and Engineering. As a consequence of developments in the curricula in the Art Department, it became a natural fit to

include students from the Art Department in the mechanical engineering capstone design project course.

Industrial partners have for a long time advocated exposing students to inter-disciplinary and multi-disciplinary projects in the engineering curricula. National professional societies such as ASME and ASEE have also endorsed such arrangements. The ability to work on a multi-disciplinary project in a multi-disciplinary team is now a required outcome for graduates of an Accreditation Board for Engineering and Technology (ABET) accredited program. With this in mind, the department sought to develop multi-disciplinary design initiatives by exploiting the strengths of the various curricula offerings in departments such as fine arts, electrical engineering and marketing.

INDUSTRY INVOLVEMENT IN THE MECHANICAL ENGINEERING CAPSTONE DESIGN PROJECT COURSE

The industry sponsored capstone design project course began almost fifteen years ago when it was introduced as an interdisciplinary design course. Following a revision of the mechanical engineering curriculum, the content of the course changed two years ago to an integrated product development course consisting of students from several departments. The objectives of the course are to (1) provide students with insight into the industry work environment, (2) develop their professional and technical skills, (3) prepare students to work effectively in diverse multi-disciplinary teams, and (4) to apply the curriculum to effective product design and manufacture.

Design projects have ranged from the design of a Ram Air Turbine Deployment Actuator with the Sundstrand Corporation, to be deployed if all power in the aircraft from engines fails to the design of a human powered helicopter supported by Boeing Helicopters of Philadelphia, Pennsylvania. Table 1 lists the projects and their sponsors for the past fourteen years. The success of such industry-university collaborative efforts is documented in papers written by faculty in the Department of Mechanical Engineering and Industry Representatives [2-7]. Currently, the Department of Mechanical Engineering is collaborating with General Motors to offer its students a meaningful design experience.

Howard University is one of General Motors (GM) key institutions. As a member of this select group of universities, GM has open access to communicate with, and recruit students from the university. The design collaboration described in this paper was initiated with a proposal to GM executives and key personnel were assigned to work with the Howard team on the project. Key personnel at GM were drawn from various divisions of the company to include Marketing, Electrical Engineering, Mechanical Engineering, Business, Concept Innovation, etc. Two GM employees were also assigned as mentors to work with the student teams on a regular basis. The mentors visit the Howard campus on a monthly schedule for design reviews and to work individually with student teams. These mentors are appointed to the mechanical engineering faculty without compensation (WOC).

In initiating the project, faculty from Howard University traveled to Warren, Michigan in the summer of 2002 and spent three days meeting with key personnel to review candidate project descriptions. The visit also provided the faculty the opportunity to tour the various facilities of the company and to gain a better understanding of automotive operations. Each proposed project in the partnership has to meet criteria set by the faculty and GM personnel. In addition to the usual academic constraints imposed by accreditation, the proposed design projects are intended to enhance the marketability of targeted GM automobiles. In 2002-2003, the design project involved the design of a tailgating package for the Saturn VUE Sports Utility Vehicle (SUV). The current 2003-2004 project is much more open-ended in which students are required to propose and design packages for the Saturn ION vehicle that will increase it's appeal and sales to the Generation-Y buyer.

IMPLEMENTATION OF MULTIDISCIPLINARY INITIATIVE

Beginning in late April of each year, faculty and representatives from GM engage in dialogue to decide on a design project for the coming academic year. These discussions continue through video and telephone conferences throughout the summer until a suitable project has been defined.

Each design project is executed over the two semesters in the academic year. The students from the four academic disciplines are introduced to the project with few details during the first week of the academic year. The faculty, represented by a faculty member from each of the four disciplines, is present during the first class meeting. In addition to the entire senior mechanical engineering class, participating students include those selected by their faculty from electrical engineering, marketing and fine arts. Once the teams of students are formed through random selection and some adjustments for gender balance, the teams meet to select two members as leader and co-leader. Because the majority of the students are from the mechanical engineering department, the students are instructed to select a leader from that discipline.

Following the first meeting of the students and the project faculty, arrangements are made for a three-day visit by the class and faculty to the GM Tech Center in Warren, Michigan. During the visit, students are introduced to key personnel and consultants who will be available to assist in the execution of the project. In addition to tours of the various divisions at the center, the students are lectured on various topics of automobile operations including concept creation, manufacturing, marketing, electrical systems and vehicle architecture. One of the important sessions involves team-building exercises at the Innovation Zone of the Tech Center. At the conclusion of the visit, the sponsors of the project issue the students a Single Mission Challenge (SMC) to include the mission of the project, background information on the need for

the design, goals and performance, constraints on potential design solutions, and most importantly the project design deliverables.

In order to provide guidance to the students, the 3-credit per semester course meets once per week for three hours. This meeting time is dictated by the existing structure in the mechanical engineering curriculum. To succeed in the collaborative effort, faculty from the other three departments created new or modified existing courses to satisfy the demands and requirements of the multi-disciplinary initiative. In a typical semester schedule, the student teams submit monthly written progress reports to the faculty and GM representatives. The reports are reviewed prior to a visit by GM representatives to the university campus in order to receive oral presentations and to consult with each team on an individual competitive basis.

EXECUTION BY STUDENTS

The first semester emphasizes conceptual design, creativity, market analysis, and research into previous designs, trade studies to select the best concepts to meet specification requirements. During one of the early visits to the campus, representatives from GM hold a half-day creativity and team-building workshop for the students in an atmosphere that is similar to a design-studio concept primarily used in architectural programs. The market analysis and background research on buying wants/desires provide the teams with data to propose an acceptable business plan. Primary data is obtained by market surveys at events such as collegiate and professional football games. To add to the primary data collected, students review the published literature and web based information to support the decision making process. In addition to the business plan, the teams are expected to propose modifications in the form of additions or deletions to the subject vehicle and to communicate such changes through concept sketches and artist renderings. As part of the first semester deliverables, the teams are expected to provide simple models of proposed concepts and necessary modifications.

Based on a critical review of the first semester work, a recommendation is made collectively by the faculty and GM technical mentors on an acceptable package concept for further validation by detailed market and engineering analyses. Throughout the two semesters, the teams learn the iterative design process by continuing to modify their design layout based on additional information from marketing and engineering trade studies. As a capstone design project, the teams are expected to apply the basic knowledge acquired in the various disciplines to the design of a product that meets the specifications and requirements. As an example, the team is expected to convert design conceptual drawings into CAD models that can be analyzed with finite analysis packages such as ANSYS or Unigraphics. In addition to the faculty at the university, the students are encouraged to seek help from all sources including designated consultants in the various divisions of the GM enterprise.

As stated earlier, the department of mechanical engineering has provided the leadership in institutionalizing a multi-disciplinary team capstone design project at the university. During the first year of the collaborative effort with GM, the students were specifically tasked to design a tailgating package for the Saturn VUE vehicle. In designing the package, the teams performed market analyses through the acquisition of primary and secondary data to support an acceptable business plan. The result was fed into an iterative process in which engineering calculations were performed to validate the proposed concepts. As noted in Table 1, the project assignment for the current academic year is open ended with constraints in which the teams are expected to propose and execute their own designs in order to produce option packages, which will increase the appeal and sales of the Saturn Ion Quad Coupe. Examples of option packages designed by students in the 2003-2004 class include an under-seat storage compartment, a collapsible storage unit and a headrest bag latch. These examples are respectively depicted graphically in Figures 1, 2 and 3.

FIGURE 1:
UNDER-SEAT STORAGE COMPARTMENT

The grading system employed in evaluating the work of each student team and to measure individual effort follows the approach of Thigpen and Glakpe [6]. Each team member provides a confidential Individual Effort Report Card (IERC) at the end of each monthly oral presentation to the faculty and GM representatives. The results of the IERC are compiled to assess the contribution of each team member at the end of each semester. With a team grade from the faculty and industry representatives and the score from the IERC, a grade is assigned to each student. An individual‘s grade may be lower or higher than the team grade depending on the level of effort reported from the peer evaluation assessment.

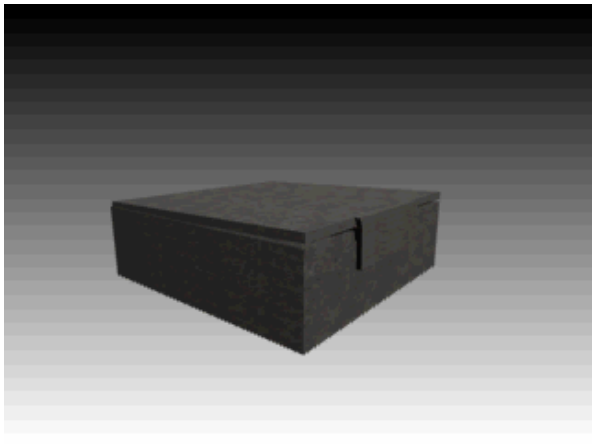

FIGURE 2:
COLLAPSIBLE TRUNK PARTITION

FIGURE 3:
HEAD-REST BAG LATCH

RESOURCES, BENEFITS AND CHALLENGES

The capstone design course requires a significant investment in resources. Four faculty members support approximately 25 students. In addition, resources are required to support travel for students, faculty and GM mentors and to provide funding for purchase of materials to build models and prototypes of design projects. However, there are numerous benefits for students, our industry partner and the faculty who are involved in providing instructions for the course.

Students gain insight into the practical aspects of engineering in the workplace, develop skills in working on multi-disciplinary teams, experience a transitional step between classroom and industry, gain an understanding of how the curriculum is relevant to real world product design, manufacturing and marketing, develop and improve communication skills and, most importantly, improve their opportunities for employment. The capstone design course gives students an advantage in developing entrepreneurial skills.

The course also provides sponsors rights to the final design products. In addition, they have access to research that they may not have time to explore on their own. Moreover they have direct access to the best students prior to hiring. They also gain opportunities to provide direct input in improving engineering education and curriculum to meet their needs.

For faculty, the conduct of this course, although team-taught requires as much effort as a single engineering science course. The challenge of coordinating a course with students and faculty from several departments is great. In addition, the faculty must assure that realistic design projects are chosen to assure that the educational objectives of the program are met. At times, the objectives of the industry sponsor may not meet curriculum objectives. Here faculty must be tactful and yet assure program goals are met. However, participation by faculty in this course increases their awareness of current concerns and needs of industry and it enhances their opportunities for new areas of research funding.

SUMMARY

An approach to the conduct of a capstone design in mechanical engineering with multi-disciplinary teams has been described in this paper. The multi-disciplinary teams are composed of students from engineering departments in addition to those from the disciplines of marketing and fine arts. The key features of the course involve students working on a multi-disciplinary design problem with the support of an industrial affiliate whose representatives are involved in the teaching of the course during the academic year. In doing so, the students are exposed to an industrial environment within a classroom setting and are thus better prepared for the challenges they may face on accepting a work assignment for the first time after graduation.

Compared with the conduct of previous capstone design projects that were limited to students in mechanical engineering, the present mode of teaching the capstone design course requires the co-operation of all the departments involved. It is critical to have faculty advocates in the other departments to convince others of the value of such collaboration, and to identify students who are convinced of the need for such a partnership with colleagues in other non-allied departments.

The continued success of the multi-disciplinary capstone design course described in the paper cannot be demonstrated without the involvement of an industrial partner such as

General Motors. The industry affiliate not only provides resources to support instructions in the design project but they also assist in the formative and summative assessment of the mechanical engineering curriculum as well as those in the other supporting departments. The recommendations from such evaluations over the years have provided the department the impetus to revise it's curriculum and will in the future acquire resources to provide the state of the art tools required for the teaching of a capstone design course to a multi-disciplinary group of students.

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