The Evolution of the Capstone Design Course in the Mechanical Engineering Curriculum at Howard University

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Abstract *– The Department of Mechanical Engineering at Howard University has, for more than twenty years, included industry participation in the conduct of its Senior Capstone Design course primarily to expose students to real industry design projects in addition to the need to meet accreditation standards. Prior to the change in the conduct of the course, students worked with individual faculty members to design and execute a project. The final grade in the course was awarded based on the evaluation of the faculty member and was not subjected to a review by a "jury" of faculty members. In a typical mode of delivery of the course and depending on the industry partners involved, design projects from either aerospace or automotive industries were assigned to student teams with one project assigned during each academic year. Student teams worked on the same project competitively and were not previewed to opposing teams' design until the final presentation of the academic year which runs from August to May. In the recent past however, the department has been able to foster collaborative relations with other industrial partners and has been able to offer multiple projects to teams of students which removed the competitive dimension of earlier projects. The experiences in the teaching and the conduct of the projects have been documented in a number of papers by faculty in the academic department.*

The intent of this paper is to report on the historical evolution of the conduct of the capstone design course at Howard University with emphasis on the transition from the conduct of the capstone, senior project as an "independent" course to a more structured one to include participation by industry partners. Following a brief introduction of the department, a description is provided of the mechanical engineering curriculum at Howard as an ABET accredited program. The processes involved in the selection of a project, its introduction to the students, team formation and the expectations from the students are described in the paper. The involvement of an interdisciplinary faculty team in the teaching of the capstone course is also described in the paper. Other sections of the paper include the use of the capstone course in enhancing the communication skills of the students in addition to examples of strategies that are exercised in guiding the students on proper conduct as it relates to their professional development. The paper concludes with a summary and a few recommendations on enhancing the capstone course and the curriculum in preparing young men and women to enter the workforce or continue with advanced studies.

INTRODUCTION

Like most engineering programs in the US, the mechanical engineering program at Howard University continues to strive to achieve accreditation by the Accreditation Board for Engineering and Technology, Inc. (ABET). In obtaining and sustaining accreditation, the Department of Mechanical Engineering has to demonstrate, among other requirements, "that students have an ability to design and conduct experiments, as well as to analyze and interpret data" [1]. Similar to other engineering programs, the department has instituted year long capstone design projects that satisfy most of the student learning outcomes prescribed by ABET Criterion 3. The ABET student learning outcomes that are satisfied by the capstone design course include: a) an ability to design a system, component, or process to meet desired needs; and (b) an ability to function on multi-disciplinary teams. The importance of a capstone course in an engineering curriculum and its adoption in varied forms by engineering programs is documented by Todd et al [2]. Experiences by other engineering programs in the conduct of the capstone design course continue to be documented in papers that are presented at national and international conferences. The example includes two papers [3, 4] that were presented at the 2007 annual meeting of the ASME on varied capstone design experiences in two mechanical engineering programs.

Engineering design has been vertically integrated into all the engineering curricula at Howard University following the award of a major grant to the university in 1990 under the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) initiative. ECSEL was one of the first National Science Foundation Educations Coalitions formed through a partnership among a number of universities including City College of New York, Howard University, Massachusetts Institute of Technology, Morgan State University, Pennsylvania State University, the University of Maryland and the University of Washington. Today, in the mechanical engineering curriculum at Howard,

students in their first year are required to enroll in an introductory design course in which team work is stressed in groups of interdisciplinary students. Students follow a product development thread in the second and third years in which traditional courses such as Mechanical Design are offered in additional to courses in manufacturing through Product Development. In the final year students are provided with a capstone design experience through an industry defined design project that is approved by the faculty to meet the curriculum goals and objectives. The experience in the teaching of the capstone design course and the execution of the assigned design projects by students is well documented in a number of papers by Thigpen et al [5-16].

The intent of this paper is to report on the historical evolution of the conduct of the capstone design course at Howard University with greater emphasis on the transition from the mode of an "independent project" course to one that is structured with industrial sponsors. Following a brief introduction on the process in acquiring a sponsor, a description is provided of the mechanical engineering curriculum at Howard. The processes involved in the selection of a project, its introduction to the students, team formation and the expectations from the students are described in the paper. The involvement of an interdisciplinary faculty team in the teaching of the capstone course is also described in this paper. Other sections of this paper include the use of the capstone course to enhance the communication skills of the students. In addition, examples of strategies that are exercised in guiding the students on proper conduct as it relates to their professional development are also included. The paper concludes with a summary and a few recommendations to enhance the conduct of the capstone design course.

MISSION AND OBJECTIVES OF THE DEPARTMENT

To contextualize the history of the capstone design course in the mechanical engineering curriculum at Howard University, it is important to state the mission and goals of the department as they relate to the skill sets that must be acquired by students who graduate from the program. The mission [17] of the department of mechanical engineering department at Howard University is "to provide mechanical engineering majors a high-quality engineering education and to contribute new knowledge through research in mechanical engineering and allied disciplines. In addition, the department seeks to maintain recognition through scholarly work and service to the college, the university and the external community." To achieve the mission of the department of mechanical engineering, the faculty of the department, with input from other constituents, established the following Undergraduate Program Educational Objectives:

- Graduates of the Mechanical Engineering Program have acquired knowledge in mathematics, science and engineering and have developed problem solving skills necessary for productive careers in mechanical engineering and other professions and to pursue graduate, professional and life long education.
- Graduates of the Mechanical Engineering Program have acquired concentrated knowledge in at least one area in mechanical engineering. Areas of concentration may include aerospace, applied mechanics, energy engineering, and manufacturing and robotics.
- Graduates of the Mechanical Engineering Program can design and conduct experiments, analyze and interpret data, and effectively use modern technology in communication, research, and problem solving.
- Graduates of the Mechanical Engineering Program have the ability to formulate engineering problems and design a mechanical system or component to meet desired needs.
- Graduates of the Mechanical Engineering Program have developed teamwork, leadership and communication skills to effectively solve engineering problems.
- Graduates of the Mechanical Engineering Program are exposed to issues dealing with people in relation to themselves, society and the environment and understand the need for social, professional and ethical responsibility in engineering practice.

The mission and objectives that drive the curriculum were developed collectively by the faculty with input from external constituencies as part of a total revision of the curriculum in 2002. These guiding principles are documented in a handbook [17] that is given to students during their first visit to see an academic advisor.

DESCRIPTION OF THE CURRICULUM

In the mechanical engineering program at Howard University, students are required to complete a minimum of 128 credit hours and a minimum grade point average (GPA) of 2.0 in order to receive the degree, Bachelor of Science (BS) in Mechanical Engineering. Prior to the year 2002, the requirement ranged from 143-145 credit hours depending on the selected technical elective. The curriculum is structured into four main core threads: a social science/humanities thread; a thread involving mathematics and engineering science; a thread with a focus on laboratory experimentation and a thread that involves the integration of design in the curriculum.

A semester-by-semester scheme that has been developed by the faculty [17] based on a four-year completion period is used by the department to guide students through their matriculation in the program. The scheme requires students to take a minimum of 23 credits in social sciences/humanities, 68 credits in mathematics and engineering science, 9 credits

in laboratory experimentation; and 22 credits in courses that focus on engineering design. To give students room to pursue interests in preparation for graduate school or to enhance their entrepreneurial skills, students are given the chance to obtain 12 credit hours in a combination of technical electives (selected from the mechanical engineering curriculum) and "free electives" for which departmental guidelines exist for the selection of such courses.

THE CAPSTONE DESIGN COURSE

As part of the mechanical engineering curriculum, students are expected to complete a two-semester capstone course in which students work in teams to execute a project that is defined by industrial affiliates in consultation with the faculty. Prior to the structured industry participation in the capstone design course, a student worked independently with a selected faculty member on a project of mutual interest. The arrival, in 1988, of a new chairman of the department changed the way the capstone design course was being conducted. The chairman, Professor Lewis Thigpen, sought the participation of industry in the conduct of the capstone course. Based on a proposal outlining the elements of a successful capstone design course, he was invited to visit with the CEO of Sundstrand Corporation in Rockford, Illinois. He is shown in Figure 1, on clutches, with the President and CEO, Harry Stonecipher, during the visit to Sundstrand. As a result of the visit to Sundstrand, the company offered its support to provide an engineer who would work with the department on a project that would be assigned to student teams. That was the beginning of the structured capstone design course that is currently in place in the mechanical engineering curriculum at Howard University. During the 1989-1990 academic year the first team of students worked on a two-semester project to design an actuator for the deployment of a Ram Air Turbine. The experience in the conduct of the capstone design course over a three-year period with projects defined by the Sundstrand Corporation is documented in the paper by Thigpen et al [5]. As listed in Table 1, the partnership with Sundstrand continued for seven academic years.

The conduct of the capstone design course with single competitive team projects continued with the entry of the Boeing Helicopters, Philadelphia, following the end of the partnership with Sundstrand. The approach to the execution of the projects did not change, however, Boeing Helicopters assigned two engineers to the project with one being a former student of the department who worked on a Sundstrand project as a student and was therefore very familiar with the expectations of faculty from students. Student teams worked on the projects competitively and were not allowed to preview the opposing teams' design until the final presentation of the academic year which runs from August to May. Similar to Sundstrand, the assigned project each year was focused on the needs of the aerospace industry as to be expected. During the department's six year affiliation with Boeing Helicopters, student teams worked on a number of projects beginning with the design of flow spoilers and ending with a project on a human-powered helicopter.

FIGURE 1
PROF. LEWIS THIGPEN AND SUNDSTRAND CEO HARRY STONECIPHER
(TAKEN FROM SUNDSTRAND TODAY, JULY 27, 1990)

At the end of Boeing Helicopters' sponsorship, the department submitted a proposal to General Motors to associate with the giant automobile company and allow students to work on automotive projects. The relationship began in the 2002-2003 academic year with the student design of a tailgating package accessory for one of their automobile models. The success of such industry-university collaborative efforts is documented [5-16] in papers written by faculty in the Department of Mechanical Engineering and Industry representatives. The affiliation with General Motors continued the tradition began with Sundstrand in which a single project was assigned to teams of students in the capstone course and was executed competitively with each team unable to find what the other teams were doing until the final presentation at the end of the academic year. Projects from the GM were executed in multi-disciplinary teams including students from Electrical Engineering, Art in the College of Arts and Sciences and students from Marketing in the School of Business. During the 2006-2007 academic year, however, multiple projects were assigned to different teams and this allowed students to view each team's progress on assigned projects throughout the academic year. Table 1 shows a chronology of projects completed by students since the inception of the re-designed senior capstone design course to involve industry participation. As shown in the Table, there were two projects during the 2006-

2007 academic year from General Motors (GM); additionally, a new partner, the Sandia National Laboratories (SNL) joined with the department to offer a project on the characterization of a falling particle. In that year students from the department were joined by students from the chemical and electrical engineering departments to work on the project defined by the SNL. Two projects were executed in 2007-2008, one from the automotive industry and the other from the national laboratory. In the 2008-2009 academic year, student teams were assigned to work on three different projects, one from the partner national laboratory, one from a new partner, Hamilton-Sundstrand, and the other an in-house project defined by the faculty for students to re-design an EV1 automobile that was donated by General Motors to the School of Engineering. As expected, all projects are designed to challenge the students to use their training in basic engineering sciences, mathematics and communication and to work in teams to find and report solutions that meet technical constraints in addition to costs and are considered friendly to the environment.

A. ***Academic Year***	*B.* ***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
2004-2005	Create a Functional Body Design for the GM Hy-wire “Skateboard” Chassis	General Motors
2005-2006	Create a Functional Three-Step Removable Roof System for the Pontiac Solstice	General Motors
2006-2007	1. Design of Front and Rear Fascia with Speed and Remote Activated Spoiler for the General Motors Pontiac Solstice 2. Power Doors: A New Level of Convenience 3. Measuring Solids Flow Rate of a Falling Particle Curtain	General Motors General Motors Sandia National Labs
2007-2008	1. Characterization of a Falling Particle Curtain 2. Design a Functional Automobile Body for a Skateboard Chassis	Sandia National Laboratories General Motors
2008-2009	1. Quantification of the Relationship between a Heated Plume and the Effect on Speckle Pattern 2. Improvement of Radial Coolant Flow Distribution in a Multi-Fluid Evaporator 3. Conversion of the SATURN EV1into a Hybrid Vehicle	Sandia National Laboratories Hamilton-Sundstrand Howard University

2009-2010	1. Particle Interactions under Controlled Flow Conditions 2.Design of a Pressurized Element Interconnection for Lunar Habitation	Sandia National Laboratories NASA Marshall

TABLE I
PAST AND CURRENT DESIGN PROJECTS

To increase diversity among industrial affiliates that offer projects to students and assist in the teaching of the capstone design course, NASA Marshall joined the list of industrial affiliates to offer a project to a student team during the 2009-2010 academic year. The affiliation with NASA was facilitated by a former student who was employed by NASA on the completion of his doctoral studies from the department. In addition to a competitive project offered by the SNL to two teams of students, NASA Marshall assigned a project to a student team on the design of a pressurized element interconnection system for linking lunar rovers with a habitation module.

CONDUCT OF CLASS

To ensure the integrity of the curriculum in meeting ABET accreditation requirements, faculty representatives work with industry partners in the selection of a design project from a candidate list provided by the sponsors. Beginning in late April of each year, faculty and representatives from the industry partners engage in dialogue to decide on a design project for the coming academic year. These discussions continue through telephone conferences and e-mail exchanges throughout the summer until suitable projects have been defined.

Each design project is executed over the two semesters in the academic year. The students are introduced to the project with few details by the faculty during the first class meeting during the academic year. All students participating in the capstone design course are expected to be in attendance during all scheduled class periods. Faculty members from each of the participating departments (in the case of inter- and multi-disciplinary projects) are also present during class periods. 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 visits by the class and faculty to the industry partner site. In the past, students have made approximately three-day visits to industry sites with financial support from the partners. The exact visit period is determined after taking into account the schedules of all involved in the project, especially those of the staff members at the partner sites. In the case of the SNL, there are security issues that must be addressed in making arrangements for the visit. Consequently, the visit may not occur shortly after the opening of the academic year; in the interim however, the students selected for the project are able to communicate with partner representatives through a dedicated video conference machine. During each visit students are introduced to key personnel and mentors who will be available to assist in the execution of the project. In addition to tours of the various divisions at the site, students are given an in depth tour of the facilities that are available for performing various technical tasks.

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 among participating departments of the university, faculty from those departments have created new or modified existing courses to satisfy the demands and requirements of the joint capstone project initiative. In a typical semester schedule, the student teams submit monthly written progress reports to the faculty and industry mentors. The reports are reviewed prior to a video conference presentation by the students.

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 the industry mentors. 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.

SUMMARY AND CONCLUSIONS

The evolution of the capstone design course, a two-semester senior project course, in the curriculum of the mechanical engineering department at Howard University has been described in this paper. Following a description of the mission and objectives of the department, a brief overview of the existing curriculum is presented. The effort of Professor Thigpen, former chairman of the department in changing the conduct of the course from an “independent project” course to involve industry participation and to stress teamwork is documented. The transition in 1989 to the current mode of conducting the capstone course placed the department in a strong position to meet ABET 2000 requirements in preparing

students to acquire the ability to design a system, component, or process to meet desired needs, and to function effectively on multi-disciplinary teams. The key features of the course involve students working on design, build and test problems with the support of industry partners whose representatives are involved in the teaching of the course during the academic year. The challenge to the department is to be able to sustain the effort year after year with industry partners who are willing and have the resources to commit to the preparation of men and women of the future labor force.

Historically, the capstone projects have transitioned from purely design projects with support from the "for-profit" sector of the US economy to projects that involve not only design, but requirements to build and test as in the case of the SNL projects. Improvements must continue to be made in the selection and conduct of the capstone course as they relate to the overall mission and objectives of the department. One such improvement would involve changing the requirements so that students in the capstone course can pursue in parallel a purely research project derived from the capstone project and to obtain credit by enrolling in the independent course, Undergraduate Research. To avoid problems associated with such an independent course strict guidelines must be developed by the faculty to ensure fairness and for students to meet or exceed the course requirements in order to receive a passing grade. The continued success of a capstone design cannot be demonstrated without the involvement of an external industrial partner. The external partner mentors provide not only resources to support instructions in the design project but they also assist in the formative and summative assessment of the mechanical engineering curriculum. The recommendations from such evaluations provide the mechanical engineering department useful feedback as the faculty of the department work to revise and make improvements in the curriculum to meet or exceed accreditation standards.

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