Linking Engineering Education and Research in the Capstone Design Course at Howard University

E.K. Glakpe[1],H.A. Whitworth[2], T.J. O'Hern[3]

[1,2] Howard University, Department of Mechanical Engineering, Washington, DC, USA
[3]Sandia National Laboratories, Alburquerque, New Mexico, USA

eglakpe@howard.edu[1],

Abstract

The Department of Mechanical Engineering at Howard University has, for almost twenty years, included industry participation in the conduct of its Senior Capstone Design primarily to expose students to real industry design projects in addition to the need to meet accreditation standards. 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 team's design until the final presentation of the academic year which runs from August to May. The experiences in the teaching and the conduct of the projects have been documented in a number of papers by faculty members in the department.

In enhancing the capstone design course at Howard and to offer capstone projects which differ from the traditional design projects offered by the automotive and aerospace industries, the department recently partnered with two entities, one a non-profit national laboratory and the other a major for-profit aerospace engineering company. Consequently, in the last three years, students in the capstone design course have been exposed to research focused projects from the two new partners in addition to problems from the automotive industry. In the current academic year two student teams have been respectively tasked to design and implement techniques to enhance the predictability of Digital image Correlation (DIC) and to perform analytical and experimental studies on a novel heat exchanger. As part of these problem based learning projects, students employ various CAE tools available in the department to aid in the design and conduct of experiments to validate their designs and for the analysis of the data acquired in the process.

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 role of the two new partners in assisting the program with the preparation of students to enter the workforce or pursue other career options. Following a brief introduction on the process in getting the involvement of the partners, 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. Results from one of the design projects assigned by the new partners will be presented to show the outcomes achieved by the students. The paper concludes with a discussion on faculty and institutional roles on the project, lessons learnt in the grading of the course, proposed future enhancements of the collaboration and most importantly, the benefits derived from an association with industrial partners in the teaching and conduct of a capstone design course.

Introduction

Most engineering programs in the US are accredited by the Accreditation Board for Engineering and Technology, Inc. (ABET). The mechanical engineering department at Howard University is one such program that has continued to meet the requirements of ABET for accreditation due to innovative ways of structuring the curriculum and delivering instruction to its students. 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]. Depending on the engineering program, most mechanical engineering departments have instituted year long capstone design projects that satisfy most of the student learning outcomes prescribed by ABET Criterion 3. 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]. Two papers [3, 4] were presented at the 2007 annual meeting of the ASME on varied capstone design experiences in two mechanical engineering programs.

Before the ABET institution of design emphasis in the engineering curricula, the engineering programs at Howard University in 1990 received a major funding under the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) with the goal of design instruction and practice across each curriculum. ECSEL was one of the first National Science Foundation Education's Coalitions. Currently, in the mechanical engineering curriculum, 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 that includes students in Computer Science, Electrical Engineering, Civil Engineering, and Chemical Engineering. Students follow a product development thread in the second and third years in which traditional courses such as Mechanical Design are offered in addition to courses in manufacturing through Product Development classes for a total of at least 11 credit hours out of 128 credits that are required for graduation. Pockets of design are also found in classes that are traditionally labeled as engineering science, such as Fluid Mechanics and Heat Transfer. In the final year students are provided with a capstone design experience of six credit hours through an industry defined design project that is approved by the faculty to meet the curriculum goals and objectives. The experiences in the teaching and the conduct of the projects have been documented in a number of papers by Thigpen et al [5-11].

In this paper the authors report on the historical evolution of the conduct of the capstone design course at Howard University with greater emphasis on the recent role of a national laboratory, over the last three years, in the preparation of students entering the workforce or pursuing other career options. Additionally, a brief introduction is given to a new partner, Hamilton-Sundstrand, a for-profit aerospace company that has recently formed a partnership with the department in the conduct of the capstone design course. Following a brief introduction on the process in acquiring sponsors, 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. Further, a few results from the research-based design projects of the students are presented to show the outcomes achieved by the students. The paper concludes with a discussion of faculty and institutional roles in the conduct of the capstone design course, lessons learned in the grading of the course, proposed future enhancements of the collaboration and most importantly, the benefits derived from an association with a national laboratory and an aerospace company in the teaching and conduct of a capstone design course.

Historical perspective

In each academic year of the last twenty years, the Department of Mechanical Engineering at Howard University has included industry participation in the conduct of the Senior Capstone Design. Prior to the structured industry participation, a student worked independently with a selected faculty member on a project of mutual interest. Depending on the industry partners involved, real industry 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 projects competitively and were not allowed to preview the opposing team's design until the final presentation of the academic year which runs from August to May. In a few of the academic years, 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 three projects during the 2006-2007 academic year, two projects from General Motors (GM) and one from Sandia National Laboratories (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.

The department has been fortunate to work with a number of industrial affiliates. Beginning with Sundstrand Corporation, an aerospace industry, design projects have ranged from the design of a Ram Air Turbine Deployment Actuator to the Design of a Global Express Wing Brake. Following the relationship with Sundstrand, the department affiliated with Boeing Helicopters, another aerospace company to work on a number of projects for six years beginning with the design of flow spoilers and ending with a project on a human-powered helicopter. 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 in papers [5-11] written by faculty in the Department of Mechanical Engineering and Industry Representatives.

Due to the worldwide downturn in economic activity, the department has not collaborated recently with direct support from General Motors on a capstone project; however, in an effort to continue the strong relationship with students and faculty from the Department of Art, an automotive project was defined to re-design the General Motors EV1 as a hybrid vehicle with more than one power system. As in the past year (2007-2008), the Department of Mechanical Engineering continued its relationship with the Sandia National Laboratories to offer students a meaningful design experience on projects that are directed at solving problems of national interest. A new partner, Hamilton-Sundstrand (HS) recently (2008-2009 academic year) joined with the department to offer a meaningful design experience for students in the capstone course. As described later in the paper, 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.

Partnerships with Sandia National Laboratories and Hamilton-Sundstrand

By interpreting the ABET requirements broadly, the department has recently been able to define capstone projects that are more research based than previous projects with more design focus.

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
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 and 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

Although the department has in each of the last three years proposed a traditional multidisciplinary design project with automotive focus to one team of students, demands of the industry affiliates have necessitated the execution of projects that require student teams to function in a research environment. Consequently, not only are the students required to use their knowledge in the design and build an experimental facility, they are also expected to design the experiment, including the experimental protocol, in order to generate meaningful and repeatable data to support other research efforts. During the 2006-2007, the design project involved the design of a facility to measure solids flow rate of a falling particle curtain. The 2007-2008 project continued with the previous year's project in which the students were required to improve on the previous facility and to design and conduct appropriate tests to characterize the falling particle curtain. Following that tradition of research-based projects, two new projects from the two industry partners were executed in the 2008-2009 academic year. The Sandia national Laboratories student team was tasked to implement Digital Image Correlation (DIC) in a non-isothermal environment whereas the Hamilton-Sundstrand student team designed an experimental facility to study the mal-distribution of flow in a Multi-Fluid Evaporator (MFE). In addition to a number of capstone faculty at the university, the two industry teams provided four primary technical personnel in addition to other technical staff persons who served as consultants to the students when needed. They are collectively referred to in the paper as mentors.

Conduct of capstone class and execution by students

The process of forming partnerships by the department with industrial affiliates is documented in papers by Thigpen and al. [5-12]. Each design project is executed over the two semesters in the academic year. The student teams that are formed by the course coordinator are introduced to the project by the faculty and industry mentors 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. 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. For a project in which the majority of the students are from the mechanical engineering department, the students are instructed to select a leader from that discipline.

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 department(s) 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 the 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 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.

Both research-based projects are executed in similar fashion by the student teams. The execution of the SNL project will be used to highlight the approaches taken by the students and mentors. During the three year partnership with the SNL (and one with HS), students have worked on projects that were designed to support major initiatives of the industry sponsors to obtain reliable data in support of other research/design projects. All projects task the student teams to design, build and test, and utilize each experimental facility to acquire data or to improve upon an existing design. In the first academic year (2006-2007) of the partnership with SNL, the students were tasked to design, build and test a system for measuring the solids flow rate of a falling particle curtain. A total of seven students from three participating departments worked on the project. Most of the first semester was spent by the students in clearly defining the open-ended problem, conducting literature reviews on flow meters and finally to propose at least three approaches to measuring solids flow rates. On review of the semester's work, the students were guided by the faculty in pursuing one design concept during the second semester of the academic year. Like all other capstone projects, the students provided monthly written reports of their progress to the faculty and mentors. Fig. 1 shows the major part of the experimental facility that was designed and built by the students. The rig is designed to hold a hopper that stores and dispenses the solid particles that are used in the study. Part of the study was to determine the effect of various hopper designs on the solids flow rate. The students used five different hoppers in their study. Fig. 2 is a picture of the experimental facility designed by the students during the 2008-2009 academic year for the DIC experiments. In each approach, the students used engineering and scientific principles in addition to software tools such as NX (Unigraphics) to design each experimental setup that was coupled to data acquisition systems including a dedicated computer workstation.

Fig. 1 Experimental Facility for Flux Test

Fig. 2 Experimental Facility for DIC Project

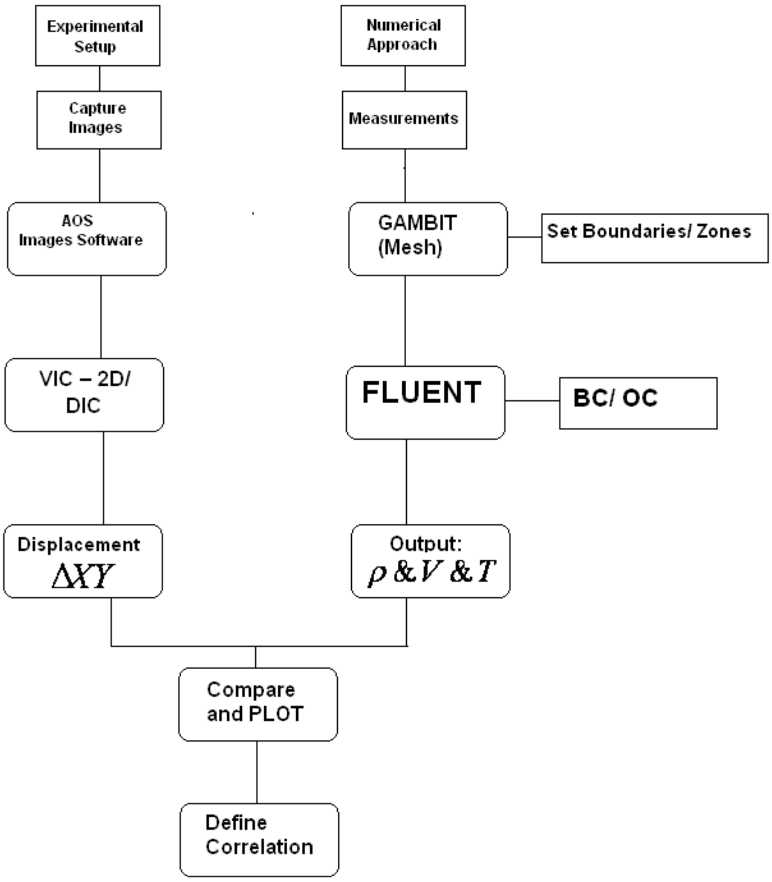
Unlike the 2007-2008 academic year in which a student team continued to build upon the partial success of the previous team, a new project was assigned by the SNL during the past (2008-2009) academic year. The team was required to develop a DIC approach for use in a non-isothermal environment. Fig. 3 shows a schematic of the overall experimental/numerical setup of the project. Five students worked as a team on this project. Starting with the designed and built "experimental rig", the students proceeded to create a non-isothermal environment by using a safe and reliable household appliance to generate a heated plume. With the assistance of a high

speed camera that was purchased for use in the first two SNL projects, the students were able to capture images that are further processed to show the displacements that result on a speckle pattern. In processing the images, the students had access to the Video Image Correlation 2D (VIC-2D) software recommended by the SNL at no cost to the department. VIC-2D is software developed by Correlated Solutions that uses a set of algorithms to correlate images of a specimen as it is subjected to forces that cause deformation. This comparison technique is valuable for monitoring the behavior of specimens during mechanical property tests. The VIC-2D software

uses the digital image correlation technique to make strain measurements. This system is able to provide two-dimensional strain maps of an entire planar specimen surface. The equipment consisted of computer software and a personal camera. The digital camera records the video from the trials and a third-party software iMovie was incorporated to extract still images at specified intervals. VIC-2D analyzes the images and calculates displacement.
In addition to VIC-2D, the student team employed video editing software to allow users to edit personal movies. The software imports video footage to the computer and allows the user to edit the video clips, add titles and music. The student team employed the software, iMovie, to edit the video records of each trial, paving the way for use of the Digital Image Correlation technique. By importing the files into the software, the team was able to specify the desired time of capture for still images from the movie. The software was set to extract a still image from every fifth second of the video, to match the data-sampling rate of the acquisition software. Thus, the still images reflected the visual state of the speckle pattern at the exact moment a temperature reading was logged.
Numerically, the students employed at least two commercial software packages to assist in the generation of additional data that could not be done due to the limitation of the experimental facility. To do so the team used GAMBIT/FLUENT to model the geometry of the experimental facility and also the fluid flow and heat transfer characteristics of the heated plume. By using the limited experimental data to validate the numerical calculations, the team developed confidence in the use of the acquired numerical data that could not otherwise be obtained from the experiments. Fig. 4 is a plot of the measured temperature values as compared with the numerical temperature values obtained from the FLUENT simulation. In obtaining the time history of temperature, the student's model included the interaction of the laboratory walls as the boundaries of the problem. As mentioned earlier, the team also relied on the industry software NX (Unigraphics) for the structural and geometric design of the experimental facility. The commercial software tools employed are available in the department as part of the university's membership in the Partners for the Advancement of Collaborative Engineering Education (PACE) organization [13]. As part of the capstone design assignment, the students were guided by tutorials to learn and understand the functions of the three codes, GAMBIT, FLUENT and NX with the assistance of faculty members who are familiar with the software codes for the proper modeling of the geometry and the application of boundary conditions.

As a team project, the conduct and execution of the capstone design course brings its challenges and opportunities for learning and professional development. Faculty mentors must be vigilant in making sure that student stay focused on the project and no one team member carries the loads of other team members, hence the need for a confidential peer evaluation system [10-12]. Each team is expected to have a team leader who is responsible for scheduling group meetings with written agenda. The faculty coordinator is copied on all e-mails that are distributed including the invitation to attend any of the team meetings. Each meeting is followed by a distribution of meeting notes recorded by a member and not necessarily the team leader.

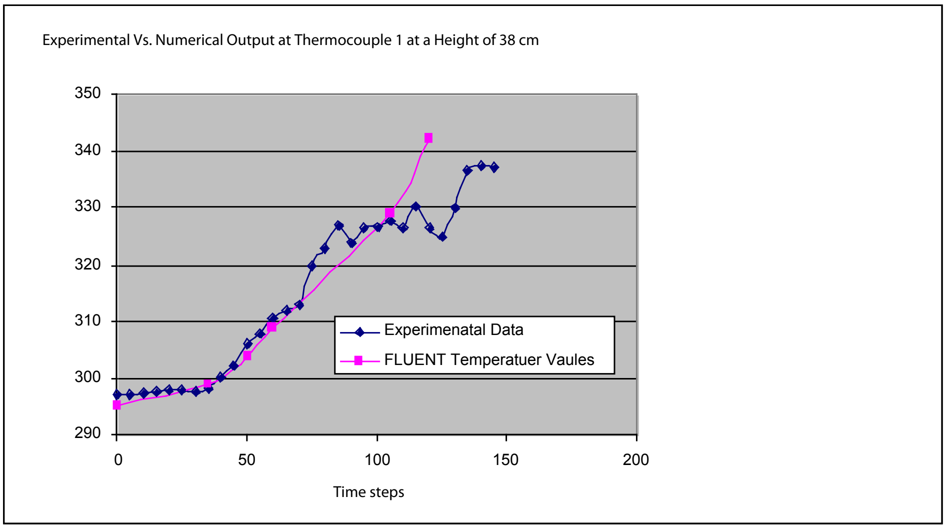
Fig. 3 Schematic of Experimental/Numerical Procedure



Resources, benefits and challenges

The successful conduct of a meaningful capstone design course requires a significant investment in resources. Resources are required in the form of budgeted time for the mentors to spend with students. The course requires students and faculty to spend more time than that required for a regular 3-credit hour course per semester. Additionally, resources are required to support travel for students, faculty and mentors and to provide funding for purchase of materials to build models and prototypes of design projects. With the generous support of the SNL, the department was able to acquire the high speed camera that was a key element in the desire to provide a meaningful experience to the students. As a member of PACE, the department was able to provide the hardware and software resources needed to execute the CFD codes and other installed programs for computer aided engineering and report writing. In spite of the high level of resources required, by departmental standards, there are numerous benefits for students, our external partners and the faculty who are involved in providing instructions for the course.

Fig. 4 Validation of Numerical Code



Students gain insight into the practical aspects of engineering in the workplace, develop skills in working on teams, experience a transitional step between classroom and the external environment, gain an understanding of how the curriculum is relevant to real world research methodology, manufacturing and implementation, develop and improve communication skills and, most importantly, improve their opportunities for employment. The capstone design course enhances the professional level of the students and it gives the 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. Such formal and informal inputs provide feedback to the faculty to use in the continuous improvement of the program as required for accreditation.

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 in some cases 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 external 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 project course in mechanical engineering with a research focus has been described in this paper. The approach in teaching and the execution of the capstone course has the potential of producing graduates who are capable of working in traditional engineering positions or are better prepared to succeed in graduate programs. The key features of the course involve students working on a design, build and test problem with the support of industry partners whose representatives are involved in the teaching of the course during the academic year. Due to scheduling issues and curricula differences in the departments of electrical and chemical engineering, an inter-departmental collaboration did not materialize and consequently, their students have only been able to participate in the first year of the collaboration. In spite of this setback, however, the students who participated in the project were exposed to a national laboratory environment within a classroom setting and were thus better prepared for the challenges they may face on accepting work assignments for the first time after graduation. 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 inter- and multidisciplinary departments.

Compared with the conduct of previous capstone design projects that were limited to the automobile industry, the collaborations described in this paper are with a national laboratory and an aerospace company that are charged with finding solutions to problems of national interest. The collaborations with the two entities provide students the opportunity to work on problems that are more research focused compared with the development of a product as in past projects. The continued success of the capstone design course described in the paper cannot be demonstrated without the involvement of external partners such as the SNL and HS. 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 as well as those in the other participating academic departments. The recommendations from such evaluations provide the mechanical engineering department, in particular, useful feedback as the faculty of the department work to revise and make improvements in the curriculum to meet or exceed accreditation standards.

Acknowledgements

The support of the capstone design course in mechanical engineering at Howard University by Sandia National Laboratories and Hamilton-Sundstrand is greatly appreciated. The authors are particularly grateful to Dr. Anthony Thornton, Dr. T.Y. Chu, Ms. Dominique Foley Wilson of Sandia National Laboratories and Dr. Kevin Greenaugh of NNSA for their support; and to Mr. Gregory Quinn and Mr. Mark Zaffetti of Hamilton-Sundstrand. The authors are also grateful to the team-taught faculty, Dr. M. Lucius Walker, Jr, Professor Emeritus, Dr. Chi C. Lee, Professor of Art, Mr. David Smedley, Associate Professor of Art, Howard University, for their continuing support of the capstone design course.

References

01. ABET Web Site, http://www.abet.org
02. Todd, R.H., et al., "A Survey of Capstone Engineering Courses in North America," Journal of Engineering Education, vol. 84, no.2, 1995, pp. 165-174
03. Agustin, W. P., et al., "Balancing a Radio Telescope as a Capstone Design Project", Proceedings of IMECE2007, 2007 ASME International Mechanical Engineering Congress and Exposition, November 2007, Seattle, Washington, USA
04. Dong, J., and Dave, J., "Design-Build-Test – The Capstone Design Project", Proceedings of IMECE2007, 2007 ASME International Mechanical Engineering Congress and Exposition, November 2007, Seattle, Washington, USA
05. Thigpen, L., Hou, C., Fairchild, J., and Nallenweg, R., "A Successful Capstone Design Course Featuring Industry Involvement", Creativity, Educating World-Class Engineers, ASEE Annual Conference Proceedings, Vol. 2, Toledo, Ohio, June 1992, pp. 1256-1263.
06. Thigpen, L., and Glakpe, E.K., "Introducing Industry Culture in the Engineering Curriculum," Innovations in Engineering Design Education, ASME, Orlando, FL., March 1993, pp. 287-290.
07. Thigpen, L. and Glakpe, E. K., "Academic and Industry Cooperation in Mechanical Engineering at Howard University", Proceedings ICEE'99 Conference, Technical University of Ostrava, Ostrava and Prague, Czech Republic, August 10 – 14, 1999.
08. Thigpen, L., "Innovations in the Teaching of Design in Mechanical Engineering at Howard University", Engineering Education: Curriculum Innovation and Integration, Edited by W. Aung and S. Carmi, Engineering Foundation Conference Proceedings, Santa Barbara, CA., January 1992, pp. 315-319.
09. Thigpen, L., and Glakpe, E.K., "Introducing Industry Culture in the Engineering Curriculum," Innovations in Engineering Design Education, ASME, Orlando, FL., March 1993, pp. 287-290.
10. Thigpen, L. and Glakpe, E. K., "Academic and Industry Cooperation in Mechanical Engineering at Howard University", Proceedings ICEE'99 Conference, Technical University of Ostrava, Ostrava and Prague, Czech Republic, August 10 – 14, 1999.
11. Thigpen, L. and Glakpe, E. K., "The Capstone Design Experience in Mechanical Engineering at Howard Uni-

versity", Proceedings, Frontiers in Engineering Education, Session 11b2, pp. 25-29, San Juan, Puerto Rico, November, 1999
12. Glakpe, E.K., Thigpen, L., Whitworth, H.A., and O'Hern, T.J., "A Unique Collaboration with a National Laboratory on the Conduct of the Senior Capstone Design at Howard University", Proceedings of ICEE'2008 Conference, Pecs and Budapest, Hungary, July/August 2008
13. PACE Web Site, http://www.pacepartners.org/