AC 2011-1278: THERMAL SCIENCE CAPSTONE PROJECTS IN MECHANICAL ENGINEERING

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Thermal Science Capstone Projects in Mechanical Engineering

Abstract – **It is perceived that the majority of capstone projects for senior mechanical engineering students usually deals with designs that do not include issues related to thermal sciences; i.e., thermodynamics, heat transfer and fluid mechanics. This may lead students to falsely think that the thermal sciences are usually not critical in practical designs since the capstone course is supposed to mimic actual engineering designs in the industry. The thinking that thermal issues are incidental is dangerous since vital industries - oil, electronics, power generation and conversion and cryogenics, to name but a few - rely heavily on thermal design. Actually one of the biggest current challenges is energy- its sources and conservation, which feeds into any kind of sustainable design. Lack of thermal projects in capstone courses also may prevent interested students from making thermal sciences their focal area and future career. The relatively low number of thermal science projects in capstone courses may be due to the fact that the instructors assigned to teach these courses are specialists in other areas of mechanical engineering.**

This paper explores these issues through surveying capstone projects in a number of universities. It probes capstone-teaching faculty and reflects on their attitudes toward thermal-science projects. The paper attempts to determine if there is a lack of thermal-science projects in capstone courses and if so what the reasons are. A third purpose of the paper was to probe the feelings of non-thermal faculty teaching capstone towards thermal projects, and whether or under what conditions they would be willing to offer more thermal design projects in the future. The paper also poses a few general questions regarding the role of thermal sciences in capstone design and suggests a strategic way for implementing more thermal science capstone projects.

Introduction

Mechanical engineering emerged as a field during the industrial revolution in Europe in the 19th century.[1] Thermal sciences is a term usually given to a group of mechanical engineering disciplines that include thermodynamics, heat transfer and fluid mechanics. By extension, one may add technical electives and graduate-level courses that involve some or all of these; i.e., design of thermal systems, energy conversion, internal combustion engines, combustion, heating ventilating and air- conditioning, intermediate and advanced fluid mechanics, transport phenomena, advanced and statistical thermodynamics, convection, conduction, radiation, and the like. The term thermal science is used interchangeably with others such as thermo-fluids, thermal-fluids or thermal science and fluid mechanics. Sometimes, the whole group is referred to as thermodynamics.[2]

The thermal sciences are considered "difficult" subjects. Both fluids and heat transfer require a great deal of calculus, while thermodynamics requires a lot of conceptual understanding of abstract ideas. The National Council of Examiners for Engineering and Surveying (NCEES)

reports on the national results of the Fundamentals of Engineering Examination of ABET-accredited engineering program examinees. The national passing rate in thermodynamics and heat transfer reported by NCEES continues to be relatively low compared to other areas, i.e., 51% in 2008, 53% in 2009 and 58% in 2010.[2] In terms of applications of the thermal sciences, the passing rates in refrigeration and air-conditioning, for example, are worse: 42%, 41% and 44% in the last three years. These rates warrant more attention to be paid to the thermal sciences.

The thermal sciences, nonetheless, are very important engineering disciplines with critical and far-reaching engineering and industrial applications. As a matter of fact the solutions to some of the monumental crisis of our times lie within the subject matter of the thermal sciences. Energy production, conversion and storage are all treated and governed by the laws of thermodynamics. Further, the efficiency of such processes is also obtained by the laws of thermodynamics. The amounts and flow of harmful products of the energy conversion, transportation and other industries are also treated by thermodynamics and fluid mechanics. The combustion phenomenon that produces mechanical propulsion (cars, airplanes, trains, etc.) and electrical power (steam and nuclear power plants) is a subject of the thermal sciences. These sciences are critical in thermal management of electronics, such as personal computers and data transmission systems.

Design is widely considered to be the central and distinguishing activity of engineering.[3] The engineering capstone design course is the culmination of undergraduate training in engineering expressed in the act and art of design.[4] This course can be arguably considered the most important educational component in almost all undergraduate engineering curricula, which is reflected by the importance placed upon it by ABET's accreditation criteria. This course is in a position to determine a program's compliance with many ABET criteria. ABET's Criterion 3 states, in part, that a student should be able to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.[5]

There has been at least one conference solely dedicated to the scholarship of capstone design in engineering. It was first convened at the University of Colorado in June of 2007 under the name National Capstone Design Conference. There were over 170 participants from industry and universities throughout the United States and a few other countries. This conference was focused on improving the capstone or senior design course experience. Generous industry sponsorships from companies such as IBM, Ball, Boeing, Coors, and General Dynamics, as well as grants from NSF and ASEE were provided. Some interesting trends emerging from the conference were a rise in industry sponsored projects and use of faculty with significant industry experience to teach capstone design courses. There was also a move toward establishing lasting partnerships with the industrial sponsors. The industrial benefits of sponsoring capstone projects include recruiting known, excellent students, and obtaining new ideas for product improvements and manufacturing techniques.

Other findings and trends from the conference included using challenging but reasonable projects, negotiating intellectual property requirements of sponsors, and confidentiality issues. Newer trends in capstone design included collaborative efforts between different engineering

departments at separate universities within the US, the use of international collaborative projects, and establishing design partnerships between engineering, business and health science students.[6]

The same conference was recently held (June 2010) for the second time in Boulder, Colorado. Topics ranged from assessment, grading, team selection and dynamics, communication and technical writing, innovation, entrepreneurship and commercialization, globalization, industry partnerships and mentoring, intellectual property, design for people with disabilities, sustainability, non-technical skills and a software package for conducting the course, among others.

Many excellent papers with critical understanding of design and capstone were presented and discussed. In one paper, it was stated that the concept stage of design promoted an undergraduate engineering student to become a "systems thinker",[7] another was a case-study for investigating the loss of design information in collaborative design projects,[8] while a third talked about a globally distributed capstone engineering design experience.[9] There was no specific discussion of what the nature of projects in the capstone course should be, or what the ratio of thermal-science projects to mechanical-design projects was or should be.

Faculty knowledge and attitudes impact the practices that teachers employ in their courses in a wide variety of ways.[10] Capstone design is no exception; actually, it may be impacted more severely. The purpose of this paper was to probe capstone-teaching faculty and to reflect on their attitudes toward thermal-science projects, and the general status of thermal science projects in the course. Another purpose was to determine if there is a lack of thermal-science projects in capstone courses, and if so to suggest reasons for that**.** A third purpose was to learn from non-thermal faculty teaching capstone what their feelings were towards thermal projects, and whether or under what conditions they would be open to offering more thermal design projects in the future. The paper will also pose a few general questions regarding the role of thermal sciences in capstone design.

Data Collection

Information for the current paper was collected using a questionnaire targeting a few issues related to capstone and thermal science projects in capstone courses. The questionnaire was intentionally kept short and concise in order to make it easy and fast to complete. Faculty members are usually loaded with many responsibilities, and very likely would refuse to complete a lengthy survey swiftly. Questions regarding simple statistics, background, attitudes and opinions regarding capstone courses and thermal projects were directly posed. The questionnaire is reproduced below.

Questionnaire

Please complete and email to

……

Thank you for your cooperation.

Name: _____

University: _____

1. How many times (or years) have you taught Senior Capstone?
2. What is your technical area of expertise?
3. On average, how many groups (projects) do you have in your class?

In the following, "thermal" relates to fluid, thermodynamic, or heat transfer aspects.

4. How many of your design projects are primarily thermal design projects?
5. If your main area is outside the thermal sciences, would you be willing to have more primary thermal science projects if you can get direct and sustained help from a thermal science faculty?
6. Other comments regarding thermal projects in capstone design, or lack thereof.

Responses were received from 11 different capstone instructors from six US and one Canadian university. The total number of capstone projects covered by the respondents was 447. The areas of expertise of faculty included machine design, mechatronics/controls, process/product design and thermal science.

Results and Discussion

Basic treatment of the collected data was performed in order to identify possible trends. Figure 1 is a plot that shows the percentage of thermal and non-thermal capstone design projects based on the total number of projects covered by this data sample. It is clear that the thermal science projects are significantly less than those of non-thermal projects, i.e., 31.2 % compared to 68.8%.

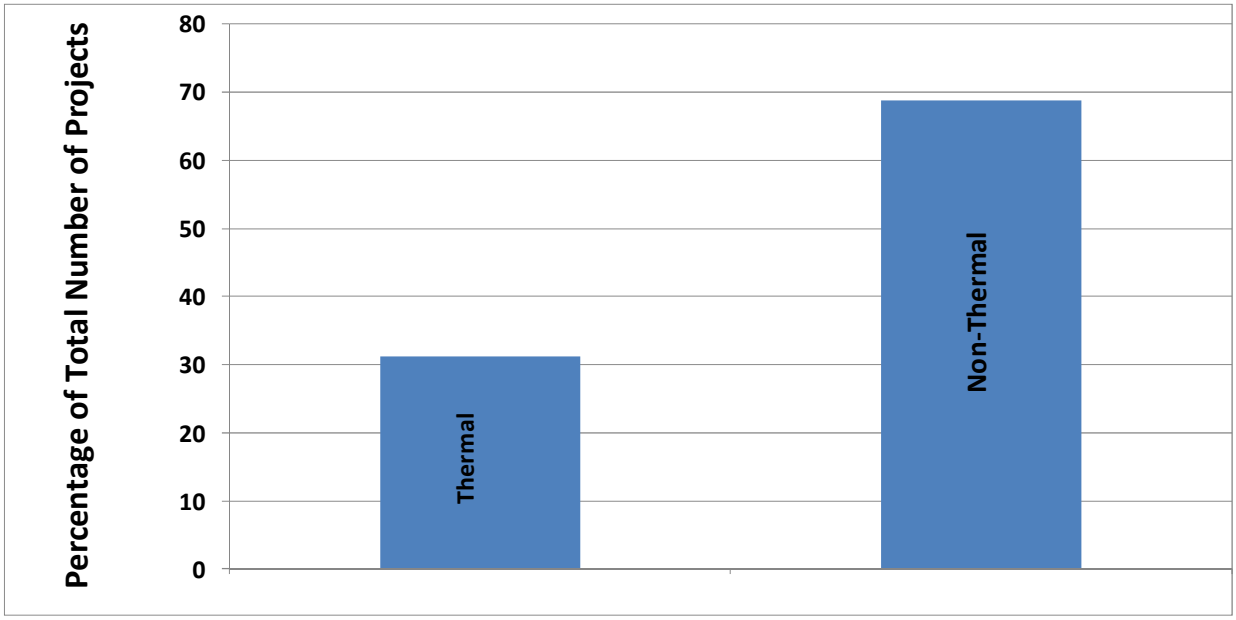

Figure 1. Percentage of thermal and non-thermal capstone design projects

Figure 2 graphically shows the percentage of thermal science faculty that taught capstone design compared to non-thermal faculty who taught the course. The percentage of thermal faculty is about 36.4% compared to 63.6% for non-thermal faculty, essentially the same division as seen for the project types.

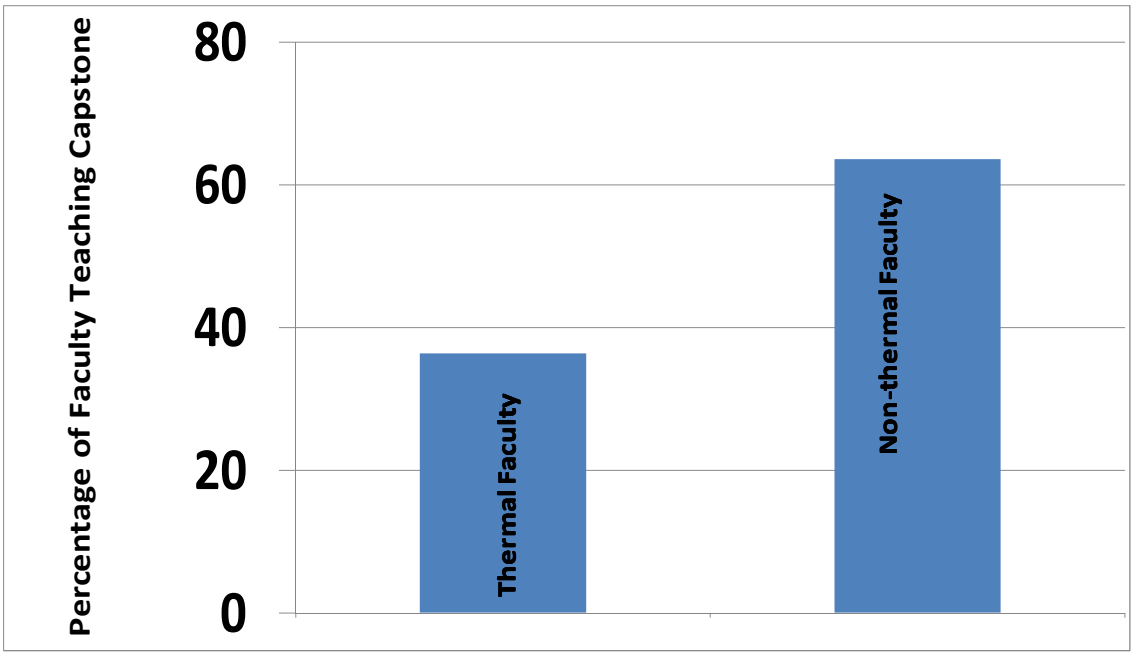

Figure 2. Percentage of thermal and non-thermal capstone instructors

Few factors contribute to the portfolio of projects offered in capstone design courses. The area of expertise of the instructor plays a significant role. Thermal science faculty tends to assign thermal projects in their capstone course and others do the same, unless the choice of projects is decided by outside factors. There seems to be a correlation between the area of expertise of the instructor and the type of projects offered in capstone classes.

In response to the fifth question of the survey, three (42.8%) of the non-thermal science instructors surveyed expressed willingness to offer more thermal projects if they get support from thermal science faculty, while one said it made no difference, Fig. 3. A fifth was not willing to offer more thermal projects and indicated that 20% thermal-science projects in his capstone course was a good proportion.

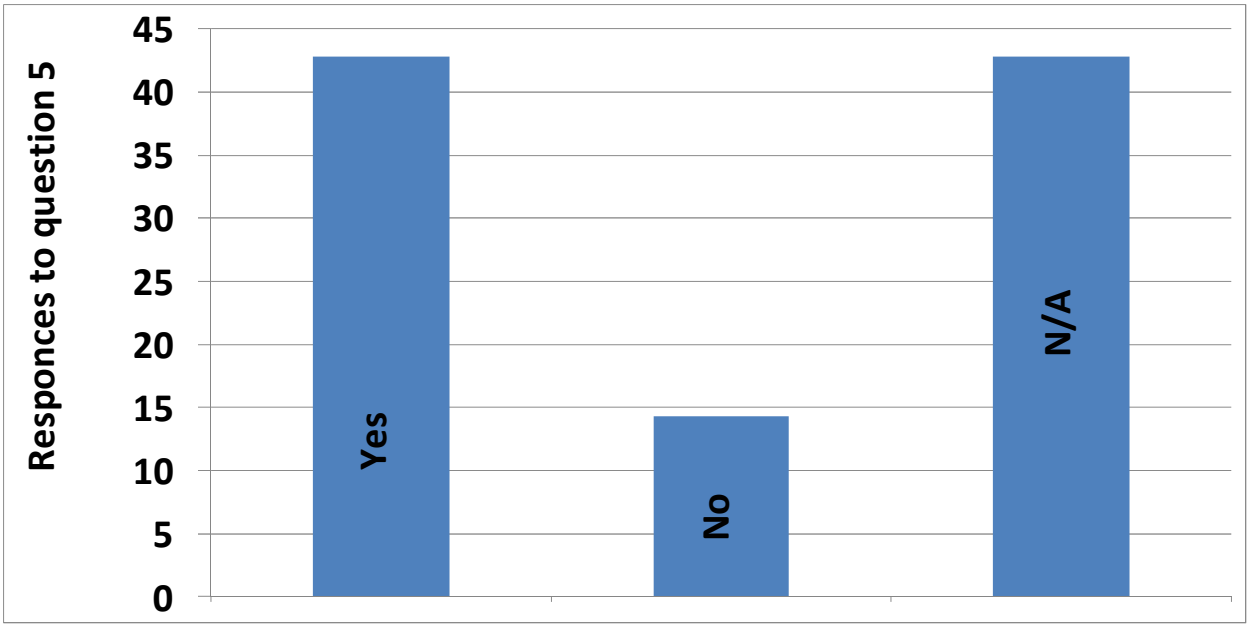

Figure 3. Percentage of capstone instructor's willingness to include more thermal projects

In a few cases the nature of projects was mandated by sponsoring industrial partners, or in one case, by a funding agency which targeted specific initiatives. Examples included NSF-funded capstone projects focused on design of mechanical devices for people with disabilities and specific projects given by Ford Motor Company to one university. For these cases the fifth question was not applicable. In one case the instructor, who was assigned to teach the capstone design course on regular basis, decided to steer the capstone course in a specific direction: designs for the disabled community, therefore the projects offered all lied in that area.

There were some rather surprising comments, or assertions, made by some instructors. One faculty member indicated that he did not think that projects that are primarily thermal science were a good fit to the capstone course, because they generally tend to be over-defined. He also stated that such projects do not generally allow for interactions between students and customers or clients as much as other projects do.

One counter example for this last comment is the following. Take a thermal design project to improve the design of an AC system for a certain manufacturer of such devices. In this project, students are suppose to reduce the size and weight of such system and attempt to reduce the manufacturing cost. Such project allows a lot of interactions between the students and the manufacturer in terms of obtaining initial and basic information about the current systems- how there are made, their size and weight, etc. Students would also obtain a list of requirements from the manufacturer and list them as goals and objectives. They would go back to the client with some initial ideas and get feedback, and so on. In other words, such projects would have the provisions for all the steps, exercises, activities and dynamics of a successful capstone experience.

The faculty member's responses and the discussion given above raised the following questions that beg for answers.

- Should capstone design courses include a diverse portfolio of projects for students to choose from based on their preference? In other words, should the capstone projects be like a collection of technical electives in various areas, so that a student can choose his/her focus area? Suppose a student decided in his junior year that he/she likes thermal science and that he would like to strengthen his education in that area. Therefore he chooses to take all of his technical electives in the thermal science area. To round his experience, this student would tend to like to have his crowning design experience by working on a thermal design project in his/her capstone course. Should such a student be denied the opportunity to do so, because all projects were given by an industry that is focused on robotics, for example, or because the instructor's area of expertise was controls, for example, and that all the projects were control-related?
- If projects are provided by sponsors, doesn't that limit students' choices?
- How or where is the student's voice heard in all of this? And how is his/her choice of a capstone experience honored?
- If all the projects in a capstone class purely deal with machine design, may that not give the students impression that thermal sciences are not important or thermal issues are incidental?

Conclusion

The role of thermal sciences in capstone design projects was probed using a short survey that was completed by a number of faculty members who teach the course. Based on the analysis of the data set, the following trends regarding capstone projects seem to emerge.

The type of capstone projects assigned depends to a considerable extent on the area of expertise of the instructor, although the existence of sponsoring agencies and industrial partners also plays a role.
The majority of capstone design instructors tend to be non-thermal science faculty.
More instructors would assign thermal design projects if they had more support from thermal faculty.

A possible and easy to implement solution for the low percentage of thermal science projects in capstone courses would be for thermal science faculty to offer meaningful projects and to offer to mentor and advice students working on these projects, in order to relieve non-thermal capstone instructors from the burden of trying to advise students on issues outside their area of expertise.

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