AC 2007-832: TEACHING HEAT TRANSFER THROUGH INDUSTRIAL PARTNERSHIP

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Teaching Heat Transfer through Industry Partnership

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Abstract

In this research project, a heat transfer course was taught to senior undergraduate students in a new way that involved an industrial engineer as a collaborative instructor (an adjunct). The industrial engineer was invited to bring engineering products to the classroom and demonstrate the latest design approach for the product's improvement. Through the exercise, topics typically not covered in a traditional classical heat transfer course were discussed, and enhancements in students' learning of the course were measured using an evaluation tool specifically designed to this purpose.

Results indicated that students reacted very positively to inviting industrial adjunct faculty. In addition, the qualitative perception of the authors is that students were more engaged in this interactive method than in the traditional method of teaching. Two limitations of the new method of teaching include the time shortage in covering the complete content and the difficulty of evaluating the effectiveness of the adjunct faculty because of their limited availability to students.

Introduction

The ongoing expansion of the new College of Engineering at the University of North Texas (UNT) created an opportunity for the addition of a new, innovative mechanical and energy engineering (MEE) program and an excellent prospect for the establishment of an innovative approach to engineering education. As part of our planning approach for the MEE program and innovative teaching approach, a small-group team-learning approach to Learning-to-Learn practice was adopted. Because heat transfer is one of the essential subjects for any mechanical engineering program, it was selected as the topic for the pilot course. Our hope is to use the experience in shaping a teaching style for other courses in the MEE program.

Traditionally, the course was taught by standard method of teaching referred to as "chalk-and-talk" style. Recently, a great deal of attention has been directed toward teaching methods collectively called "active learning" methods. Research studies evaluating student achievement have demonstrated that many strategies promoting active learning are superior to lectures in the development of students' skills in thinking and writing.[1] Furthermore, cognitive research has shown that a significant number of students have learning styles best served by pedagogical techniques other than lecturing.[2-4]

Heat transfer as a pilot course

Heat transfer application is a required senior-level undergraduate course in the mechanical engineering technology program at the University of North Texas (UNT). The required textbook for this course was written by Yunus Cengel.[5] Course objectives and student learning outcomes from the course syllabus are listed in Appendix A. Each learning outcome addresses at least one course objective. Each course objective addresses at least one outcome criterion in accordance with Technology Accreditation Commission (TAC) of the Accreditation Board for Engineering and Technology (ABET) and possibly one or more criteria set forth by the

American Society of Mechanical Engineers (ASME). Letters in parentheses after course objective items indicate ABET criteria[6] (a-k) and ASME criteria[7] (l-n). Numbers in the parentheses after student learning outcomes indicate addressed course objectives.

In this study, the course was taught jointly by an academic faculty and an industry partner. To engage students in active service learning, the faculty formed student groups consisting of three to four students. Each group was asked to design an evaporative cooler. The students were also asked to research and select an appropriate adjunct industry instructor to participate in a design-oriented project on emerging technology. The role of the industry partner was to introduce applications of heat transfer concepts in design of new products, product specifications, advantages, limitations, etc. in the product their company offers related to this issue. Students were asked to make observations on aspects of the mechanical operation of the new technology in relation to fundamentals of heat transfer, uniqueness of the technique, cost effectiveness, and other relevant topics. In a particular, the case industry partner was asked to bring in the most recent version of his/her company product and demonstrate its applications. Once the group members had completed their project, they were required to provide a report on their design. The performance of individual students as well as groups was assessed to determine how actively engaged the students were in the process.

A comparison study was conducted to determine the effectiveness of two models for teaching the heat transfer course. During the first semester, a faculty member using the traditional problem solving format taught students. During the second semester, the same faculty member, teamed with an industry partner, taught a different group of students. After the two classes were completed, the students' grades and their course evaluations were .

Industry partnership activities

Two relevant industries in the area – namely, Texas Instruments (TI) and Marlow Industries, Inc. participated in this study. Texas Instruments is a large industry with a multibillion-dollar annual budget that is highly active in the area of thermal management in electronic devices. Marlow Industries, Inc., is a much smaller company (with a multimillion-dollar annual budget) that designs, produces, characterizes, and markets thermoelectric coolers. Representative engineers from both companies were invited to teach components of the course for one week each. The following paragraphs describe the content of the material they covered in the course.

TI course coverage

A TI Ph.D. senior engineer who manages a thermal design group provided our students with typical thermal issues in electronic devices and offered solutions to overcome these issues, Figure 1. This industry partner covered thermal trends in integrated circuit (IC) packages and then discussed heat transfer modes (conduction, convection, and radiation) in packages. He showed that decrease in package size, die size, and system complexity moves system temperature toward hot sides and lower power process shifts system temperature toward cooler temperatures. Next, he discussed equivalent circuits for thermal modeling of packages and system-level thermal analysis. Among the topics he covered were heat sinks, heat pipes, package thermal enhancements, and high-power package design. He then spent a complete 1.5-hour session on modeling aspects of thermal management in electronic packages. He started by discussing component-level modeling like two- and three-dimensional models for heat sink analysis and continued with a discussion of three-dimensional modeling of systems like cell phones. He underlined the importance of cost effectiveness in design.

The TI representative concluded his lecture with the following remarks:

- The next few years promise to be very challenging thermally.
- More systems will be on the edge of performance limits.
- High-speed die usually need cooler junction operating temperatures.
- Pushing electronics into new applications challenges the ability to cool
  – cell phone base stations
  – under hood environments
- A good understanding of how to calculate system performance is required to answer questions on application of ICs on a case-by-casebasis
  – Get out there and learn modeling tools!
- Some system designers will fail in their quest to solve the thermal problem.
- Some component houses won't get the low-power design message in time.
- More elaborate cooling techniques will be put into use.

Figure 1: TI partner lecturing on thermal management in electronic devices.

Marlow Industries, Inc., coverage

In his first 1.5-hour session, the engineer from Marlow Industries went over thermoelectric basics, cooling theory, performance characteristics, example cases, design optimization, typical applications, and power generation of thermoelectric coolers. In the following 1.5 hours, he brought a power supply and many different thermoelectric coolers with different designs and demonstrated the applications of these small but amazing devices. He thoroughly discussed thermoelectric cooler design and selection criteria (Figure 2). He also used these devices to convert room humidity to a thin layer of ice due to thermoelectric cooling that stimulated students' curiosity and enhanced their understanding of heat transfer processes. Figure

2 shows students experiencing heating and cooling processes using a thermocooler device. Toward the end of his discussions, the Marlow engineer alluded to the fact the thermoelectric coolers could be potentially used as a power source.

Figure 2: Marlow Industries engineer demonstrating the application of thermoelectric coolers.

Assessment of teaching style effect on students' learning

Table 1 compares student evaluations for two consecutive semesters (Fall 2005 and Fall 2006) when the course was taught on standard method in Fall 2005 and with industry partnership in the Fall 2006. The questionnaire was designed to assess the two styles of teaching; the data show that students favored the use of an industry partner in teaching such a complex subject in almost all categories of questions asked. As indicated in question 4, the level of student engagement and activity in the course could have been more. The authors' experience is that although students were given the opportunity to be active in the selection of an industry partner, students' response was not overwhelming. It appears that students do not have the required level of maturity to pinpoint a relevant industry, initiate contacts, and facilitate industry engagement. Time management in this style of teaching is extremely crucial. As indicated above, two weeks was spent on covering the two guest lectures. Three mid-semester exams will cover three sessions with 1.5 hours each (equivalent to 1.5 weeks). Losing at least one class period for either spring break or the Thanksgiving holidays will add the number of weeks covered by lecturers and exams to 4 weeks (that is almost one month, or roughly 25% of the total long semester). The remaining 3 months is all left to cover about 12 chapters, which will be a difficult, if not impossible, task. Routine course evaluation of this course indicated that item number 7 in the course objective score last in more than twice. An adjustment was made, and this difficulty was rectified; but time management is, and will be, a crucial factor in success of this style of teaching.

Table 1. Fall 2005/Fall 2006 Heat Transfer Student Survey
Average Response Comparison

[Response Definitions: 1=Not at All. 2=To a Limited Extent. 3=To a Moderate Extent. 4=To a Great Extent. 5=To a Very Great Extent. Numbers in the parentheses represent the standard deviation.]

Question	Fall 2005 N = 11	Fall 2006 N = 9
1. To what extent did you understand heat transfer before the start of this class?	2.27 (1.1)	2.33 (0.50)
2. To what extent do you understand heat transfer after completing this class?	3.91 (1.0)	4.22 (0.67)
3. To what extent did your instructor explain new concepts by making explicit links between what you already know and the new material?	3.91 (0.83)	4.33 (0.50)
4. To what extent were students required to be active participants in the teaching and learning process?	2.91 (1.04)	2.78 (0.67)
5. To what extent did the instructor's teaching methodology increase your understanding of the course content?	3.64 (1.03)	4.33 (1.15)
6. To what extent did classroom activities enhance your understanding and/or skills in the subject area?	3.36 (1.20)	3.67 (0.70)
7. To what extent have the learning experiences in this class increased your interest in the practice of mechanical engineering?	3.36 (1.10)	4.22 (0.97)
8. To what extent do you think the content of course is relevant to emerging technologies?	4.45 (1.25)	4.67 (0.70)
9. To what extent has the content of this course increased your desire to pursue a career in mechanical engineering?	3.73 (0.90)	4.00 (1.32)
10. To what extent did the class examples and projects give you a better appreciation of current technology applications?	3.55 (0.69)	3.89 (1.05)
11. To what extent were homework assignments essential to the learning of the course content?	4.64 (0.50)	3.78 (0.97)
12. To what extent did course exams accurately assess your performance in this course?	3.55 (1.30)	4.11 (1.05)
13. To what extent did course methodology teach you how to apply knowledge and skills in new contexts?	3.36 (1.03)	4.00 (0.70)
14. To what extent did the class textbook contribute to your ability to learn the course content?	4.18 (1.17)	4.00 (0.87)
15. To what extent are you satisfied with the teaching/learning process in this course?	3.64 (1.29)	4.22 (0.83)

Comparison of students' grades

Grades earned by students were compared in Fall 2005 (when the course was taught in the traditional method) and Fall 2006 (when the course was taught with industry partnership style). Results shown in Table 2 indicate that no noticeable differences in students' performance were observed when the course was taught by the two different methods. It is worth noting that available data in both courses was limited to course enrollment. Table 3 lists students' written comments.

Table 2. Grade Comparison for the Two Styles of Teaching Heat Transfer

Semester	A	B	C	D	F
Fall 2005* (without industrial partnership	2 (14.3%)	4 (28.6%)	5 (35.6%)	3 (21.4%)	0
Fall 2006** (with industrial partnership)	2 (18.2%)	5 (45.5%)	1 (9%)	3 (27.2%)	0

Number of students in the course = 9.
**Number of students in the course = 11.

Table 3: Students' Written Responses

What teaching strategies used by the professor helped you to understand and learn the course content?

Practicing some examples on the board, then explaining how they are related to real life situations.

I have had other classes where the teachers only explain what the book already tells us. In this course, the instructor's attention to detail and knowledge of the subject matter made comprehension simple.

Open book tests. Working example problems in class.

I enjoyed listening to what our visitor had to say and fascinated by the technology he showed to us and was interested in learning more.

Working through example problems helped me better understand how to work through the problems on my own.

Relating our textbook examples to everyday applications is a big help for me.

Organization at lectures to include new ideas as well as examples in the same class period. Industry guest speakers help to encourage real world application of studies as well as to introduce a break in lecture. Both of these are very useful to enhance class content.

Need assigned homework; otherwise no real work effort is made.

Working out problems on the board in a great detailed step-by-step procedure, and by explaining the practical uses behind some of the heat transfer equations.

Conclusions

As indicated by students' written comments given in Table 3, students reacted very positively to inviting industrial partners. Their discussions facilitated students' familiarity with practical applications of textbook materials that enhanced students' learning of the heat transfer topic. Authors perceived that students were engaged more in this interactive method of teaching compared to the classical style of lecturing. However, students appreciated worked-out example problems solved in class using traditional method of teaching. Although the existing content of typical heat transfer course is quite extensive, there are many topics of emerging technologies like thermoelectric devices which have not found their way into textbooks. Students will at least need to be made aware of such devices and their applications, especially in an applied program. Time management by the instructor of heat transfer in handling such a course is extremely crucial in the successful inclusion of industrial partnership in the course while maintaining appropriate rigor of the course.

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Appendix A
COURSE OBJECTIVES

On successful completion of this course, the students will

1. Understand thermal processes and the First Law of Thermodynamics (a, b, c, d, f, g, l, m).
2. Introduce conduction heat transfer (a, b, c, d, f, l, m).
3. Know steady-state and transient temperatures in various solid geometries of practical importance (a, b, c, d, f, l, m).
4. Understand mechanisms of importance in convective heat transfer and the meaning of pertinent dimensionless parameters (a, b, c, d, f, l, m).
5. Involve the various correlations for a convective heat transfer process (a, b, c, d, f, l, m).
6. Understand the thermal design of a heat exchanger (c, d, l, m).
7. Know radiation exchange within an enclosure (c, l, m).

STUDENT LEARNING OUTCOMES

a) Calculate heat transfer rate for typical engineering applications (1, 2, 3, 5, 6).
b) Analyze conduction heat transfer mechanism (1, 2, 3).
c) Analyze convection heat transfer mechanism (1, 4, 5).
d) Analyze radiation heat transfer mechanism.
e) Design heat exchangers (1, 6).
f) Formulate solution to transient heat transfer for geometrical solids (4).
g) Evaluate cooling of electronic equipment (6, 7).

Technology Accreditation Commission of the
Accreditation Board for Engineering and Technology
Program Outcomes (Criteria)
Graduates must have

a. an appropriate mastery of the knowledge, techniques, skills, and modern tools of their disciplines.
b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering, and technology.
c. an ability to conduct, analyze, and interpret experiments and apply experimental results to improve processes.
d. an ability to apply creativity in the design of systems, components, or processes appropriate to program objectives.
e. an ability to function effectively on teams.
f. an ability to identify, analyze, and solve technical problems.
g. an ability to communicate effectively.
h. a recognition of the need for, and an ability to, engage in lifelong learning.
i. an ability to understand professional, ethical, and social responsibilities.

j. a respect for diversity and a knowledge of contemporary professional, societal, and global issues.
k. a commitment to quality, timeliness, and continuous improvement.

American Society for Mechanical Engineers Outcomes Criteria
(for Mechanical Engineering Technology programs)

Graduates must apply the following concepts to the analysis, development, implementation, or oversight of mechanical systems and processes:

l. technical expertise in
   - engineering materials,
   - statics,
   - dynamics,
   - strength of materials,
   - fluid power or fluid mechanics,
   - thermodynamics, and
   - either electrical power or electronics.
m. technical expertise having added technical depth in a minimum of three subject areas chosen from:
   - manufacturing processes,
   - mechanical design,
   - computer-aided engineering graphics,
   - engineering materials,
   - solid mechanics,
   - fluids,
   - thermal sciences,
   - electro-mechanical devices and controls, and
   - industrial operations.
n. expertise in applied physics having an emphasis in applied mechanics, plus added technical topics in physics and inorganic chemistry principles appropriate to the program objectives.