AC 2009-874: CONNECTING LAB EXPERIMENTS TO A DESIGN PROJECT

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Introduction

A senior level heat transfer laboratory course incorporates a major design and build project competition which accounts for about 1/3 of the course. This project addresses the ABET Mechanical Engineering Program Criteria that requires graduates to possess the ability to design in the thermal engineering area. The remaining 2/3 of the laboratory course consists of standard thermal engineering experiments on such topics as thermocouples, convection, and power plants. A unique feature of these standard experiments is the way in which they support the design project. With the variety of experiments available, the students run demonstration experiments that emphasize certain key features of the design project, such as geometry and heat transfer relations. This approach provides the students with a sense of continuity in the course and an understanding of problem solving in the experimental realm. This connectivity is further enhanced through the incorporation of a team building experiment that is a mini-version of the design project, which is conducted during one of the 2-hour lab periods early in the course.

This paper presents the several different design projects that are used in the course and the supporting standard experiments for each of the projects. Resource implications for teaching a lab course in such a fashion are discussed. Finally, student feedback to this approach is analyzed.

Background

The senior level heat transfer course consists of nine demonstration experiments. These are traditional hands-on experiments for the students which include data processing, technical writing, and presentation of the data. Of these demonstration experiments, two are tours of campus facilities, one involves the fabrication and calibration of thermocouples, one focuses on the determination and analysis of errors in experimentation, and one is a design of experiment. The remaining four experiments are changed semester to semester in support of the design and build project. These four experiments focus on basic principles of heat transfer, modeling techniques, and team building. As a whole these demonstration experiments cover the first nine weeks of the semester. The remaining weeks concentrate on the design project.

The design project changes from semester to semester, is open-ended and incorporates many aspects of heat transfer. The various projects run the gambit of radiation, phase change, convection and conduction as the major modes of heat transfer. The design challenge incorporates a major design experience in the thermal sciences in accordance with ABET criteria to design, build, and test in thermal/fluids area. The metric goal for this program outcome is that ninety-five percent of the students shall exceed the minimum competency level on their ME 412 design project. For the fall semester 2008, 93% met the metric goal. For completeness sake, the course learning objectives are included.

Literature Review

It is not uncommon to include a design project in a thermal fluids laboratory experience for Mechanical Engineering undergraduate students. Choate and Schmaltz[1] discussed a design and build senior capstone experience in the thermal fluid sciences emphasizing professional ethics and communication as well as the use of open ended design problems in undergraduate education. Kim[2] explored the use of innovative design projects in a thermal fluids laboratory course to improve the undergraduates understanding of experimental data and design of experiments. Knight and McDonald[3] looked at balancing the laboratory experience and design projects in the distinct stems of Mechanical Engineering. Hoke and Somerton[4] explored student evaluation of the design experience in a senior level heat transfer laboratory course.

Course Learning Objectives

1. Heat Transfer Measurements and Apparatus
    a. Students fabricate thermocouples
    b. Students demonstrate an understanding about the calibration of thermocouples
    c. Students demonstrate an understanding about the use of thermocouples
    d. Students participate in computer data acquisition
    e. Students calculate uncertainty error
    f. Students identify systematic errors
2. Demonstrating Basic Heat Transfer Principles
    a. Students experience the basic principles of conduction
    b. Students experience the basic principles of convection
    c. Students experience the basic principles of radiation
    d. Students experience the basic principles of heat exchangers
    e. Students experience the basic principles of power plants
    f. Students experience the basic principles of refrigeration systems
    g. Students process experimental data to provide meaningful results
3. Employing Experiments in Problem Solving
    a. Students design an experiment to be used in solving a problem
    b. Students participate in a design, build, and test project
4. Communication and Teaming
    a. Students communicate experimental results with a technical memo
    b. Students communicate project results with a technical report
    c. Students are provided with team building experiences

Design Projects

The heat transfer laboratory course has incorporated a project of one manner or another since the courses inception some 25 years ago. The project evolved into a more open ended design and build project approximately 15 years ago. In general, the project is presented as a heat transfer design proposal to solve some problem. For instance, the desire to heat water with only the hot air exhaust from a car, the ability to thaw food without the aid of a microwave oven or other powered device, or the ability to cook a hot dog with only a solar energy input. These design concepts are then mapped to the equipment available in the laboratory. The exhaust from the car is replaced with a 20 amp hot air gun that the students are provided along with a 400 mL beaker with 100 mL of water. Their charge is to heat the water as quickly as possible in 8 minutes. The second example was inspired by the As Seen on TV miracle thaw which utilizes the heat capacity of a tray to accelerate the thawing of food. In operation, the students design challenge is to passively melt 200 mL of frozen water in a 2 minute time frame. Passive in this case refers to no energy input. In the last example the students are provide two infrared heat lamps that produce approximately 500 W to increase the center temperature of a hot dog in 5 minutes.

Team building

Several years ago, the instructional staff opted to add in a team building experience early in the semester to focus on merging individual strengths and minimizing individual weaknesses of students working in teams, build community in the laboratory experience, and emphasize the cooperative aspects of engineering design. Initially this was accomplished with some basic team building design efforts such as toothpick tables or straw bridges. In more recent years, the instructional staff migrated to a team building experience that emulated the final design project. There are several reasons for this:

1. Returns focus to heat transfer as primary design aspect
2. Exposes students to the design project earlier in the semester
3. Allows the students some initial trail and error solutions to the design project

In the laboratory, the students are given the team building exercise and have 30 minutes to design a solution with a limited amount of simple materials and then to build. After this time period each team's design is tested. Specific team building exercises will be discussed in the following section.

Demonstration Experiments

The demonstration experiments are rotated to support the design project so as to enhance the overall learning experience for the students. For instance, when the passive ice melter design project is assigned the team building experience is the melting of a simple ice cube in a 2 minute timeframe, the convection experiment analyzes natural convection from a heated flat plate, the conduction experiment emphasizes a finite difference approach to transient heat conduction, and the heat exchanger experiment is a tube bank. The inspiration for the design project is a flat device and therefore it would seem prudent to emphasize natural convection from a flat surface in support of the design project. The students are required to approach the design challenge without any power input; therefore, natural convection analysis is emphasized. As part of the project analysis, a numerical model is built and the students are therefore exposed to numerical methods in experimentation via the conduction experiment. In this design project example, the heat exchanger choice is not of great impact. The solar hot dog cooker emphasizes radiation as well as natural convection. The team building exercise utilizes one of the infrared lamps to heat 50 mL of water. In support of the natural convection aspect, the demonstration experiment is natural convection from a cylinder. The heat exchanger is a double pipe heat exchanger emphasizing the cylindrical nature of the hot dog and heat transfer analysis in a cylindrical geometry. In the hot air gun boiler project, the main convection is obviously forced and therefore this is the emphasis in the demonstration experiment. The flat surface is chosen in anticipation that the students are initially focused on just pointing the hot air gun at the bottom of the beaker. The tube bank heat exchanger is selected in this application to encourage students to look at designing a gas-liquid heat exchanger for their design solution. The team building is a mini boiler where the students need to raise the temperature of 50 mL of water in 4 minutes. A complete of list of design projects and the mapping to the demonstration experiments is provided in Table 1. It should be noted that the current heat transfer laboratory has the ability to vary the conduction experiment; however, the relevancy of the numerical methods that are introduced in the conduction experiment can not be overlooked in their application to the design projects.

Table 1
Mapping of Project to Demonstration Experiment

Design Project	Conduction	Convection	Heat Exchanger	Team Building
Passive Ice melter	Fourier's law and numerical analysis of transient heat conduction	Flat Plate Natural	Tube bank	Mini ice melter
Electronic Cooling	Fin heat conduction	Flat Plate Forced Average	Double pipe	Cooling cup
Solar powered Hot dog cooker	Transient conduction with different shapes	Cylinder Natural average	Double pipe	Solar Water Heater
Hot Air Gun Boiler	Fourier's law and numerical analysis of transient heat conduction	Flat Plate Forced Average	Tube bank	Mini Hot air gun boiler
Solar Powered Hot air Balloon	Fourier's law and numerical analysis of transient heat conduction	Flat Plate Forced Average	Tube bank	Mini Hot Air Balloon
Candle Desalinator	Fin heat conduction	Forced Convection local heat transfer about a cylinder	Tube bank	Candle Boiler

Student Feedback

In the fall of 2008 the students were surveyed as to how well connected the demonstration experiments were to the overall design project. In that semester there were 45 students enrolled in the course, and 23 respondents. The feedback survey is presented in the appendix. The summary table is below.

Table 2
Summary of Student Survey

Survey Question	Average Response (4 strongly agree, 3 agree, 2 neutral, 1 disagree, 0 strongly disagree)
The team building experience linked well with the final design project	3.1
The team building experience helped in formulating ideas/designs for the final project	2.9
The team building experience set the framework for the final design project	3.1
Analyzing the various modes of heat transfer in the demonstration experiments helped in completing the analysis for the design project	3.0

The numerical responses imply that the students in general agree that there was a connection between the 2 parts of the course and that the basics introduced in the first nine weeks supported the design project and the team building experience set the stage for the project. The students had few written comments. None of which focused on the manner in which the project connected to the other aspects of the course.

Conclusions and Recommendations

From the instructional staff perspective, selecting the course experiments to support the design project invigorates the course and gives an overall global enhancement to the heat transfer laboratory experience for the students. The student feedback is generally supportive of the concept that there is a relationship between the two and they do agree that the team the building exercise lays the groundwork for the project. The subtleties of matching geometries may not come across to the students as well the instructional staff would hope. In the future, the staff would like to expand the projects and add in another experiment that focuses on numerical modeling building to allow for some variance in the conduction experiment.

Citations

1. Choate, Robert and Schmaltz, Kevin, “Design, build and test in a thermal fluids laboratory course” 2005 ASEE Annual Conference and Exposition Conference Proceedings, 2005, p 2975-2986

2. Kim, H.W. Shawn “Improvement of an undergraduate thermal fluid laboratory through innovative laboratory design projects”, 2004 ASEE Annual Conference and Exposition Conference Proceedings, 2004, p 6939-6952

3. Knight, Charles V and McDonald, Gary H. “Attributes of a modern mechanical engineering laboratory”, 2005 ASEE Annual Conference and Exposition Conference Proceedings, 2005, p 933-941

Hoke, Paul B. and Somerton, Craig W. Source: “Student evaluation of the thermal/fluids design experience”, 2001 ASEE Annual Conference and Exposition Conference Proceedings, 2001, p 9067-9076

Appendix A

Survey on Heat Transfer Laboratory Design Project

Please help us in determining how effective the activities in Heat Transfer laboratory impacted your learning

1. The team building experience linked well with the final design project.

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
4	3	2	1	0

2. The team building experience helped in formulating ideas/designs for the final project.

Strongly Agree Agree Neutral Disagree Strongly Disagree

3. The team building experience set the framework for the final design project.

Strongly Agree Agree Neutral Disagree Strongly Disagree

4. Analyzing the various modes of heat transfer in the demonstration experiments helped in completing the analysis for the design project.

Strongly Agree Agree Neutral Disagree Strongly Disagree

Written comments