Incorporating the Design of Experiments into a Heat Transfer Laboratory Course

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I. Introduction

One of the recent trends in mechanical engineering curriculum is the move away from an instrumentation laboratory course towards a just-in-time delivery of instrumentation topics in the specific technical laboratory courses, such as fluid mechanics lab, vibrations lab, or heat transfer lab. This is indeed the case in the Department of Mechanical Engineering at Michigan State University where during our transition from a quarter program to a semester program the instrumentation course was eliminated with the understanding that instrumentation associated with a technical area, for example thermocouples with heat transfer and pressure transducers with fluid mechanics, would be integrated into appropriate technical laboratory course. A downside to this approach is that several of the standard topics covered in an instrumentation course could be left out in the cold. In particular, the teaching of the experiment design is a prime candidate for this type of neglect. With the coming of Engineering Criteria 2000 and its specification in Criterion 3 that "engineering programs must demonstrate that their graduates have ... an ability to design and conduct experiments, as well as to analyze and interpret data" [1] programs that have abandoned the instrumentation lab model must assure that the design of experiments is integrated into the technical laboratory courses.

This issue has been addressed in the Department of Mechanical Engineering at Michigan State University by transforming a standard radiation heat transfer laboratory experiment (either one dealing with the measurement of emissivity or the measurement of transmissivity) in the heat transfer laboratory course into a design of experiment laboratory exercise. This exercise is shared in this paper starting with a description of the exercise, followed by some principles emphasized in lecture and some selected measures of the student's success in achieving the learning objectives. Finally, a number of lessons learned in this endeavor are provided.

II. Description of Experiment Design Unit

The objectives of this experiment are provided to the students in the lab manual as follows:

1. To review the basic principles of radiation heat transfer.
2. To reexamine the basic tenets of the Scientific Method as related to research design.
3. To design an experiment and develop an experimental procedure.

To achieve these objectives the student team is to design an experiment that will permit the determination of transmissivity of several non-opaque materials. To provide additional motivation for the students the problem statement is actually posed in a more realistic setting.

> The Rhino Consulting Corporation has been hired by the Jupiter automobile company to do thermal system modeling for a climate control system. In thermal environmental engineering for automobiles it is found that the largest factor in the heating and cooling loads is the solar radiation coming into the passenger compartment. Thus knowledge of the transmissivity of the windows is of critical importance for the thermal design. As an engineer for the Rhino Consulting Corporation it is your job to design an experiment to measure the transmissivity of various materials. [2]

The laboratory course has both a lecture component (1 hour per week) and a laboratory component (2 hours per week). The lecture component is normally used to review the technical material for the experiment (the students will have previously taken a standard heat transfer course) and introduce the students to the experiment. For this experiment the lecture focuses on the scientific method, the concept of designing an experiment, and the array of experimental equipment available in the laboratory. This leaves little time for a review of the principles of radiation heat transfer. Through their experience the authors have recognized that the student's background in radiation heat transfer is quite weak, but rather than spending lecture time attempting to fill in this background, an approach has been used to put the burden of review on the students (much as it would be if they were practicing engineers and came up against a problem where their technical background was limited). This approach requires students to complete a worksheet on radiation heat transfer prior to the lecture period. The worksheet elicits sufficient detail about general radiation concepts to adequately prepare the student for the task of designing a simple radiation experiment. It is administered as a pre-lab exercise. This worksheet is shown in Figure 1.

As noted above the lecture component has three parts. First students are re-introduced to the Scientific Method [3]. Five main concepts are covered

empirical verification
operational definitions
controlled observations
statistical generalization
empirical confirmation

Simply, the students are told that to design an experiment they must understand the problem, understand the subject matter, review the literature, develop operational definitions, test the validity of their approach, and analyze the effectiveness of the experimental design. Then the

Figure 1. Radiation Worksheet

Radiation Worksheet

To Be Completed and Turned In at the Beginning of Lab Lecture
(will count for maximum of ten points on the technical memo)

Student Name: ___________________________________

1. What is a photon? (1 pt)

2. Under what conditions is radiation heat transfer important? (1 pt)

3. Write an equation that represents the Stefan-Boltzman law. (1 pt)

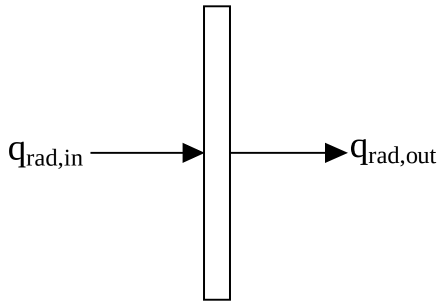
4. What is transmissivity? (1 pt)

5. A radiant heater may be considered a gray surface and the room it is occupying may be considered black surrounds. If the heater is at 200°C with emissivity 0.85 and the room walls are at 22°C, determine the radiative heat flux away from the heater. (2 pts)

6. Solar radiation of 300 $W/m^2 \cdot K$ is incident the outside surface of a window with solar transmissivity of 0.78. What is the value of the radiation heat flux the leaves the inside surface of the window? (2 pts)

7. What types of measurements will need to be made to determine the transmissivity of a non-opaque material? (2 pts)

students are given some direction as to the measurement of transmissivity. Basically, they are told to consider the physical situation shown below



where the transmissivity is defined as

$$\tau = \frac{q_{rad,out}}{q_{rad,in}}$$

Then to measure the transmissivity the students must consider the following:

1. A way to produce a radiation heat flux

2. A way to measure the radiation heat flux

3. A way to separately determine $q_{rad,in}$ and $q_{rad,out}$

The lecture concludes by demonstrating the equipment that is available in the lab to make radiation measurements. The lab has a variety of radiation sources the students can use. The lab also has two ways of measuring a radiation heat flux: a thermopile (part of the Technovate radiation experiment [4]) and an infrared thermometer (Omega model OS920C). A number of temperature measurement devices are also available. The operation of the equipment is discussed and demonstrated. Materials with known values of emissivity or transmissivity are provided to guide the students in their design. At this point the students are expected to be able to develop an operational definition for transmissivity on which their experiment will be based.

Students are organized into teams of two or three, which is consistent with the teaming approach used in the course. Prior to the students designing the experiment they are instructed to go to the library, identify an American Society for Testing and Materials (ASTM) standard on the measurement of transmissivity, and write a brief summary of the standard identifying the operational definition. The engineering librarian at MSU has developed a guide to using ASTM standards that is shown in Fig. 2. Students are also to identify three technical papers that are relevant. This gives them an opportunity to use some of the computer-based literature searches that are available. Working with their lab instructors, they design a procedure and implement it in the laboratory facility. As part of this development the students must determine the variables that

Figure 2. Guide to Using ASTM Standards

Finding ASTM Standards

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The American Society for Testing and Material(ASTM) publishes an annual book of standards which the Engineering Library purchases each year. The most recent addition of the Annual Book of ASTM Standards is kept in the Reference area of the Library and the older years are kept in the regular book stacks. The call number for the Annual Book of ASTM Standards is TA 401.A653.

ASTM documents published as part of the Annual Book include classifications of materials and products, practices, product and materials specifications, test methods, and number of other types of documents. About 30% of the ASTM documents in the volumes are new or revised each year. The first volume, v. 00.01, is the index for the entire set. It includes a subject index and alphanumeric list of the ASTM standards. Below is a sample entry from the subject index.

<u>Transmissivity and reflectivity</u>

transmissivity of transparent part[1], test, F1316[2] (15.03)[3]

Notes

1. This is the title of the ASTM Standard.

2. This is the ASTM standard number.

3.This is the volume number where the ASTM standard will be found. Within the volume standards are arranged in numerical order. This example standard, F1316, would be found in volume 15.03. beginning on page 851.

are critical to hold constant to ensure a valid experiment. To validate their experiment design the students will test materials of known properties. Though the students normally have a scheduled two hour lab period, while they are working on this experiment an open lab process is implemented in which they have access to the lab Monday through Friday from 8:00 am to 5:00 pm. This gives the students an opportunity to be creative in their experimental design without the pressure of time. A technical memorandum is submitted by the student team documenting their experience. This should include their summary of the ASTM standard, citations of the three relevant papers, a step by step procedure for running their experiment and experimental verification of their procedure. Grading is done by the laboratory instructors using the form shown in Fig. 3. This form is also provided to the students so that expectations are clear. Grading emphasis is placed on their experiment design not on the results of their tests.

III. Results

Reviewing the student work associated with this showed an exaggerated distribution of excellent student work to weak student work. It would appear that those student teams that did badly on this experiment performed worse than they had done on the standard heat transfer experiments in the course. For example the median score for this experiment was 80, the average median score for the standard heat transfer experiments was 90. This is most probably due to the more challenging nature of this experiment versus the standard experiments, as well as the students inexperience with the design of experiments. However, the better reports are truly outstanding and demonstrate a great deal of thoughtfulness in designing the experiment. This might suggest that the basic skills associated with this unit are coming from extracurricular activities rather than curricular activities.

When this course was taught in the spring semester of 1998 a course survey was administered that asked the students to evaluate their level of confidence with the course learning objective topics. A 5-1 scale was used with 5 indicating complete confidence and 1 indicating no confidence. A summary of the results of this course surveys is Table 1. It is seen that the ability to design an experiment to be used in solving a problem received a score of 3.86, which seems to be acceptable, but certainly not among the higher scores on the table. It is interesting to note that the student's understanding the physical aspects of heat radiation received a score of 3.75, one of the lowest rated objectives.

IV. Lessons Learned

The addition of a learning experience on the design of experiments to the Heat Transfer Laboratory course has been an ongoing development for approximately two years. During this time there has been a concerted effort to continually improve the experience. Some of the lessons learned during this development includes:

- Teaching assistants assigned to the lab must have excellent teaching abilities for this endeavor to be successful.

- An open, unsupervised lab access has worked very well with little or no abuses.

Figure 3. Grading Sheet

ME 412
Heat Transfer Laboratory
Radiation Transmissivity Experiment
Grading Sheet

Names: ____

Worksheet	/10
Discussion of basic theory Definition of radiative heat transfer, transmissivity. Clear statement of the problem	/10
Procedure Clearly written procedure for conducting the experiment	/20
Analytical/Experimental Results for test run Reproducibility Error analysis Control observations Justification of experimental method chosen	/30
Library Search Summary of ASTM Standard Mini literature review (3 citations)	/20
Overall Quality	/10
Total	/100

Comments:

Table 1. Student Evaluation of Course Learning Objectives for ME 412

Course Learning Objective	**Mean**
A. Ability to fabricate, calibrate , and use thermocouples	4.46
B. Ability to participate in computer data acquisition	4.43
C. Ability to calculate uncertainty error	3.78
D. Ability to identify systematic errors	4.21
E. Understanding the physical aspects of heat conduction	4.21
F. Understanding the physical aspects of heat convection	4.26
G. Understanding the physical aspects of heat radiation	3.75
H. Understanding the physical aspects of heat exchangers	4.04
I. Understanding the physical aspects of power plants	3.89
J. Understanding the physical aspects of refrigeration systems	3.43
K. Ability to process experimental data to provide meaningful results	4.21
L. Ability to design an experiment to be used in solving a problem	3.86
M. Ability to participate in a design, build, and test project	4.36
N. Ability to communicate experimental results with a technical memo	4.25
O. Ability to communicate project results with a technical report	4.21
P. Ability to participate in with team building experiences	4.46

- Key to the success in the experiment is requiring review of the experimental procedure with the instructional staff prior to running the experiment.

- The students are very uncomfortable with this experiment because of its novelty, hence additional opportunities for student - instructor interactions must be provided

- The heat transfer knowledge the students bring into the course is at a comparable level. However, there is a wide range of abilities in terms of developing an experiment, which may be due to different experiences gained outside the curriculum.

- Radiation may not be a good choice as the technical focus of such an experiment. It may be better to use convection or conduction.

Bibliography

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