2006-978: THE USE OF STUDENT-GENERATED LAB PLANS IN THE THERMAL SCIENCES

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The Use of Student-Generated Lab Plans in the Thermal Sciences

Abstract

Practicing engineers are often required to design experiments that will be carried out by others (who may or may not have engineering degrees). Engineers must be able to clearly define the purpose of an experiment and specify the equipment and procedures needed for successful completion. As a means of developing this ability, mechanical engineering students at Ohio Northern University (ONU) are required to generate their own procedures for experiments in the thermal sciences. Rather than follow a set of pre-determined steps, students must consider how to use the available equipment to meet the specified objective. Students generate their own lab plans, review plans developed by their peers, and ultimately develop experiments that are conducted by other students in the class.

This paper discusses the thermal sciences course sequence, describes the experiments that are performed, and explains how these experiments are implemented in order to achieve the objective described above. The effectiveness of this implementation is evaluated in two ways. First, the two instructors involved evaluate the quality of student-generated lab plans, and identify areas where progress does (and does not) occur as the sequence progresses. Second, a series of self-assessment surveys are given to the students several times during the three-quarter sequence.

Introduction

The Mechanical Engineering Department at Ohio Northern University currently requires students to take a sequence of five quarter-long courses in the thermal sciences. Three of these courses include laboratory components. These laboratories are designed to:

1. Reinforce and apply theoretical concepts developed in lecture
2. Introduce equipment, instrumentation, and techniques related to thermal and flow measurement
3. Apply knowledge of data acquisition systems, including LabVIEW
4. Develop interpersonal and written communication skills
5. Teach students to design their own experiments using available equipment to achieve a specified objective.

The first four goals can be accomplished with traditional experiments\(^1\), in which students follow a specified procedure to generate a clearly-defined set of data. During the first two years of their college careers, students encounter this approach numerous times. The fifth objective, while often an essential skill in professional practice, is seldom considered in introductory labs. This paper discusses efforts by the Mechanical Engineering faculty at ONU to provide a laboratory experience which satisfies all five of these goals by integrating student-generated experimental procedures into the thermal sciences labs.
Course Sequence

During their first two years at ONU, Mechanical Engineering students take several laboratory courses in the physical sciences and general engineering. The experiments are designed to reinforce what is learned in the corresponding lecture and usually apply a traditional approach, with students following a clearly defined set of steps to reproduce a predictable outcome. Students also learn the basic concepts of instrumentation and develop a familiarity with “hands-on” activities. During the third and fourth years, several Mechanical Engineering courses also include laboratory components. These serve a much broader set of purposes, from introducing specific methods and procedures (e.g. tensile testing) to providing familiarity with specialized equipment (rapid prototyping, wind tunnel, programmable logic controllers, etc.).

Table 1: Laboratory courses or courses with an experimental component. Thermal science courses are shown in *italics*.

<table>
<thead>
<tr>
<th>Year</th>
<th>FALL</th>
<th>WINTER</th>
<th>SPRING</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Physics: Mechanics</td>
<td>Physics: Heat, Sound &amp; Light</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Physics: Elec. &amp; Magnet. Circuits 1</td>
<td>Circuits 2</td>
<td>Material Science Chemistry 2 Computer Apps (incl. LabVIEW)</td>
</tr>
<tr>
<td>3</td>
<td>Manuf. Processes</td>
<td>Mechanisms</td>
<td><em>Thermodynamics of Fluids</em> Finite Element Analysis</td>
</tr>
<tr>
<td>4</td>
<td><em>Fluid Mechanics</em></td>
<td><em>Heat Transfer 2</em> Control Systems</td>
<td>Technical Electives</td>
</tr>
</tbody>
</table>

Beginning in the Spring Quarter of the Junior Year, students take a sequence of three courses in the thermal sciences which include a laboratory component: ME 363 Thermodynamics of Fluids, ME 464 Fluid Mechanics, and ME 468 Heat Transfer 2. Students entering this sequence have already taken a first course in Thermodynamics, which introduces the basic concepts of thermophysical properties and property relations; heat, work and conservation of energy; and non-reacting mixtures. Table 1 illustrates the locations of these courses in the current Mechanical Engineering curriculum.

Laboratory Format

For many experiments performed in the thermal sciences, only one set of equipment is available due to cost, size, or other limitations. Because of this, it is impractical to have all of the students in a section performing experiments at once. To overcome this limitation, thermal sciences labs are conducted as “open labs”. The class meets once each week to receive information from the instructor and to exchange information with other students, but the experimentation is conducted by each group independently at a time of their choosing.

Approximately five experiments are conducted during each ten week laboratory course. A list of typical experiments for each of the three thermal science courses is shown in Table 2.
Table 2: A sample itinerary of experiments in the thermal sciences.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Experiments</th>
</tr>
</thead>
</table>
| ME 363      | Thermo of Fluids     | 1. Determination of Thermocouple Time Constants  
2. Thermal Conductivity  
3. Boiling and Nucleation  
4. Gas Turbine Engine  
5. Hydrostatic Forces |
| ME 464      | Fluid Mechanics      | 1. Measurement of the Drag on an F-16 Model  
2. Calculation of Drag Using the Momentum Deficit Method  
3. Design of a Supersonic Converging/Diverging Nozzle  
4. Design of a Residential Piping System  
5. Analysis of a Centrifugal Pump |
| ME 468      | Heat Transfer 2      | 1. Flat Plate Heat Transfer and Reynolds Analogy  
2. Heat Transfer on a Cylinder in Cross-Flow  
3. Design of an Energy Efficient Window System  
4. Analysis of a Double-Pipe Heat Exchanger  
5. Design of a Point-of-Use Hot Water Heater |

Detailed instructions are available for the first experiment, providing students with a template for developing their own lab plans in future experiments. Students have one week to complete the experiment and submit a formal report. Each subsequent experiment is conducted over the course of a two week period. At the beginning of the first week, the topic and objectives of the experiment are introduced, and any required theory or background information is provided. Students then have one week to develop their own lab plan. Each team of two students is required to submit a lab plan which adequately covers the following topics:

- Objective
- Data to be collected
- Equipment
- Procedure
- Equations required for data reduction
- How data is to be presented
- References

At the end of the first week students exchange lab plans, which are evaluated by their peers and returned with suggestions for improvement. Corrections and suggestions do not affect the grade of the authors; however, if a group evaluates a lab plan which subsequently turns out to be incomplete or incorrect, the evaluating group is penalized. While this penalty is rarely invoked, it does provide motivation for students to perform a thorough review.

Once a lab plan has been completed, reviewed by peers, and approved by the instructor, students have one week to perform the experiment and write a final report. At the end of the second week, these reports are collected and a new experiment is introduced.
A sample lab plan can be found in the Appendix. This lab plan was submitted in ME-468 Heat Transfer 2 during the Winter Quarter of the 2005-2006 academic year, by students who had nearly completed the thermal sciences sequence.

**Assessment**

A multi-year assessment process has begun, which will evaluate each of the five goals listed in the introduction of this paper. Student surveys are conducted at several intervals during the three-quarter sequence:

Survey A: Before the thermal sciences laboratory sequence begins, students are given a survey to assess their experimental background, attitudes and confidence levels. This assessment serves as both an evaluation of past experience and a basis for comparison with later results.

Survey B: At the end of each of the first two laboratory courses, students are asked to evaluate how well the objectives were accomplished during that quarter.

Survey C: At the end of the third laboratory course, the initial survey is repeated in order to evaluate how student perceptions have changed.

This assessment is still underway; however some preliminary results regarding the development of lab plans will be considered for Survey A and Survey C.

One of the questions asked of students prior to (Survey A) and on completion of (Survey C) the laboratory sequence is:

"Please list the essential components of a Lab Plan. (What information is required to adequately perform a pre-defined experiment?)"

No prompts or list of potential answers was provided. There were 23 respondents to Survey A, which was given to Juniors who had not yet begun the thermal sciences laboratory sequence. There were 27 respondents to Survey C, which was given the following year to Seniors who had just completed the sequence (most of these students had also participated in survey A). Table 3 shows the percent of respondents who included each topic in their list. For example, 10 of the 23 respondents (43%) of Survey A included words related to “objective” or “goal” in their responses.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Survey A Prior to laboratory sequence</th>
<th>Survey C Upon completion of laboratory sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equations/Theory</td>
<td>61% (2)</td>
<td>96% (1)</td>
</tr>
<tr>
<td>Procedure</td>
<td>74% (1)</td>
<td>93% (2)</td>
</tr>
<tr>
<td>Objective</td>
<td>43% (4)</td>
<td>74% (3)</td>
</tr>
<tr>
<td>Equipment List</td>
<td>57% (3)</td>
<td>74% (3)</td>
</tr>
<tr>
<td>Data/Presentation of Results</td>
<td>30% (5)</td>
<td>41% (4)</td>
</tr>
<tr>
<td>Nomenclature</td>
<td>0% (6)</td>
<td>30% (5)</td>
</tr>
<tr>
<td>References</td>
<td>0% (6)</td>
<td>19% (6)</td>
</tr>
</tbody>
</table>
Not surprisingly, students who had completed the thermal sciences laboratory sequence were consistently more likely to list each of the expected topics than were students who had not begun the sequence. Perhaps more significant is the fact that the inclusion of an objective is much more important to those students who have completed the sequence. The authors are very pleased with this result, since it suggests that the students are learning to think of experiments as a means of acquiring knowledge, rather than simply a collection of equipment and procedures.

Other questions included in Surveys A and C were intended to assess the attitudes of students towards various aspects of the laboratory courses. These questions and the average responses are shown in Table 4.

Table 4: Responses to questions assessing student attitudes toward experiments.

<table>
<thead>
<tr>
<th>Question</th>
<th>Scale</th>
<th>Survey A</th>
<th>Survey C</th>
</tr>
</thead>
<tbody>
<tr>
<td>How important do you think the ability to perform experiments is to a practicing engineer?</td>
<td>1 Not Important 5 Very Important</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>How important do you think the ability to design experiments is to a practicing engineer?</td>
<td>1 Not Important 5 Very Important</td>
<td>4.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Rate your ability to perform experiments given a detailed equipment list and set of instructions</td>
<td>1 Minimal 5 Exceptional</td>
<td>3.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Rate your ability to develop and perform your own experiments to measure specified system properties, given a detailed equipment list</td>
<td>1 Minimal 5 Exceptional</td>
<td>2.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Given a general objective, theoretical background, and list of available equipment, please rate your ability to develop a detailed lab plan which could be used by one of your peers.</td>
<td>1 Minimal 5 Exceptional</td>
<td>3.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Rate your ability to perform an experiment designed by one of your peers in this class.</td>
<td>1 Minimal 5 Exceptional</td>
<td>3.1</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Comparing the results of Survey A and Survey C, a few tentative conclusions can be made. First, note that students at both levels seem to understand the importance of design of experiments to the practicing engineer. Also, students who have completed the sequence seem to have greater confidence in their ability to develop experiments. Even more telling, students who have completed the sequence seem to have confidence in the ability of their peers as well.

Another assessment tool is, of course, the quality of work submitted by the students. A representative student lab plan is provided in the Appendix. (This lab plan was submitted in the ME468 Heat Transfer 2, the final course of the thermal sciences sequence, during the Winter quarter of the 2005/2006 Academic year.) Some consistent trends noted by the authors include:

- Overall quality of student-generated lab plans improves significantly during the three quarters in which they are required.
• Students are invariably uncomfortable with the ambiguous nature of the experiments at first, but often express a desire for even more freedom in developing experiments by the time the Thermal Sciences sequence is complete.
• The ability of students to develop clear, complete experimental procedures shows a marked improvement.
• Students struggle with interpretation of experimental results, even after completing the laboratory sequence. This is an area in which increased emphasis needs to be placed.

Conclusions

The ability to design experiments is an essential skill for many practicing engineers. The Thermal Sciences laboratory sequence at Ohio Northern University is used as a mechanism for helping students develop this ability. Students are provided with an overall objective, theoretical background, and the necessary equipment. Before conducting an experiment to accomplish the stated objective, students are required to determine what data needs to be collected, what steps must be taken to collect it, and how the data should be presented.

While assessment of this approach to laboratory instruction is just beginning, student surveys indicate an increased understanding of the importance of the experimental objective and an increase in the students’ (perceived) ability to develop experiments. These survey results generally agree with the actual work submitted, which shows a marked improvement in the ability of students to identify necessary data and develop experimental procedures which accomplish the stated objective. The ability to interpret experimental results is a continuing weakness, even after completion of the laboratory sequence.

Bibliography

Appendix: A typical student-generated lab plan

Lab Plan: Experiment #4
Analysis of a Heat Exchanger
Heat Transfer 2 (ME-468)

Scott Dusenbury
Michael Hylton
January 31, 2006

Objective
The objective of this lab is to examine the characteristics of a double pipe heat exchanger. The overall heat transfer coefficient of this heat exchanger will then be determined using two different methods.

Methodology
To perform this experiment, a laboratory heat exchanger will be configured for both parallel and counter flow. Once the valves are set and the system has stabilized, the inlet and outlet temperatures for both the hot and cold water will be recorded, along with their corresponding mass flow rate. Using the recorded data, the Logarithmic Mean Temperature Difference and the Effectiveness-NTU methods will be used to determine the overall heat transfer coefficients for the heat exchanger. These results will then be compared against each other.

Equipment
1. Hampden laboratory heat exchanger
2. Water heater
3. Water pump

Procedure
1. Turn on water heater and pump
2. Adjust valves to obtain a parallel flow according to the schematic
3. Record all inlet and outlet temperatures and mass flow rates
4. Adjust valves to obtain a counter flow according to the schematic
5. Record all inlet and outlet temperatures and mass flow rates
6. Turn off water heater and pump

Equations
To determine the overall heat transfer coefficient using the LMTD Method, a series of two equations must be used. First, the log mean temperature difference must be found using the equation below:

\[
\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} \quad (1)
\]

where \( \Delta T_1 \) is the temperature difference at the hot fluid inlet, and \( \Delta T_2 \) is the temperature difference at the hot fluid exit.

Once this is found, the overall heat transfer coefficient, \( U \), is found using the equation:

\[
\dot{Q} = U A_s \Delta T_{lm} \quad (2)
\]

where \( \dot{Q} \) is the heat transfer rate and \( A_s \) is the surface area.

For the Effectiveness-NTU Method, the first step is to calculate \( Q_{\text{max}} \). This is done with the equation below:

\[
Q_{\text{max}} = C_{\text{min}} (T_{h,in} - T_{c,in}) \quad (3)
\]

where \( C_{\text{min}} \) is the minimum heat capacity between both fluids. The actual heat transfer rate is found next with the equation below:

\[
\dot{Q} = C(T_{out} - T_{in}) \quad (4)
\]
Appendix (continued): A typical student-generated lab plan

The effectiveness is then found by relating these two values:

\[ \varepsilon = \frac{\varepsilon_k}{\varepsilon_{k_{\text{max}}}} \]  

(5)

Once the effectiveness is known, the number of transfer units, NTU, must be found. For the parallel-flow case, that equation is:

\[ \varepsilon = \frac{1 - \exp[-NTU(1 + c)]}{1 + c} \]  

(6)

where \( c \) is the capacity ratio shown below:

\[ c = \frac{C_{\text{min}}}{C_{\text{max}}} \]  

(7)

For the counter-flow case, the equation is:

\[ \varepsilon = \frac{1 - \exp[-NTU(1 - c)]}{1 - c \cdot \exp[-NTU(1 - c)]} \]  

(8)

Once the number of transfer units are found, the overall heat transfer coefficient is found from the equation below:

\[ NTU = \frac{U A_s}{C_{\text{min}}} \]  

(9)

Presentation of Data

- Table listing overall heat transfer coefficients
- Comparison of results for different methods

References


Nomenclature

- \( A_s \): Surface area of cylinder
- \( C \): Heat capacity of the fluid
- \( C_{\text{max}} \): Maximum heat capacity of two fluids
- \( C_{\text{min}} \): Minimum heat capacity of two fluids
- \( c \): Capacity ratio
- \( NTU \): Number of transfer units
- \( Q \): Heat transfer rate
- \( Q_{\text{max}} \): Maximum heat transfer rate
- \( T_{\text{in}} \): Inlet temperature of the fluid
- \( T_{\text{c,in}} \): Outlet temperature of the fluid
- \( T_{\text{in}} \): Inlet temperature of the fluid
- \( T_{\text{out}} \): Outlet temperature of the fluid
- \( \Delta T_{\text{in}} \): Temperature difference at the hot fluid inlet
- \( \Delta T_{\text{out}} \): Temperature difference at the hot fluid outlet
- \( \Delta T_{\text{lm}} \): Log mean temperature difference
- \( U \): Overall heat transfer coefficient
- \( \varepsilon \): Effectiveness of heat exchanger

Approval

____________________   ______ 
Reviewer      Date

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Reviewer      Date