2006-1355: DESIGN YOUR OWN THERMODYNAMICS EXPERIMENT, A PROBLEM-BASED LEARNING APPROACH IN ENGINEERING TECHNOLOGY

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Abstract

Thermodynamics is a difficult course for many undergraduate students in engineering. Engineering technology students usually struggle with the abstract concepts used in thermodynamics because they are often difficult to relate to everyday experiences. So, one may ask: What is the best way to teach thermodynamics in engineering technology? What topics should be covered? How should laboratory activities be organized and aligned to enhance the learning process?

These are some of the critical questions thermodynamics instructors face and should address to ensure successful course outcomes. Moreover, instructors have to decide how to present the course material in timely and efficient manner so students can swiftly and effectively retain and apply the concepts learned. An active learning approach is needed where students are highly encouraged to participate in the learning process. Several active learning approaches have been proposed and used in the past, including Problem-Based Learning (PBL). In this paper, a case study based on the problem-based learning approach is presented where course and laboratory activities are organized, aligned and coordinated so the students can logically and actively participate in the learning process. As part of a thermodynamic course, students acquire the necessary analytical and organizational skills for a comprehensive self-guided experimental task. Specifically, engineering technology students learn the fundamentals of experimental data analysis including curve fitting and error propagation analysis. Subsequently, electronic data logging and equipment-sensor interfacing, and sensor calibration are introduced through simple lab activities. Then the students are asked to perform first and second law analyses for a thermodynamic device and learn to quantify energy flow and the appropriate efficiency metrics. Once the students have mastered the assigned tasks, they select a thermodynamic device and design their own thermodynamic experiment. The experimental design should include first and second law analyses, error propagation analysis, and appropriate data logging equipment selection. At the end, students submit a written report and make an oral presentation to defend their proposed experiment.

The goal of the self-guided assignment is to encourage students to apply the concepts learned in the course. The experimental activities are presented in a sequential manner so each student can develop the necessary skills and enhance his or her level of self-confidence when dealing with a demanding task in the area of thermal sciences.

As part of the case study, evaluation of a designed experiment is presented to determine how effectively the implemented methodology enhances the learning process in engineering technology.

Introduction

Teaching thermodynamics has always been a challenge within the context of engineering technology. Usually, engineering technology students excel in hands-on activities better than in purely analytical tasks. Therefore, a successful active learning approach that hinges on practical activities should be incorporated into each engineering technology course to facilitate the learning process. Laboratory activities represent a unique opportunity to engage the students in a way that complements the typical course lectures.

As part of a comprehensive approach to improve the way thermodynamics is taught in engineering technology, a detailed learning methodology is presented. The problem-based approach presented compels the student to take a bigger role in the learning process.

Background

Problem-based learning (PBL) has been a subject of interest in recent years[1-3]. In an attempt to facilitate learning in a time demanding environment, educators have proposed, devised, incorporated and structured PBL into technical courses in the medical field[4-5] as well as in engineering courses[6-8]. Cawley[9] detailed the use of PBL in the development and delivery of a mechanical engineering course. Nasr, et al.[10] used PBL in a particular thermodynamic course which made use of learning modules and real-life applications.

Even more recently, Nasr and Ramadan[11] used PBL in an engineering thermodynamics course and introduced an evaluation tool to determine the effectiveness of PBL in that particular case. Specifically, Nasr and Ramadan[11] PBL method consisted in the development and implementation of several course modules which students had to undertake and participate in with minimal supervision. The objective was to help students be more responsible for their own learning. Tebbe[12] also used PBL in a thermal and fluid systems design and thermodynamics course in which he conducted a survey among the students to gauge the student perception of PBL activities versus the traditional approach. Tebbe[12] PBL method consists of several class exercises which the students undertake with minimal supervision. These publications show that PBL continues to be used as a teaching/learning tool in engineering courses because it encourages students to assume a more direct role in the learning process. However, their methods seem to be time consuming and re-direct attention away from the traditional approach in a way that puts too much pressure and responsibility on the students for their own learning. In this paper, a balanced PBL activity is used to help students transition from the traditional to a self-guided PBL approach. The method is described in detail later in the paper.

Description of Methodology

In an attempt to fully incorporate PBL into an engineering technology thermodynamic course, an active learning approach has been devised and tested in a real classroom environment. The approach, as depicted in Figure 1, consists in giving each student the necessary tools and instructions to be able to tackle experimental tasks which involve the use of thermodynamics concepts. As part of the active learning approach, students receive a fair amount of educational material which they have to internalize and assimilate to be able to successfully accomplish the course objectives. The approach makes use of the traditional teaching/learning approach but combines it with self-guided tasks to enhance the student's comprehension and understanding of a variety of topics. To measure the student's level of comprehension, an array of assessment tools is used including a specific self-guided tool.

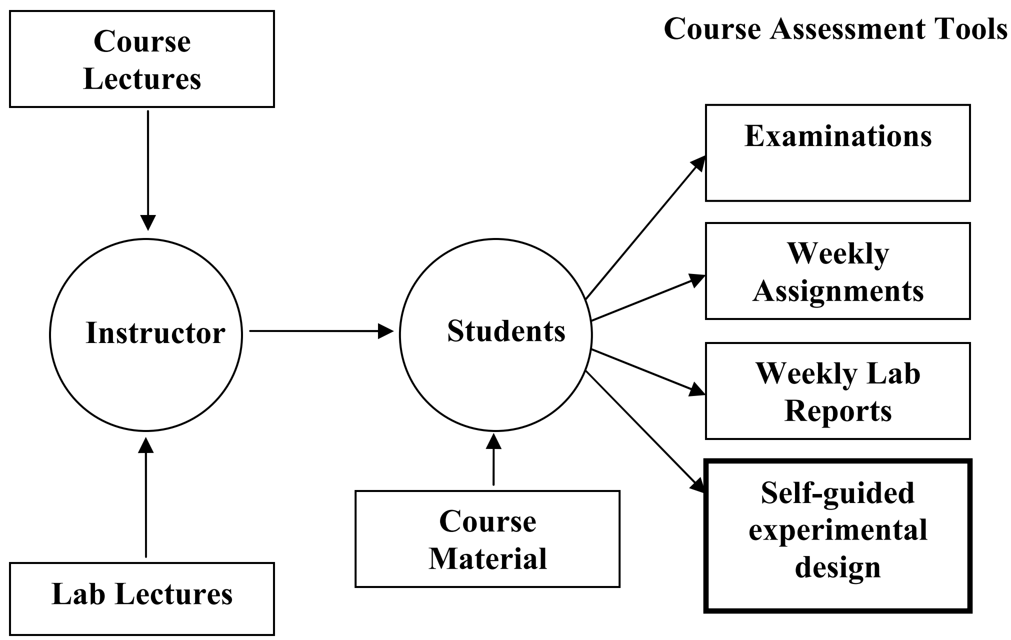

Figure 1. Structure of engineering technology thermodynamics course

In detail, the implemented methodology consists of the following components:

- Classroom lectures
    - Explanation of fundamental theories and basic principles, and real systems
    - Discussion of problem solving strategies

- Laboratory lectures
    - Application of theories and basic principles to real systems
    - Explanation of data analysis, data collection systems, and report writing guidelines
- Course material
    - Textbook, lab manual, internet sites

- Course assessment tool
    - Examination
    - Weekly assignments
    - Weekly lab reports
    - *Self-guided experimental design*

Self-guided experimental design

The purpose of the self-guided laboratory experimental design is to encourage students to actively participate in the learning process by incorporating and utilizing all the tools presented during the lectures. The different topics are presented in a sequential and timely manner so the students can have ample time to learn and assimilate the course material. The objective is to follow a problem-based learning approach for a specific part of the course while still adhering to the traditional approach when necessary. The problem-based approach has already been implemented and used for the last two semesters. Figure 2 illustrates how the self-guided activity is structured around each student.

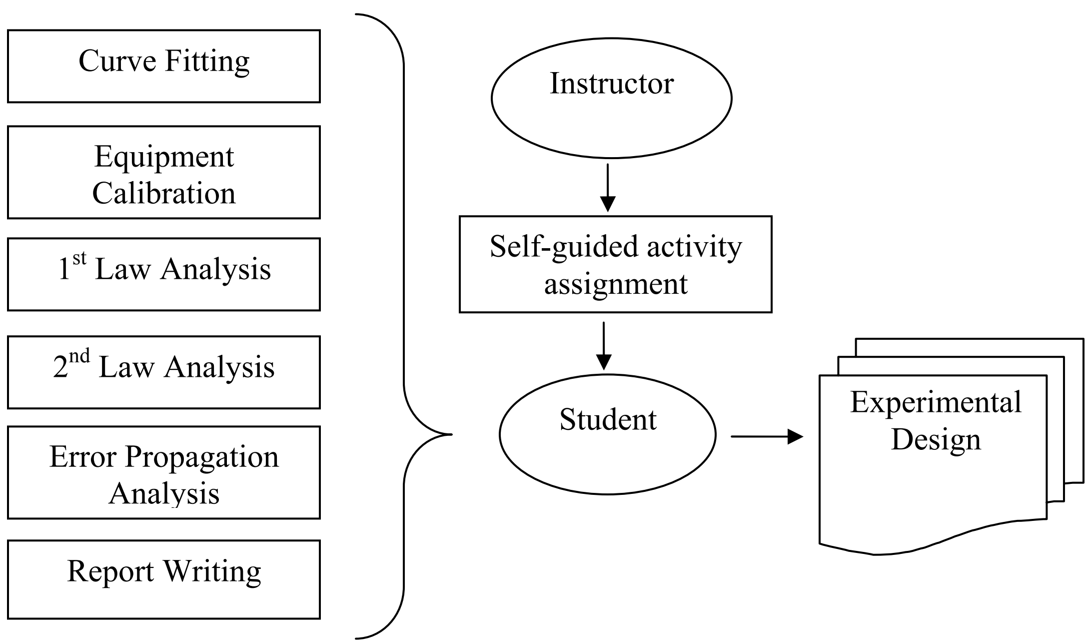

Figure 2. Self-guided activity in engineering technology thermodynamics

As part of the self-guided activity, students specifically learn the following subjects as part of the laboratory lectures:

- Data analysis of lab-generated data by using model fitting techniques including the least squares method

- Installation and calibration of laboratory sensors and data logging equipment

- First and Second law analyses of thermodynamic devices by using:
    - computational tools
    - physical hardware in the laboratory

- Measurement of appropriate efficiency metrics

- Error propagation analysis of lab-generated data and calculated results

Once the students have acquired the necessary skills, the students are asked to design a thermodynamic experiment for a device of their interests that involves heat flow and/or work. The experimental design should clearly indicate and include the following:

- Experiment's objective

- Appropriate background information

- Experimental input and output variables

- List of instruments necessary for measuring each variable including the instrumentation's relative error or accuracy with high signal-to-noise ratio, and specified component cost

- Calculated (output) variable or metric with the associated error propagation analysis based on the first and second laws of thermodynamics

- Set of instructions describing how the experiment should be run and what important questions should be answered

The self-guided experimental activity provides students with specific instructions but gives them enough flexibility to use and adapt them in different applications, the true spirit of problem-based learning. Evidently, the self-guided activity puts specific responsibilities on students which help them become more independent.

All the students taking thermodynamics take part in the self-guided activity by forming groups of 3 to 4 students who proposed their ideas to the instructor. The instructor approves only those ideas that are challenging and can be implemented in a foreseeable future. Students are encouraged to select ideas that can be economically implemented. The instructor may use the students' experimental design and recommendations if budgetary constraints and funding levels allow full implementation of the experimental design. The course is taught every semester and is a core course in the engineering technology curriculum. The self-guided activity is and will remain an active part of the course.

The following case study discusses and explains how a group of students designed their own thermodynamic experiment based on the implemented PBL approach.

Case Study: Household Refrigerator

As part of the thermodynamic course in the Department of Engineering Technology and Industrial Distribution at Texas A&M University, students learned the laws of thermodynamics for closed and open systems. They also learned specific applications of those laws like in the case of power and refrigeration cycles. As part of the self-guided experimental activity, a group of 4 students designed and proposed a thermodynamic experiment to measure the coefficient of performance (COP) of a household refrigerator. The experimental design proposal contained the following sections: Introduction, Theoretical Background, Experimental Design, Description of Performance Metrics, Questions, Description of Experimental Hardware, and Data and Error Propagation Analysis. The following provides a brief explanation of the students' proposed experimental plan:

Introduction: The students clearly stated the objective of the proposed experiment which was the measurement of the actual coefficient performance (COP) of a household refrigerator.

Theoretical Background: The students carefully explained the refrigeration cycle from a thermodynamic point of view. They also describe the cycle using the first law of thermodynamics. They provided T-s diagrams for the real and ideal cycles and identified opportunities for efficiency improvements based on the Carnot Cycle. The group also presented the appropriate metric, $COP_{refrigeration}$ for a household refrigerator as shown below:

$$COP_{REFRIGERATION} = \frac{\dot{Q}_{evaporator}}{\dot{W}_{electric\_motor}}$$

Where,

$\dot{Q}_{evaporator}$ = Evaporator load, kW

$\dot{W}_{electric\_motor}$ = Electric motor load, kW

Experimental Design: The students outlined in detail all the necessary steps to measure the proposed metric. The outlined steps take into account practical issues including equipment warm-up time, data logging equipment installation and calibration, software-hardware connectivity and data stability. They also considered and proposed modifications of a household refrigerator so the appropriate experimental variables could be measured.

Description of Performance Metrics: The students outlined step by step how to convert input variable data such as compressor motor power, pressure, temperature, and volume flow rate at the inlet and outlet of the evaporator and compressor, to the desired metric.

Figure 2 shows how input variable data are converted to COP. The steps take into account the phase change process and type of refrigerant. The students presented a complete set of equations necessary for measuring COP.

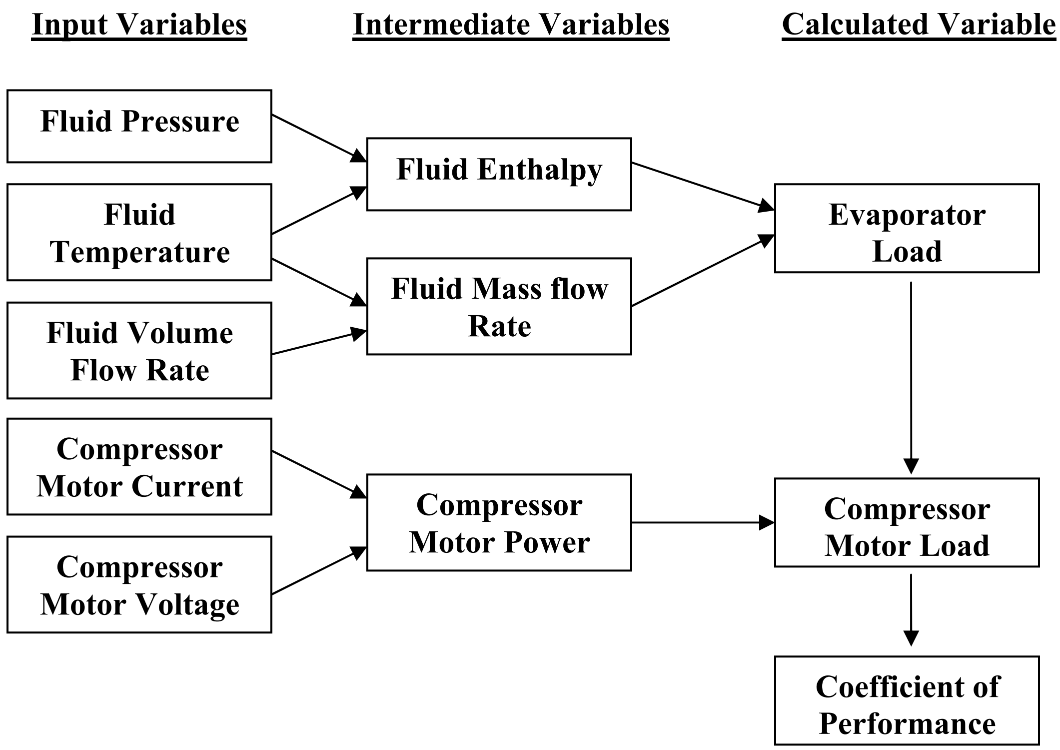

Figure 3. Case study performance metric derivation process

Questions: The students posed several questions which take into account the actual refrigeration system. They also presented a set of steps necessary for comparing the real system with an idealized refrigeration cycle. The questions compelled the participants to see the connection between the theory and application.

Description of Experimental Hardware: The students selected an ordinary household refrigerator and the associated data logging equipment for the proposed experiment. The students surveyed a variety of measurement equipment that could be used to measure all the experimental variables. The students carefully specified economical and reliable sensing equipment which is commercially available and provides suitable accuracy. The equipment included a commercially available refrigerator, a digital flow meter installed in-line with the compressor, a digital refrigeration service manifold for measuring pressure and temperatures, and a multi-meter amp and voltage meter. They also provided instruction on how to connect all the sensing equipment which requires connections to the existing refrigeration tubing and other components. They also took into account how to recharge the refrigeration system after all the installation modifications are complete. They also specified sensing equipment with the appropriate input variable range to maximize signal-to-noise ratio based on preliminary analytical calculations. The students also provided a budget for all the components including the refrigerator which did not exceed $2,500

Data and Error Propagation Analysis: The group clearly identified the input variables and their precision level and relative error. By using an error propagation method introduced during the lab lectures, the students were able to estimate the calculated variable (COP) relative error associated with the input variables. After conducting a simple sensitivity analysis which was also introduced during the lab lectures, only those input variables with the greatest impact on COP were selected for error propagation analysis.

Case Study Discussion

The proposed experimental plan noticeably shows that a particular group of students was able to use the different topics covered in the engineering technology thermodynamic course and satisfactorily implemented them in the development of an experimental design. The students had the opportunity to combine abstract concepts and formulate an appropriate metric for quantifying the thermal performance of a real refrigerator. The students also made judicious selection of experimental hardware to conduct a data-sensitive experiment of high reliability. To evaluate how well the students met the laboratory assignment, a list of outcomes was elaborated based on the course outcomes.

The following list of outcomes was used to assess the students' ability in meeting the stated objectives:

- Clarity of stated objectives
- Presentation of basic principles and background information
- Appropriateness of proposed experimental equipment
- Error propagation analysis (EPA)
- Selection of output variables or metrics
- Clarity of experimental steps
- Suitability of proposed questions and how well the experimental design satisfies the stated objectives

Case Study Experimental Design Assessment

A matrix based on the outcomes outlined previously was devised to assess qualitatively the effectiveness of the implemented active learning approach, Table 1. For the case study discussed above, the assessment is as follows:

Table 1. Experimental Plan Assessment Matrix

Objectives	Basic Principles	Equipment	EPA	Output Variables	Experimental Steps	Questions/Satisfies objectives	Overall Score
E	**G**	**G**	**G**	**E**	**E**	**G**	**G**

Legend:

E-Excellent
G-Good
S-Satisfactory
NI-Needs improvement
U-Unacceptable

Based on the qualitative assessment of the implemented PBL approach, Table 1, it is evident that the students were able to satisfactorily meet the stated objectives. The students showed that they were able to implement and integrate many of the concepts discussed in the class and laboratory lectures. The proposed experimental design showed the students' ability in dealing with a real-life application with little supervision.

The problem-based learning activity described above and its outcomes were also compared with the traditional approach used in previous semester. Several noticeable observations were made including the students' ability to think independently and to rely less on the material discussed in class. For instance, the students were able to select real-world applications and apply the first and second laws of thermodynamics with a high degree of confidence. The students also performed their own literature and background review and identified practical ways to measure the experimental variables without any instructor's assistance. Previous students who learned under the traditional approach rarely showed the same level of self-confidence, drive and direction. At the moment, these observations are based on the instructor's own experience with the students and their overall performance evaluation (grades). The self-guided experimental design is also an assessment tool that measures the students' ability to apply basic concepts in real world applications. A total of 8 groups participated in the described problem-based activity the last time the course was offered. Table 2 shows the overall assessment for all the groups.

Table 2. Overall Assessment Matrix

Group Number	Topic	Overall Score
Group 1	Household Refrigerator	Good
Group 2	Steam Turbine	Good
Group 3	Water Heater	Satisfactory
Group 4	Hair Dryer	Good
Group 5	Refrigeration Plant	Satisfactory
Group 6	Diesel Engine	Good
Group 7	Gas Turbine	Good
Group 8	Gasoline Engine	Satisfactory

The overall qualitatively assessment indicates that the students benefited from the PBL activity in a way that previous students never experienced. However, it is hard to know exactly how many students were positively influenced by the method because they all work in groups of 3 to 4. Therefore, the current method is still being modified to accurately determine its overall impact. The implemented PBL method is also being used to determine which experiments are cost-effective and can be used as teaching tools in the laboratory in the future.

Conclusion

The goal of the self-guided problem-based activity was to show how engineering technology students can be challenged in a way not typically encountered at the undergraduate level. Based on the self-guided activity assessment and observations made recently, students that participated in the PBL activity enhanced their level of self-confidence when dealing with a demanding task in the area of thermal sciences. It is also evident that the implemented problem-based learning approach can be used to complement the traditional approach in a substantial way. Undoubtedly, PBL will continue to be an integral part of the students' learning experience.

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