

# **AC 2009-1911: PROJECT-BASED LEARNING IN INTRODUCTORY THERMODYNAMICS**

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# Project-Based Learning in Introductory Thermodynamics

## Abstract

The sophomore year is a critical decision point for engineering students. In freshman year, they might have been given exciting introductions to engineering design and applicable science by faculty dedicated to teaching. In sophomore year, they encounter traditional lecture presentation of challenging engineering science courses, probably by faculty more dedicated to research than undergraduate teaching. This may present either a threat or opportunity for retention of students. Introductory thermodynamics is usually such a 'gateway' course that must introduce to students both a new branch of science and an unfamiliar abstract method of scientific reasoning. Test scores, surveys, and classroom assessments indicate that many students did not really understand the laws of thermodynamics until the end of the course, if at all, even if they could apply the 'formulae'. A supplemental or alternative approach such as project-based learning may be very useful.

This paper describes a design project in a mechanical engineering program at an urban research university. It was initially supplemental, but became a framework for alternative presentation of thermodynamics in a problem-based learning approach. The design project is intended to apply key topics in thermodynamics to a familiar domestic problem of heating, ventilation, and air conditioning (HVAC) system design for a residential application, based on manufacturer's specifications, second-law principles, and actual climate data. Students work in small teams of 2-3.

The project is assigned and discussed at the beginning of the semester, so that it naturally motivates the learning of needed concepts throughout the semester. Teams were given annual climate data for different locations and defined home insulation, infiltration, and heat source properties. They were required to perform an energy audit and equipment thermodynamic performance evaluation to select specific units appropriate to the calculated heating and cooling loads. They recalibrate manufacturer ratings of the chosen units for local climate, and calculate the average cost of heating and cooling as well as the lifetime cost of the systems. This involved identifying the vendor and obtaining the necessary performance and cost data from them. Discussions were encouraged among the teams using an online discussion forum. Each student team was required to submit a final project report at the end of the semester and present their data.

This project was implemented for a number of years by four different instructors. This holistic design and teamwork experience at the sophomore level appears to have given students a springboard benefit in the curriculum that persists into later courses and professional practice. Direct and indirect assessments of the project-based method were conducted and the results will be presented in the paper. The design project is assessed based on classroom presentations and a written report with technical analysis, design process, and professional conclusions. It is intended to continue restructuring the course syllabus around this project in the future.

## Introduction

Student engagement and participation in their learning experience has been known to enhance their understanding of the subject material in many ways. Therefore there has been an emphasis on active learning methods and Problem-Based Learning (PBL) approaches especially in engineering education<sup>1-3</sup>. A PBL approach naturally introduces the student to abstract concepts that need to be applied to a practical problem. PBL also has a universal appeal particularly in engineering that goes beyond cultural contexts as is evidenced by the large number of publications devoted to such approaches in various geographical locations<sup>3-5</sup>.

PBL and project-enhanced learning are slightly different approaches. The former refers to approaches where the structure of the course is driven by an open-ended problem posed to the students. The latter refers to approaches where a project is integrated with a traditional lecture based course, and can be implemented in a gradual and transferable way over time and among multiple sections and instructors. While there are some differences in the benefits of each, there is evidence to suggest that both enable critical thinking and increase the learning achievements and self confidence of the students<sup>1</sup>.

The abstract nature of an introductory thermodynamics course is inherent in the nature of the topics covered where many new concepts, laws, definitions, and variables are introduced sequentially throughout the course. Unlike concepts in mechanics, and perhaps more like electrical science, thermodynamic concepts have probably not become intuitive through visual and tactile senses in daily life or primary education. Students are typically required to master these new ideas as they move from chapter to chapter. In his preface to the book, *Understanding Engineering Thermo*<sup>6</sup>, Octave Levenspiel quotes the following words of a student taken from another thermodynamics textbook by Andrews (1971)<sup>7</sup>

“To me, thermodynamics is a maze of vague quantities, symbols with superscripts, subscripts, bars, stars, circles, etc., getting changed along the way and a dubious method of beginning with one equation and taking enough partial differentials until you end up with something new and supposedly useful.”<sup>6</sup>

These words describe what the student faces when he or she is introduced to the various seemingly disjoint abstract topics in thermodynamics for the first time. In an introductory thermodynamics course, students typically have some difficulty in integrating the material until they arrive at the final chapters involving the power and refrigeration cycles.

Perhaps as a result of this typical student perspective, and the ineffectiveness of traditional teaching methods, there is evidence that the preparation of the students for their profession may be inadequate.

“Although engineering education is strong on imparting some kinds of knowledge, it is not very effective in preparing students to integrate their knowledge, skills, and identity as developing professionals.”<sup>8</sup>

Therefore it makes ample sense to introduce a practical project-based approach in an introductory engineering thermodynamics class. Such an approach has the advantage of showing the student the strong interrelationships between the different concepts and variables in a practical way throughout the semester thus giving them a reference point upon which to anchor their thinking. The benefits of such activities in the preparation for their profession are obvious. In spite of these facts, engineering schools don't generally emphasize such non-traditional approaches mainly because of the lack of project-based learning culture and an inertial resistance to moving away from traditional lecture-based instruction among engineering faculty.<sup>8</sup>

This paper describes the implementation and assessment of a project-enhanced instruction methodology applied to an introductory thermodynamics course in an undergraduate program in mechanical engineering at an urban research university.

## **Curriculum**

Students admitted into the freshman engineering program are required to take an introductory engineering course that includes reverse engineering activities. This course is fairly hands-on and was designed to motivate the freshman engineering students and improve the retention of interested students. Those admitted into the undergraduate mechanical engineering program are required to take two courses involving design projects in team environments in their senior year. However, in their sophomore and junior years the classes are generally traditional i.e., lecture-based with separate laboratory components. They include introductory courses such as thermodynamics which introduce and apply a number of abstract and hitherto unfamiliar concepts. Therefore, a need was felt to develop a project-based learning component in the introductory thermodynamics course to improve student learning, motivation and retention. The details of the project and the class in which it was implemented are described below.

## **The Class and Project**

The class was a typical introductory sophomore level undergraduate mechanical engineering (3 credit hours) course with approximately 30 students. The class had about 27 lecture hours with three exams, some quizzes and a team project. This course was offered by four different instructors over several semesters and all but one instructor offered the project as part of the course. The same project was offered on all the semesters by the three participating instructors.

The project was a component of the course counting for typically 10 – 15% of the total points for the course grade. Since the students were told about the project and that it carried a significant portion of their grade, they took the project seriously. The project was designed to make the students apply the fundamental principles of thermodynamics to a real-life product and economic choice, working in a team of two or three. All teams worked on the same general problem, but with different numbers. Questions and discussion were posted on an online discussion forum on the course website.

The problem posed to the students was to design the heating and cooling system for a typical single-family residence of a given size, based on a control volume analysis of the energy balance. The energy analysis was to be done for average and extreme summer conditions, and for average and extreme winter conditions (a total of four analyses), for a climate location.

Climate data for the different states in the US was made available to the students and each team selected a choice of state for them to work on. They were then asked to identify, evaluate and compare two choices for the heating and cooling systems:

(Choice 1) - Dual-purpose heat pump / air conditioner system

(Choice 2) - Gas furnace and central air conditioner.

The problem was simplified in some ways e.g., some parameters such as the infiltration of the house, the heat loss from the walls and roofs were given as inputs to the project. This was in line with the goals of the project which were to merely introduce the application of the topics of relevance to a thermodynamics course. Care was taken to ensure that the main characteristics of the calculations were kept as close to the practical case as possible so that the project was moderately open-ended.

### **Methodology**

The project instructions and the data were posted fairly early in the semester and the students were made aware that the project work was an important part of their assessment. The different topics such as first law, second law, and heat pump and refrigeration cycles were covered in sequence in the lecture portion of the course while the discussions on the project were carried out online.

Team selection has been done by the instructor and by students, or with a process of consultation. The student teams then select the location state. In any project-driven learning approach student ownership of the problem is an important first step. In this implementation it was observed that the students were excited to pick a state for their analysis and sometimes came up with their own team names thus indicating their taking ownership of the project. The students were asked to use the online discussion forum to post any questions / comments or interacted with the instructor during office hours regarding their project.

### **Traditional vs Project-Enhanced Instruction**

The concepts and topics that were introduced and applied by the students during the project included the following:

1. First Law of Thermodynamics
2. Second Law of Thermodynamics
3. Heat Pump
4. Refrigeration Cycle
5. Carnot Refrigeration Cycle
6. Unit Conversions

## 7. Estimation of Fixed and Operating Costs

The topic of psychrometrics was not covered in the course, although it is relevant to HVAC systems and hence is not listed above.

In a traditional lecture-based offering with no project, the first six topics were generally introduced in the lecture at different times and the students practice using Topic 6 in the homework problems. Apart from these, students interact with the instructor during office hours. Topic 7 is generally not discussed at all. Further, student complaints in the evaluations indicate that students struggle to identify the interrelationship between the seemingly unrelated topics that are sequentially offered in the first half of the course. Even though the instructor usually attempts to connect the topics together, the student perception is closer to a picture conveyed by the student quote mentioned earlier in the introduction. Therefore, the students have to wait till the last few classes (when the focus is on the applications of the first and the second laws to the various power and refrigeration cycles) to effectively integrate and possibly assimilate the material.

In a project-enhanced offering of the class, all the six topics above are at least introduced to the student much ahead of their actual coverage in class and homework. Therefore, the students anticipate these topics and look forward to the lecture with the intent of working on the project. This results in increased student motivation to learn. The students also see an integrated picture of the various topics above in the context of their application to the project. Therefore, the difficulties of integration mentioned in the previous paragraph are alleviated to a large extent. Further, a project-enhanced offering allows the students to be introduced to some practical economics in their field as well.

### **Enhanced Interactivity**

During the course of the project, students undertake several steps to approach their final calculations. Monitoring of these steps usually reveal some misconceptions. These misconceptions needed to be corrected through more interactions between the students or between the students and the instructor. In view of this need to support and monitor interactions, an online discussion forum was used extensively from the beginning of the class. The questions posted on the forum revealed several misconceptions which would otherwise most probably not be revealed to the instructor. At these times, the instructor guided the discussions in the right direction. An example of this aspect is provided below:

One student team that called itself 'The Heat Regulators' posted some questions on the discussion forum. The questions and the instructor responses as posted on the online discussion forum are reproduced below:

Q: "Are we to assume that the energy input rate from human metabolism during summer is -1500 Btu/hr and +1500 Btu/hr for winter? Because in summer it'd be adding heat when you are trying to cool the house and vice versa for the winter conditions..."

A: "Human metabolism always adds heat to the air in the house. Based on this you need to correctly calculate heating and cooling requirements for winter and summer. In winter it helps to

have people in the house to reduce heating costs!”

From this example, it is amply clear that the team had some difficulty in applying the basic principle of energy balance to the project and sought the instructors help. This kind of feedback from the instructor requested by the students themselves would not have occurred had it been a traditional lecture-based instruction. Both the instructor and the student would possibly have been unaware of such misconceptions in the students’ mind in that case. An added benefit of this exercise is the increased instructor motivation as well!

Below are some further examples of such interactions.

Q: “Do we have to use the nozzle and diffuser formulas and concepts for the heating and cooling systems? What is the purpose of finding the mass flow rate of the air in the house?”

A: “Mass flow rate is used only in the calculating air exchanges between the house and the ambient as it happens due to closing and opening of doors, leakage through the windows and doors etc. and this is given as 0.4.”

Q: “Shouldn't the heat input for solar radiation be higher in the summer than in the winter, considering we are closer to the sun in the summer time? Would you please elaborate on this matter?”

A: “Good question! In winter, the angle made by the sun is more oblique at the earth. (see link for a picture depicting this). Therefore, more of it may reach the house through the windows. However, there are other factors such as which direction the windows are facing etc. which also determine this. The numbers given are just some examples.”

Q: “A lot of the air conditioning units and furnaces are measured in BTU's. Is that BTU's per day, per hour? Or do we need to convert our heat from BTU/hr to BTU?”

A: “Most of the AC units and the furnaces we looked up (mainly on Bryant's website) have the heating/cooling capacities listed in BTUH, which in their glossary is defined as Btu/hr. They also use "ton" in some of their units which is defined as 1 ton = 12000 Btu/hr. So we think it should be pretty straight forward after you have your Q for furnaces/air conditioners.”

One interesting development was that the discussion forum also enabled peer-to-peer interaction as evidenced by the last question and its answer provided by another student in the same class. Of course, there is a need for the instructor to monitor such interactions to avoid propagation of incorrect ideas through the class.

In addition to these, several comments about the various aspects of the project came up in the lecture sessions or in the informal interactions with the students in the class. Such interactions would not have occurred in a traditional offering. These discussions were not recorded but needless to say, these discussions supported active participation of the students in the lecture sessions as well.

## Student Retention

Students in a 'gateway' course such as this are sometimes not sure whether they got into the wrong profession and a traditional lecture-based offering of the course does not offer an alternative to this opinion. However, a project-enhanced offering allows students to explore the profession in their own terms and eventually enables them to build their self confidence on topics that may have seemed insurmountable otherwise. A detailed study is needed to confirm our hypothesis that this translates into better student retention in the long term.

## Assessment

An attempt was made to relate the impact of project-based learning in thermodynamics to student performance in a follow-on course: undergraduate heat transfer that was typically taken by students a year after the introductory thermodynamics course, and which used some of the concepts developed in the first course. All students in the follow-on course during the Fall 2005 - Fall 2008 semesters were tracked to identify which of them took the first course with the project and which without. Comparisons were made between the overall performance of the students (a total of 159 students in all) and the results categorized in three groups: students who took the project-enhanced offering, those who took the traditional offering and unclassifiable students. The majority in the third category were students who had transferred from other colleges and universities. It was learnt that one of the universities offered the thermodynamics course with a project. The details of the project implementation were unknown. A small number of the students who transferred from this university were included in the scores with the course project. The performance indicators were the course total score and the scores in individual exams where the material related closely to the topics covered in the project. The results are summarized in table 1 below.

**Table 1. Total and Exam Scores out of 100 with standard deviation in brackets**

	Number	Total	Exam 1	Exam 4
Project-Enhanced Course	61	69.8 (12.5)	65.2 (18.1)	59.1 (22.5)
Traditional Course	78	69.8 (11.1)	64.5 (17.8)	56.8 (20.7)
Unclassified	20	70.2 (11.3)	65.2 (23.7)	63.7 (21.2)
All	159	69.8 (11.6)	64.9 (18.6)	58.6 (21.5)

The table above indicates only a marginal difference in performance between the different groups while there is some weak evidence that the first group (Project-enhanced Course) performed better in the first and final exams. This is explained as follows: The total score in the follow-on course is a reflection of the many heat-transfer topics covered, which may or may not have a related concept that was taught in the pre-requisite introductory thermodynamics course. For example, the project covered the concept of energy balance introduced through the first law in thermodynamics and its application in the context of conduction heat loss through the walls as well as heat addition through solar radiation incident on the windows. These topics were most closely related to Exams 1 and 4. Exams 1 and 4 covered the topics of conduction and radiation as well as multi-mode heat transfer and there was heavy emphasis on energy balance approaches



in these exams. However, Exam 2 covered mass diffusion while Exam 3 covered convection heat transfer correlations and both these exams did not utilize concepts of energy balance. The higher scores in these exams by first group perhaps indicate a better understanding and assimilation of these topics in the long term. However, the statistical distinction between the exam scores is not significant enough. This indicates the need for a more in-depth assessment of specific student learning outcomes related to the project in the long term. Further, specific questions designed to test specific concepts learned by the students during the project over the long term may be helpful.

Assessment data was also collected over two semesters from another follow-on course (Power Engineering). However due to the limited number of samples (total of 30 students of which 9 took the Project-Enhanced Course and 18 took the Traditional Course) the data was not statistically significant and therefore this information was not presented.

### Student Participation and Perception

It should be noted that the correlation between student learning and doing the project is also influenced by the level of participation of the students in the project. In order to maximize this participation, the project was introduced to the student within the first week of classes in almost all semesters. This is extremely critical in a project-enhanced approach

The home department uses a list of learning outcomes for each course, which is used to assess student learning. In particular, students are asked to self-report their perceived attainment of each outcome at the end of the semester. In order to assess on how the students perceived the project, the scores for the student outcomes related to the project on the various semesters when it was offered with the project is presented below in Table 2. The numbers of students who responded to the student surveys are indicated in parentheses. The project-enhanced course was offered on all Fall semesters between 2003 and 2008 and Spring and Summer of 2008. In Fall 2005 two instructors offered the option of the project.

**Table 2. Scores on the Course Outcomes survey (Project-Enhanced Course). (1 = Very dissatisfied, 5 = Very satisfied)**

Semester (Respondents):	F03 (12)	F04 (11)	F05 (7)	F05 (8)	F06 (18)	F07 (28)	Sp08 (24)	Su08 (15)	F08 (32)	Avg. (123, 155)
<b>Outcome</b>										
Work in a team to analyze a practical thermodynamics system	4.33	3.45	3.57	-	3.72	3.71	-	3.93	3.13	3.62
Overall	3.75	3.64	3.53	3.83	3.57	3.54	3.23	3.95	3.16	3.49

The overall scores average at 3.49/5.0 indicating that the students were somewhat satisfied with achieving the outcomes of the course, but certainly not very satisfied. The project-related outcome satisfaction was generally higher than the overall course outcome satisfaction, indicating that the students were on an average somewhat more satisfied with the project

compared to the other aspects of the course. There may be some reasons for the slightly lower outcomes for the project in Fall 08 that need to be looked into.

Anecdotal evidence seems to suggest that the students were either appreciative of the course project or complained about its open-ended nature, with no right answer and limited information. Both are indicative of the strong impact of the project on the student and that the students had to work hard on the project.

### **Recommendations for Future Studies**

The above data indicate that student performance data and tracking over at least seven or eight years are needed to obtain reliable assessment data. Further, an in-depth analysis that takes into account a break down of the various topics tested in the exam questions in the follow-on courses in relation to the actual concepts and applications taught in the course project in the introductory thermodynamics course may reveal more insight. There is also a need to collect data over the long term to obtain information on the impact of these exercises on the professional lives of the students.

The extent of interactivity between the instructor and the students is important for the success of project-based or project-enhanced learning approaches. Qualitative and other approaches to assessment related to this aspect are important for any future studies.

### **Conclusions**

Project-enhanced instruction is an effective tool to introduce abstract concepts at the undergraduate level, especially in engineering thermodynamics. While keeping student motivation alive in these courses, project-enhanced instruction also achieves multiple benefits.

1. It integrates the course topics before the topics are introduced in the lecture and results in better assimilation of the subject material.
2. It provides multiple avenues for feedback from the instructor while simultaneously enabling peer-to-peer interaction. Such student-driven but instructor-guided interactions help address student misconceptions on the topics of instruction and enhance instructor motivation.
3. Project-enhanced courses need to introduce projects fairly early in the course to reap the benefits listed above
4. It inspires the students and increases their self-confidence at a time when they are about to enter their serious professional career.
5. Student performance in follow-on courses may be enhanced when they take the project-enhanced offering of the course in comparison to those who take the traditional offering.
6. Students rank their satisfaction of the course project higher than their overall satisfaction for the course indicating they obtain more out of the project than other aspects of the course.

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