

Active Learning in Engineering Thermodynamics for First Year Students using a Project Approach

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ABSTRACT

Student centered learning in Engineering thermodynamics has a large potential, but is also associated with some difficulties. As a way to facilitate a student centered learning, a project based on the compressor cycle was developed for and investigated for a course in Engineering thermodynamics for first year students.

The project was evaluated based on interviews during the project, and a survey at the end of the project. The students were in general very satisfied with the project, as it increased motivation and understanding. Altogether, it can be concluded that the project was beneficial from a learning perspective, changing the learning process towards a deep-level approach.

Keywords

Active Learning, Student centered learning, Engineering Thermodynamics, Project

1. INTRODUCTION

The study presents a project approach to enhance students learning in engineering thermodynamics for first year students. The students attended a 5 year Masters program in either Mechanical engineering or Energy, environment and management at Linköping University, Sweden.

Improved education and learning of Engineering thermodynamics is important and have a large potential, but it can be argued that the process towards this goal is not straight-forward - for several reasons. One reason is that part of the subject often is considered "*dry and abstract*" by the students [2]. To counteract this, it would be beneficial to stimulate involvement and thereby

motivation of the students. One possibility is to increase the presence of "hands-on activities" like experiments and projects involving experiments. A project approach involving experiments has earlier been shown to increased student motivation for first year students in electrical engineering [6].

Although projects in engineering education are scarcely something new, the subject exhibits some features that reduce the possibilities for larger projects. Engineering thermodynamics deal

among others with engines and cycles, the substances that undergo processes in these cycles, and their action in relation to the laws of thermodynamics. Important examples are the Diesel and gas turbine engines, which many students in mechanical and energy engineering think interesting. To include such engines in a project in order to stimulate motivation and thus learning would be beneficial. There are several problems, however, that makes it difficult to actualize this – the real engines are complex, expensive and potentially dangerous, and demands prior knowledge in e.g. heat transfer, fluid mechanics and combustion. Thus, it is not straight-forward to develop such projects in this context.

To overcome the problems mentioned above, a project based on the compressor cycle has been developed, and its impact on student motivation and active learning is investigated. The compressor cycle show several important similarities with other thermodynamic cycles, and can thus serve as a complement and/or substitute. By this approach, an instructive, in-expensive and safe project is achieved. The evaluation of the project shows that the students experience an increased motivation, and a more profound understanding of thermodynamic cycles and how they are affected. The students were very pleased with the project, finding it stimulating, interesting and relevant.

To overcome these problems, a project based on the compressor cycle has been developed. The compressor cycle is another of the fundamental thermodynamic cycles that is used to move heat from a low to a high temperature, and is used in e.g. heat pumps and refrigeration systems. The compression cycle show several important similarities in its components and analysis of processes compared to the other major cycles – an understanding of this cycle is thus good for a general understanding of processes and cycles in engineering thermodynamics.



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In the projects, students work in groups with own measurements on standard refrigerators. The aim with the project is to determine the coefficient of performance of the refrigerator for two conditions, and to analyze the benefits and drawback with the methods used. The first condition is a standard condition, simply measurements on a normal refrigerator. For the second condition, the students should affect the refrigerator/cycle by e.g. insulate the condenser unit to obstruct heat transfer to the surroundings, and investigate the effects on the cycle and its performance.

One reason for including the project in the course was to depart from the idealized cycles and reach the aspects of “real” processes and machines. From a learning perspective, there are reasons to believe that embedded projects, if joined properly with the course content and other forms of education, have the potential to improve learning and change the learning from a surface- to a deep-level approach [MM]. This was investigated in the present study. Interviews were carried out with the students, and a written survey was used at the end of the course. The students were very positive about the project and the result of the interviews and survey indicate that positive learning effects were obtained.

2. ACTIVE LEARNING AND THE PHENOMENOGRAPHIC APPROACH IN ENGINEERING THERMODYNAMICS

Enhancing students’ learning can be addressed in various ways. One way is to strive toward “active learning”, which has been shown to significantly improve student learning [4, 10]. Although most University teachers would believe that students must be “active” to learn, only some teachers would agree that the teaching during lectures and lessons are often not fulfilling the classification of active learning. The idea of active learning is to get the students involved in their own learning, which is far away from the obsolete view of education as a one-way transferring of knowledge from teacher to student. Active learning has been described as *“When using active learning students are engaged in more activities than just listening. They are involved in dialog, debate, writing, and problem solving, as well as higher-order thinking, e.g., analysis, synthesis and evaluation.”* [10].

Active learning is closely related to phenomenographic approach, which claims that variation and engagement is the key to support a deep-level approach to learning. To achieve this, the students must think of the topic as meaningful and relevant. The deep-level approach to learning is all about gaining understanding, seeing the phenomenon in a holistic perspective and relating things to each other, whereas a surface approach might be described by an atomistic view of learning focused on, for instance, reproducing facts seen as separate parts. In the last thirty years, these concepts have been thoroughly investigated, particularly in the areas of education and health sciences, see e.g. [1, 7], but recently also in engineering [9].

It can be concluded that active learning is important and should be one goal of the education. How to achieve this, however, is not obvious. Since the early definition of Thermodynamics in about 1840 [13], its importance has gradually grown and is now a fundamental subject for many disciplines, for example biology, chemistry, physics and engineering. The content can differ somewhat depending on the different curricula of these disciplines, see e.g. [16]. In e.g. mechanical, energy and environmental engineering, *thermodynamics* is often synonymous

with *engineering thermodynamics*. Courses normally include and depart from the first three laws of thermodynamic, and include basic thermodynamic concepts such as system, processes, heat and work, and properties and phase change of pure substances.

According to Ballmer and Spallholz [3] *“the methodology of teaching engineering thermodynamics has not changed significantly since the late 19th century”*. This implies that the subject has been immune to the understanding and improvements in education/engineering education, which of course is not good even if it is only partly true. In addition, there is reasons to believe that engineering thermodynamics as a subject is not unique in this way. There are, however, studies that show that engineering thermodynamics education has changed, at least somewhat, the last years. Promotion of active learning, deep level approaches of learning and student engagement has been used with encouraging results the last years, see e.g. [3, 14, 15].

3. CONTEXT OF THE STUDY

The students of interest in this study were taking a course in Engineering Thermodynamics at the mid of their first year of a 5 year Master’s program at Linköping University, Sweden. The students in the course were either in a Mechanical Engineering program (130 students), or a program in Energy, Environment and Management (40 students). They had so far attended courses in Mathematics, Introduction to product development, and Computer programming. About 20% of the students were females.

Education in the programme are mainly carried out as lectures, lessons and laboratory sessions (when appropriate), although in some courses some of the lectures and/or lessons are replaced by seminars. In a typical engineering course, 40-50 % of the education is carried out as lectures, 40-50 % as lessons and 5-10 % as laboratory experiments. The traditional seminar at Linköping University can be seen as a mix of lecture and lesson.

The lectures are normally dominated by one-way communication from teacher to students as the students are supposed to listen and take notes. Asking questions is not at all prohibited, but not very common, thus this educational design makes the students’ relatively passive. During a typical lesson, 25% of the time is taken up by a summary during which the teacher briefly discusses theory and solves a few standard problems. The students then work with problems on their own, discussing problems with each other and with the teacher.

The laboratory sessions can be based upon “mechanical hardware” or be “computer labs”. Labs normally last 2-4 hours and consist of assignments solved in groups of 3-5 students. There are often some preparatory tasks for the students to work with before the lab, and they often write a report describing how they solved the tasks assigned and answer the preparatory questions etc. following the lab.

4. ENGINEERING THERMODYNAMICS

4.1 Course Content and Syllabus

Engineering Thermodynamics is a well-defined yet vast subject at the under-graduate level. When comparing available text-books and syllabuses from various universities, only small differences in content can normally be seen.

A typical content of a course in Engineering Thermodynamics, which also pertain to the present course, include the following:

- Definition and discussion of important parameters, e.g. pressure and temperature, and the “Zeroth” law of thermodynamics
- Definition and use of the thermodynamic systems (open and closed)
- Conservation of energy and mass, and energy transfer
- Properties of pure substances
- Phase change processes, and change in energy content during processes
- The First law of thermodynamics, and its application to various devices (cylinder-piston, compressor, heat exchanger)
- The Second law of thermodynamics, reversibility and irreversibility
- Entropy, isentropic processes, Tds equations
- Refrigerators and Heat Pumps
- Heat engines and power generating cycles (Otto, Diesel, Rankine and Brayton cycles)

The course lasts 7 weeks, and make up about 40% of the workload for the students during this period. The course content is presented at 9 lectures, of which 5 is held during the first 3 weeks and then 1 lecture per week. 11 lessons of 2 h follow the lectures are included during which a teacher show problem solutions (about 30% of the time), and students work alone or in small groups with problems (70% of the time). There is also a 2 h lab that deals with a simple heat pump. The project of interest in this study runs during the last 5 course weeks (see description below).

As can be seen from the course content above, engineering thermodynamics comprises a span from the most fundamentals laws of nature to models and applications of some of our most important machines. For this vast content, it is not possible to include the actual realization or technological aspects of the devices and machines of interest in an introductory course. It is important to strive towards this aim, for two reasons: i) understanding of the actual application and use of thermodynamics in relation to real situations is highly important for the work of future engineers, and ii) application to “real” devices and machines increase student motivation and thus learning. Projects comprising real machines and/or thermodynamic cycles have the potential to, at least partially, fulfill this aim.

4.2 Projects in Engineering Thermodynamics

4.2.1 Possibilities and Difficulties

An important part of engineering thermodynamics is the understanding of heat and power cycles and their processes, as well as their realization in “real” machines and devices. The problem is, however, that the “real” processes are quite complex, which makes it necessary to start studying idealized cycles and processes. Such cycles, however, cannot be realized, which limits

the possibilities for e.g. demonstrations and hands-on labs and projects.

Furthermore, the cycles of interest are e.g. the Diesel, Rankine and Brayton cycles, all of them being complex, potentially dangerous during hands-on experiments, and involve expensive equipment, which makes them difficult to use in “hands-on” experiments etc.

Another problem is that the processes and cycles investigated are highly influenced by heat transfer and fluid dynamics, areas in which students often have limited or no knowledge when entering courses in engineering thermodynamics, especially if it is the course is given during the beginning of the engineering education. An example of a problem this imposes is when discussing irreversibilities in the Rankine cycle – if the students have no or little knowledge of gas and fluid flow and e.g. flow losses, a deeper discussion of the irreversibilities is not possible.

To overcome the problems described above but still include a hands-on project, a project based on the compressor cycle has been developed. The compressor cycle is one of the fundamental thermodynamic cycles, and is used to move heat from a low to a high temperature, and is used in e.g. heat pumps and refrigeration applications. The compression cycle show several important similarities in its components and analysis of processes compared to the other major cycles – an understanding of this cycle is thus beneficial for a general understanding of processes and cycles in engineering thermodynamics.

4.2.2 The Compressor Cycle Project

In the compressor cycle project, students work in groups of 4-5 students with own measurements on standard refrigerators. The purpose of the project is to increase the students’ knowledge about:

- The compressor cycle and its processes (compression, condensation, throttling and evaporation)
- How the cycle is affected by heat transfer
- Temperature measurement and measurement errors
- Design and planning of experiments
- Documentation, presentation and analysis of measurement data

The project starts about 2 weeks after the first lecture. This means that all theory is not presented yet, but the students have to take command of their learning in order to be able to begin the project. The projects run for about 5 weeks.

The aim of the project is to estimate the Coefficient of Performance (COP) for the refrigerator for 2 cases:

1. Normal operation
2. “Affected” operation which can be one of the following
 - a. Insulation the condenser
 - b. Blow air through the condenser by a fan
 - c. Place a fan inside the refrigerator

The measurements that can be carried out is temperature as a function of time by thermocouples connected to a data logger/computer, instantaneous power and electric work used by

the compressor. Thus, neither the mass flow ratio nor the quality of the coolant can be measured.

To estimate COP by only measure temperature and power/work supplied to the refrigerator needs some consideration. The method employed is to carry out 2 measurements for each estimation of COP. From these measurements, the difference in power consumption can be calculated. This is then related to a difference in cooling power, which is determined by placing a known mass of water in the fridge and measure its temperature. See equations 1-4. In total, 2+2 measurements are necessary for the normal and affected operation.

$$COP = \frac{Q_{empty}}{W_{empty}} = \frac{Q_{empty} + Q_{water}}{W_{empty} + W_{water}} \quad (1)$$

$$Q_{empty} = COP \cdot W_{empty} \quad (2)$$

$$COP = \frac{Q_{water}}{W_{water}} \quad (3)$$

$$Q_{water} = mc\Delta T \quad (4)$$

Q_{empty} is the heat that leaks into the refrigerated space, W_{empty} is the compressor work during time t , W_{water} is the extra amount of work needed to cool the water, m is the mass of the water, c is the specific heat of water, and ΔT is the temperature difference of the water between start and end of the experiments. Q_{empty} is unknown, Q_{water} can be determined, W_{empty} and $W_{empty} + W_{water}$ can be determined.

It can be noted that the only measurements that needs to be carried out for each COP are the work corresponding to empty and with water, and the start and end temperatures of the water. This straightforward method rely on a large number of simplifications and approximations, for example that the temperature of the refrigerated space is constant and equal for the cases empty fridge and fridge with water, and that the temperature of the surrounding is constant. Despite the simplicity of the method, a COP is often obtained in the range $0.5 < COP < 1.5$ which are realistic values.

A very important part of the project assignment is to analyze the validity of the method, especially the impact of the necessary assumptions and simplifications. This is in part based on additional measurement of temperature as a function of time. For example, by measure the temperature inside the fridge, the condenser temperature and the temperature of the evaporator, a lot of information of the operation of the refrigeration can be obtained. The students should also relate to the theory of the course.

The lab where refrigerators and other equipment are located are open 24 hour a day all week (Monday – Sunday). Each experiment run for 4-12 hours, but it is not necessary to be present in the lab during this time, only for about 15 minutes at the beginning of the experiment to set up the measurement, and 15 minutes at the end to store measurement data etc. The students are free to plan their projects as they see fit. There are often students in the lab during evenings and weekends.

The project run for 5 weeks, and is examined by a written report of 12 A4 pages. After 4 weeks of the projects (about 1 week before deadline of the project report), a preliminary report is handed in by each group. This report is reviewed by another group, which means that all groups get feedback on their work.

Another effect is that the students get insight in the considerations employed by other groups, and that some experience in reviewing is obtained. The project work is graded by 1-3 points, that are counted in on the written exam at the end of the course. In order to pass the written exam, 22 points out of 50 are needed. About 75% of the students attending the course pass the exam on the first try.

5. EVALUATION METHOD

The students are interviewed in focus groups after about two weeks of the project. During the interview, the students' thoughts of the project were investigated. The interview was focused on aspects related to the students learning, although some questions were asked having project development in mind for future courses. The questions asked included if they were worth the time it took, what the project contributes with, and if/how the same knowledge could have been obtained in another way (e.g. using other forms of education) etc.

There was also a web based course survey at the end of the course. This survey is the same for all courses at Linköping University, although it is possible for the responsible teacher to add questions. The course survey is completely anonymous. The students were asked how they experienced the course, e.g. the teachers' performance, information obtained during the course, the examination and the overall opinion of the course. The survey is formulated by a number of positive statements, and the students answer by a number ranging from 1-5 where 1 means "do not agree at all", 2 means "disagree to some extent", 3 means neither agree nor disagree, 4 means "agree to some extent" and 5 means "fully agree". It is also possible to write comments in addition to the grade. Examples of the statements are:

- I am satisfied with my achievements during the course
- The efforts of the teachers in the course is commendable
- The assessment was a good test of my understanding of the course content.
- I am satisfied with the course literature
- The course has corresponded to my expectations regarding content and organization
- On a scale 1-5 (5 being the best) I give the overall credit to this course

For the purpose of project evaluation, a relatively broad question/statement focused on the project was added to the survey: "I think the project was good". The students were also encouraged to indicate what was good and what could be improved regarding the project. The intention by using a broad question was not to bias the question/answer in any direction, but instead let the students include what he/she felt most important in the answer.

The result from the interviews and the written course survey were analysed and discussed by the teaching staff. Similarities and differences in the students' opinions were noted. The results are illustrated by quotations, which serve as examples of the main opinion. Some interesting deviating opinions along with a discussion of the material are noted.

The results are divided into two sections based on the *students'* and the *teachers'* perspective, respectively.

6. RESULTS

6.1 Student Perspective

Of the 163 students attending the course, 64 (39%) chose to answer the course survey. The students were in general very satisfied with the project. For the statement regarding the project on the survey, “I think the project was good”, the mean grade was 4.1. The distribution of the result can be seen in Figure 1.

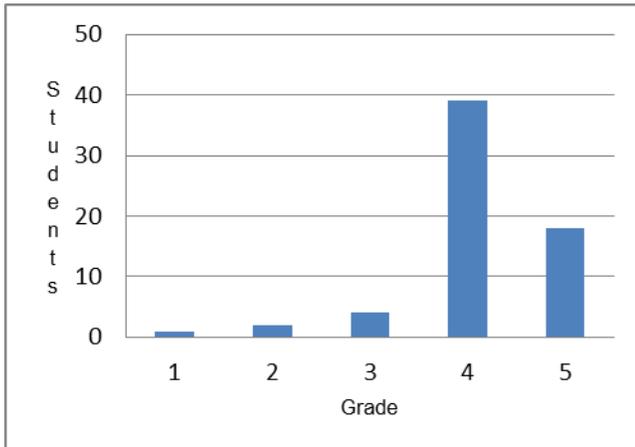


Figure 1: The result of the students grading of the project statement “I think the project was good”.

As can be seen in Figure 1, the vast majority (89%) of the students agreed to the statement (grades 4 and 5). A few of the students (5%) did not think the project was good (grades 1 and 2).

The following quotations illustrate the students’ view of the project. The main opinion of the students can be divided into three groups; *Motivation*, and *Theory, practice, and understanding*.

Motivation

“It became much more fun to study when not only theoretical things but the application and use of the gained knowledge was applied in reality”

“The motivation for studying was increased when the project was introduced”

“Working with a practical task in a project team increased my motivation. It was fun to work together, to vary out, analyze and discuss the measurements.”

Theory, practice and understanding

“After about two weeks of the project, I began to understand what the processes in the compressor cycle was all about.”

“The project gave a nice application of theory – I better understood the theory after the project, and also the relevance of the theory and simplified cycles.”

“The discussions in the group really increased my understanding of engineering thermodynamics.”

“The project included most of the theory of the course, and since everything was used at the same time I got a feeling for how things were connected.”

6.2 Teacher Perspective

From a teachers’ perspective, the project has provided several important aspects that would have been difficult to include otherwise. The discussions with the students during the project were both fun and interesting. The opinions of the students presented earlier mirror the teachers’ comprehension of the project.

One strong reason to include the project was to relate theory and its practical application, and to show that they are both important. Based on the supervision and discussions with the students throughout the project, it is clear that many students really grasped this, and that it appeared to improve their learning process.

It is clear that most students need something to relate the theory to. The compressor cycle is beneficial from this point of view, since all know what a refrigerator is, and how it is used (although they did not know much about its function before the course/project).

7. DISCUSSION

A project considering the compressor cycle in a first year course in Engineering thermodynamics has been investigated. Engineering thermodynamics is a fundamental subject that covers both theoretical and applied aspects that both are of utmost importance for future engineers. The intention with the project is to enhance the students learning by stimulate a deep-level approach to learning by including both theoretical and applied thermodynamical aspects in the same project.

Engineering thermodynamics has been described as “*dry and abstract*” by students in another study [2]. This is a problem from a deep-level learning perspective, since student motivation is one of the key issues for learning. One important aim of the project is thus to make the subject more interesting, less abstract, and thereby increase student motivation. The result shows that the majority of the students found the project interesting and inspiring, which facilitates deep-level learning. It is interesting to note that the students by themselves make the connection between theory, practice and understanding, and that theory and practice can cross-fertilize each other. The students also clearly expressed an improved understanding of “what engineering thermodynamics is all about” which is interpreted as a reduced abstractness. One of the reasons for this can be that the project is based on the compressor cycle of ordinary refrigerators that all students have actually seen and used before and consequently can relate to. To relate to what the students already know and are familiar with is pointed out to be an important aspects that facilitates learning according to Biggs [5]. This is also in line with an earlier study, where students clearly expressed the need for something to relate to when learning complex subjects [17].

Although projects in engineering education are scarcely something new, the subject exhibits some features that reduce the possibilities for larger projects; the real processes, cycles and engines at the core of the subject are complex on their own, and furthermore rely on knowledge in e.g. heat transfer and fluid mechanics. In addition, they are associated with expensive and potentially dangerous hardware. Despite this, some small projects for first course engineering thermodynamics has been described (see e.g. [11]), but most often the experimental investigation of full scale cycles has been carried out in form of demonstrations or laboratory practical’s, see e.g. (8, 14).

Comparing the type of questions asked during lessons and project supervision, a clear and present difference can be seen. During the lessons, when the students work alone with solving problems, they are very focused on solving the specific and clearly defined problems at hand. Although this is an important start when learning a new subject, it is important to proceed further, for example to reflect over the theory and its practical implications. The types of questions asked during lessons are often of the type: “How do I solve this problem”, “Why can’t this equation be used” or “What is wrong with my solution”. The teachers’ opinion is that these kinds of questions are important, but that they often are too focused on the relatively “narrow” problem at hand. During the project, on the other hand, the students are enforced to really understand how things are tied together – to understand “the whole picture”. Without the project, there is a risk that the theory becomes decoupled from what could be called practice.

The evaluation grade of 4,1 for the project is considered very good, and underlines that the students liked the project. The students were also satisfied with the course in a general sense (3.8 of 5 in overall rating of the course). Since the project grade is higher than the overall course grade, it is reasonable to believe that the probably contributes to a better overall course experience.

It would have been interesting to use a cross-sectional evaluation design, by having some students carry out the project and others to undertake some other education. Such an evaluation could for example focus on how a large project affects the overall experience of a course, and to investigate the knowledge gained from different kind of teaching/education. The latter would

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however be difficult to undertake in a fair way, since some of the experience gained during the project cannot be easily gained

during traditional education. This means that such an evaluation would include similarities and differences between education situations with embedded differences in the content the students are expected to learn.

8. Conclusions

It has been possible to use a full scale thermodynamic cycle as the basis for a project in Engineering thermodynamics for first year students with good results. The students considered the project both interesting and fun, which contributed to an increased motivation in learning Engineering thermodynamics. The project also contributed with an increased connection between theory and its practical application, which has decreased the students feeling that engineering thermodynamics is an abstract subject. The teachers experienced a change in the students’ attitude towards the subject. The type of questions asked associated with the project were more focused on understanding and how things were connected on a larger scale than on isolated aspects. Altogether, it can be concluded that the project was beneficial from a learning perspective, changing the learning process towards a deep-level approach.

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