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A Review on Enhancing the Teaching and Learning of Thermodynamics

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Abstract

Thermodynamics is a subject that deals with energy and is one of the most advanced tools for understanding our physical universe. Engineering students' difficulties in learning thermodynamics occur globally as indicated by the literature. There are various studies reporting on efforts made to overcome the deficiencies and suggestions of teaching approaches to enhance students learning such as blended learning approach, active learning techniques, computer-based instruction, virtual lab – a web-based student learning tool for thermodynamic concept related to multi-staging in compressors and turbines, TEST™ software in design projects and laboratory and so on. This paper presents a review and analysis of the different approaches on supporting students learning of thermodynamics. The criteria for analysis are the characteristics of the learning system, the effectiveness based on students' performance; the skill developed using the learning system, and students' feedback.

Keywords: Thermodynamics; teaching and learning thermodynamics; difficulties in thermodynamics

1. Introduction

Thermodynamics is related to the physical universe and plays an importance role in our lives. It is a fundamental course and has been an essential part of the global engineering curricula [1-2]. Engineers use thermodynamics principles in their study and design of a wide variety of energy systems, such as jet engines and rockets, refrigeration systems, air conditioning systems, chemical processes, automobiles, and power plants. Engineering students facing difficulties in learning thermodynamics occur globally as stated by many researchers

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[1-16]. In order to enhance the teaching and learning of thermodynamics, the approach to teaching thermodynamics has progressed from the traditional method to a more sophisticated method such as using computer technology and multimedia. Learning is a process of acquiring and synthesizing ideas and concepts. The process not only involves obtaining information but also full participation by the learner (student-centered learning) [17]. According to Moron-Garcia [18], the use of web or internet based technology can facilitate the creation of student-centered learning environment. Student-centered learning and learning environments designed with reference to constructivist theories of learning will produce in students the critical and cognitive skills that higher education aims to develop [18, 19].

This paper outlines the problems faced by students learning thermodynamics as well as reviews and analyses the different approaches in supporting students to learn and understand thermodynamics. The criteria for analysis are the characteristics of the methods of enhancement used; their effectiveness based on students' performance, the skill developed using the methods, and comments by students.

2. Problems Faced by Students Learning Thermodynamics

Many students have difficulties in learning thermodynamics for decades and quite a number of researchers have written on the issues. A quote by Arnold Sommerfeld [3] on the learning of thermodynamics:

> "Thermodynamics is a funny subject. The first time you go through it, you don't understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you don't understand it, but by the time you are so used to it, it doesn't bother you anymore."

The quote shows that thermodynamics is difficult to understand, even after going through the subject several times. This view is supported by Hassan and Mat [1] and Patron [4] that even after instruction; students retain significant misconception about thermodynamics principles. According to Patron [4], Junglas [5], Anderson et al [6], Meltzer [7], Cotignola et al [8], many students face difficulties in understanding basic concepts in thermodynamics. They have misunderstanding or misconceptions about terms such as work, heat, internal energy, enthalpy, entropy, first law of thermodynamics and their use for concrete applications. In teaching practices, Liu [9] found that most students were confused about how to properly determine the state of pure substances. Abu-Mulaweh [2], Patron [4], and Junglas [5] stated that there was a perception among engineering college students that thermodynamic is an impossibly difficult and most hated subject. This was reflected in poor final examination results of the students. The finding is supported by Bullen and Russell [10] that students at many UK universities tend to underperform in subjects such as thermodynamics. Baher [11] stated that both the learning and the teaching of thermodynamics were no easy tasks.

Students also face obstacles in mapping abstract, theoretical understanding of thermodynamic principles on to plant operation [12]. Kelly [12], found that visiting the real power plant did not help the students' understanding because the huge size of the plant makes it hard to conceptualize how the different cycles and components work together, and also by design some components of the plant were difficult to view. According to Huang and Gramoll [13], and Cox et al [14], topics in thermodynamics are abstract and difficult to visualize. Furthermore, with traditional teacher-centered educational approach engineering students sometimes learn theories that they cannot transfer to real situations, or have experiences that they cannot explain with the knowledge they have already obtained. Forbus et al [15] stressed that students lack intuition and treat thermodynamics problems as abstractions divorced from practical application. Students also face difficulties in retention of knowledge when traditional teaching method is used [1, 6, 13, 16]. According to Chaturvedi et al [16], students' learning through traditional approach is not effective in the twenty-first century. Students also have trouble in solving thermodynamic problems. Studies by Liu [9] indicated that some students cannot properly build an image of the problem and do not know how to start, therefore they struggle everywhere in solving the problem. Such common pitfalls associated with problem solving can result in difficulties as problems become more complicated.

3. Methods of Enhancement the Teaching and Learning of Thermodynamics

Due to the many problems face by students learning thermodynamics, various methods for enhancing the teaching and learning thermodynamics have been designed and developed. From 1993 to 2009 there are numerous published papers on the methods on enhancing the teaching and learning of thermodynamics. See Table 1. The list is in descending order of the year the articles were published. Besides, some thermodynamics text books such as written by Cengel and Boles [20] and Moran and Shapiro [21] had include CD-ROMs consisting of materials on the subject matter. Publishers such as McGraw-Hill also provide a courseware on thermodynamics that are accessible online.

Table 1. Methods of enhancement the teaching and learning of thermodynamics

Researchers	Methods of Enhancement
Liu	Instructional courseware in thermodynamics education. (2009)
Bullen & Russell	A blended learning approach. (2007)
Chaturvedi et al	Virtual assembly- a web-based student learning tool related to multi-staging in compressors and turbines (2007)
Junglas	Simulation programs to perform virtual experiments (2006)
Hassan & Mat	Active learning environment (2005)
Abu-Mulaweh	Portable experimental apparatus (2004)
Huang & Gramoll	Multimedia Engineering Thermodynamics (2004)
Cox et al	Teaching with physlets (2003)
Ngo & Lai	An online thermodynamic courseware (2003)
Kelly	A virtual power plant website (2002)
Anderson et al	Computer-based active learning materials (2002)
Kumpathy	TEST^{TM} software (2002)
Baher et al	Virtual lab- cyclepad (1999)
Weston	Interactive Thermodynamic cycles (1998)
Lewis et al	Computer simulation of experts (1993)

None of the developers of the methods listed in Table 1 stated that their methods were supported by learning theory. However, Huang and Gramoll [13] claimed using the same structure as Multimedia Engineering Statics which was supported by a learning theory when they developed Multimedia Engineering Thermodynamics.

An antidote for learning is to engage learners in active, constructive, intentional, complex, cooperative and reflective learning activities [22]. These characteristics are the goals of constructivist learning environments (CLEs). In the constructivist learning environments, learners engage in exploration, articulation and reflection; while instructors provide instructional support in modeling, coaching and scaffolding [19, 22]. Jonassen [19] stated that the essential components in CLEs include problem, question or project as the focus of the environment; related cases; information resources; and cognitive tools. Cognitive tools are computer tools that help visualize (represent), organize, automate, and enhance thinking skills. The focus on problem, question or project constitutes a learning goal driving the learning process. Three major components need to be included in the design of the problem: the problem context, the problem representation or simulation, and the problem manipulation space [19]. The representation of the problem should be interesting, appealing and engaging. Problem manipulation space provides meaningful learning in which learners are provided with opportunities to manipulate objects and interact with the environment. The related cases support learning by scaffolding student memory; providing different perspective, themes and interpretations; and enhancing student cognitive flexibility.

Out of the 15 methods listed in Table 1, only 2 methods do not use computer or multimedia. The methods are active learning environment [1] and portable experimental apparatus [2]. Although the remainder use computer technology and multimedia in their systems, each are different in their approach and design. However, all methods have a common goal of enhancing the teaching and learning of thermodynamics. A few methods give complete thermodynamics content such as in online courseware for use such as in lectures, as self-paced study, as reference material or as supporting exercises/exploration in classrooms. Others provide virtual laboratory experiences with different apparatus such as the power plant or thermodynamic cycles or multi-staging in compressors and turbines for the student to perform alone or in a group. Irrespective of the methods is web-based or CD-ROM, the multimedia used promotes interactivity and visualization.

4. Analysis of the Different Methods of Enhancement

The criteria for analysis are the characteristics of the methods of enhancement the teaching and learning of thermodynamics and their effectiveness based on students' performance, the skill developed using the methods, and comments by students.

4.1. Characteristics of the methods of enhancement the teaching and learning of thermodynamics

All the methods listed except two, used computer technology for the enhancement of the teaching and learning of thermodynamics. This is in line with current students' learning styles that are more interactive and visual. A study by Fowler et al [17] stated that 79% of engineering students are visual and 55% of them learn best actively. The advance in computer technology and multimedia can cater for this interactivity and visualization. However, each method of enhancement has its own characteristics as outlined below.

4.1.1. Without using computer technology

The methods without using computer technology are active learning environment [1] and portable experimental apparatus [2]. In the active learning environment, a lecture was conducted for the first part of the period detailing the theories involved and solved problems as illustration. During the second half of the period, volunteers would come up to the white board to solve problems followed with discussions on alternative approaches. Whilst in the portable experimental apparatus, a single stage vapour compression refrigeration system is used to demonstrate the concepts of thermodynamics such as the first law and second law. The objective was to help students understand the basic thermodynamic processes by using real-life applications.

4.1.2. With computer technology

Junglas [5] uses an interactive simulation program based on classical approach to perform virtual experiments with the purpose of providing insights into abstract concepts that can lead to better mental models as well as to engage students in active learning. There were 6 programs that deal with ideal gas laws and gas cycles only. Anderson et al [6] on the other hand developed active learning module on CD-ROM. The module includes interactive exercises, immediate feedback, graphical modelling, physical world simulation, and exploration. Interaction and exercises include narrative voice-overs and animations; interactive questions; short-response interactions; coaching interactions; and experimental simulations. Many of the screens contain cursor-over-popups to display additional graphics or information about the topic. The module seems to be developed with the support of the constructivist learning theory and covers all the topics in introductory thermodynamics.

Instructional courseware in thermodynamics education [9] was developed for solving 3 types of fundamental thermodynamics problems: determining gas status after specified processes; evaluating pure substance thermodynamic properties at given states; and analyzing power, refrigeration, and heat pump cycles. The courseware is very instructive and user friendly for data and information input. The presented program only provides basic governing equations for the cycles from the perspective of conservation of energy principle. Thus, it does not cover all the topics in introductory thermodynamics. Bullen and Russell [10] use a blended learning approach to teach thermodynamics to first year engineering students. The approach consists of lecture, tutorial, laboratory and supplemented by the use of a managed learning environment (MLE) and utilizing other opportunity of increasing cooperation and contact between students and students, and students and staff. This includes weekly assessed tutorials that are computer-aided to give rapid feedback to students, peer assessment of laboratory reports and just in-time teaching. It provides tools to enhance teaching and learning by delivering course materials and facilitating online communication, group work, and active learning. The blended learning approach seems to support the constructivist learning theory. Others had used cyclepad [11, 15, 27], an articulate virtual laboratory (AVL) that is user oriented and tends to be a self learning tool. Students can build, design and analyze thermodynamics cycles and receive coaching help. The software programs make conceptual tasks more accessible to students and provide explanation to the “how” and “why” of the science behind their design. The software serves as a monitoring aid during the problem solving process and free students from the burden of tedious numerical and algebraic manipulations. It also shows students the formulas underlying all the values which it calculates.

A virtual power plant website [12] was developed to help undergraduate mechanical engineering students understand thermodynamics principles through their exploration and manipulation of plant operations in a virtual learning environment. With this knowledge, students have the opportunity to solve practical problems by designing, analyzing, and manipulating the operations of a power plant. The 2 simulation packages used are realistic and provide motivation to the learners, provide student-centred activities, give reflection and collaborative construction of knowledge.

Huang and Gramoll [13] developed an interactive multimedia online e-Book to enhance the learning experience of students studying basic concepts in engineering thermodynamics. The e-Book is case-based and comprises of 42 real-world case problems with each case is presented in 4 parts: introduction, theory, case solution, and simulation. The fourth part provides an opportunity for students to experience a simulation by modifying parameters of the case problem and invoke students thinking. Movies, diagrams, graphics, animations, sounds and tables play an important role in the e-Book to help visualize and simplify abstract thermodynamics concepts such as enthalpy or entropy. The e-Book covers the same material addressed in a typical undergraduate engineering thermodynamic text book. Cox et al [14] also used interactive simulation software, a Physlet-based curricular material designed to help students learn concepts of thermodynamics with a particular focus on the use of kinetic theory models. Physlet exercises have simple animation allowing students to focus on the desired concepts. These exercises help students visualize ideal gas particles dynamics and engine cycles, and develop a conceptual framework for problem solving. The software helps students study thermodynamics by providing them with dynamic connections between graphs and thermodynamic processes, by modeling real-world applications, and changing the parameters of different systems.

Chaturvedi [16] developed an alternative web-based interactive learning tool for thermodynamics concepts related to multi-staging in compressors and turbines only and thus does not cover all topics in thermodynamics.

The system uses simulation and visualization software. The authors contended that students learning can be enhanced by creating visual images of complex thermodynamic devices and allowing students to relate these images to thermodynamic processes on temperature-entropy diagrams. The pedagogy used is "learning by doing in virtual environment". Using computer generated results and relevant equations, students calculate manually the final overall cycle efficiency. This keeps the students active in their interaction with the module.

Besides [9], Ngo and Lai [23] also developed an online thermodynamics courseware that presents the materials in a dynamic and interactive fashion. The course module contains detailed notes presented in a visually appealing manner with the use of interactive simulations, animations, and examples to reinforce concepts in the classroom. The courseware includes workshops to help students become familiar with the use of thermodynamics tables. Meanwhile Kumpaty [24] in his works, use software called expert system for thermodynamics (TEST™) for enhancing students' learning thermodynamics fundamentals. The TEST™ is interactive and is used in assignments, design projects and laboratory. Likewise, Weston [25] also developed software of visual and interactive models of thermodynamic cycles. The applications produced include air cycles, Rankine cycles, Brayton cycles, and vapor compression refrigeration cycles. Questionnaires for students, instructors or general users were developed via HTML for electronic feedback by users.

To remedy students' lack of ability to integrate thermodynamic concepts to the more complex phenomena and to increase the emphasis on understanding, Lewis et al [26] used the computer as Lab Partner (CLP) curriculum. It consists of an 11- week microcomputer-based study of thermodynamics properties and variables and includes simulations of problems encountered in students' daily lives. Students integrated experiments using real time data collection with simulated experiments and later made prediction and reflection.

4.2. Effectiveness of the learning systems

Most of the researchers claimed that they obtained positive results when applying their methods of enhancement. The effectiveness of the learning systems is divided into students' performance, skills developed, and comments by the students.

4.2.1. Students' performance

Of the 15 methods of teaching and learning enhancement as listed in Table 1, 6 did not mention students' performance using their methods. They are courseware in thermodynamics education [9], multimedia engineering thermodynamics [13], physlets [14], virtual power plant [12], thermodynamics cycle using HTML and JavaScipt [25], and portable experimental apparatus [2]. They described mainly the development and the operation of the methods as well as their advantages. The remainder of them stated improved students' performance.

According to Bullen and Russell [10], the adoption of the blended learning approach has resulted in an improved students' performance as measured by their final examination results. From 2000 – 2004, the percentage of students achieving the minimum examination pass mark has improved from 49% to 77%. For the web-based student learning tool related to multi-staging in compressors and turbines [16], there was a 14% improvement in the average score of a quiz administered for the group using the module over the group without the exposure to the module. According to Junglas [5] students using simulation programs to perform virtual experiments, take a more active part in the lecture, mainly due to the hands-on approach that complements the theoretical section. As a consequence the average score of the final examination has increased. The application of active learning environment even without the computer-based instruction [1] resulted in no failure in the final examination of this group of students compared to the group taught using conventional method of teaching that have 4% failures. The number of students obtaining grade A's was higher in the active learning class. For the application of active learning technique to computer-based instruction for introductory thermodynamics course [6], the test performance has been positive. For the online thermodynamic courseware [20], students also have a better understanding of the subject as shown by scoring better in their examination.

Lewis et al [26] carried a thorough assessment on students' performance. The post-test showed that the students displayed understanding of general, real-world questions and did very well at explaining naturally occurring phenomena. Students displayed more integrated understanding than any previous semesters. There was a greater improvement in students' ability to provide explanations (63.9% pre-test to 83.1% post-test). Students also showed statistically significant improvement from pre-test to post-test on conductors and insulators. Most methods claimed that students understand better basic thermodynamics laws and principles, and able to enhance the learning experience of students.

4.2.2. Skills developed

The methods for enhancing teaching and learning thermodynamics provide students skills such as problem solving, designing, team working and so on, depending on the methods of enhancement used. Table 2 summarizes the skills developed using the various methods.

Table 2. Skills developed by students

Methods of teaching and learning thermodynamics	**Skill developed**
Blended learning	Problem solving
Cyclepad	Problem solving
Virtual assembly in compressors/turbin	Problem solving
Cyclepad	Designing
Virtual assembly in compressors/turbin	Designing
Active learning environment	Interactivity
Simulation program for virtual expts.	Interactivity
Computer-based active learning	Interactivity
Courseware in thermodynamics education	Interactivity
Blended learning	Interactivity
Cyclepad	Interactivity
Virtual power plant website	Interactivity
Multimedia engineering thermodynamics	Interactivity
Virtual assembly in compressors/turbin	Interactivity
Online thermodynamics courseware	Interactivity
TEST^{TM} software	Interactivity
Interactive thermodynamic cycles	Interactivity
Computer simulation of experiments	Interactivity
Virtual power plant website	Team working
TEST^{TM} software	Team working
Computer simulation of experiments	Team working
Online thermodynamics	Thermodynamics property
Courseware	Tables
Courseware in thermodynamics education	Thermodynamics
Education	Property tables
Blended learning	Deep approach learning
Portable experimental apparatus	Not stated

Problem solving skill is developed using instructional courseware in thermodynamics education [9], blended learning [10], cyclepad [11, 15, 27], virtual assembly [16], and online thermodynamics courseware [23]. Cyclepad made students more systematic when approaching a problem, helped students in tracking their errors and thinking about their modelling assumptions. Students are able to calculate the final overall efficiency of the cycle manually by using virtual assembly. Cyclepad [11, 15, 27] and virtual assembly [16] developed designing skill in students. Cyclepad helped students in visualizing, simulating, analyzing and designing cycles. Students were able to complete complex designs that exceeded their knowledge. Virtual assembly enabled students to assemble a multistage compressor and turbine. Methods that employ interactivity in the systems developed interactivity skill in students [1, 5, 6, 9-13, 15, 16, 23-26]. On the other hand, methods that required working in groups developed team working skill in students. Students developed skill in obtaining the properties of thermodynamics tables using the interactive workshops of thermodynamic courseware [23] and from the software of instructional courseware in thermodynamics education [9] and interactive thermodynamic cycles [22].

Computer simulation of experiments [23] developed students' ability to reflect, to apply scientific ideas to complex ambiguous situations, to compare the result of laboratory investigations to every day observations, and to predict prediction curves based on real time experiments. Students developed a deep approach to learning when using the blended learning method compared to students who barely used the system. Portable experimental apparatus and teaching with Physlets did not mention any skill developed by students.

4.2.3. Students comments

Many students gave comments on the methods they used on enhancing their learning of thermodynamics. Almost all gave favourable remarks as shown in Table 3.

Table 3. Comments by students

Methods of teaching and learning thermodynamics	**Comments by students**
Active learning environment	Positive on interaction and assessment
Computer-based active learning	Positive on materials Comprehensibility
Blended learning	Positive on the discussion forum
Cyclepad	Positive on excitement of learning, easiness using the software, understanding of cycles, and time consumption Negative on working with computers
Physlets	Positive on interactivity, visualizing and understanding concepts
Online thermodynamics courseware	Positive response from Students for reviewing notes & assignments' solutions
TEST^{TM} software	Positive on learning, problem solving, and continue usage in engineering practice
Interactive thermodynamic cycles (HTML)	Positive on as learning tool, delivery of thermodynamics fundamentals, examination preparation Negative on substitution for actual hands-on experience
Computer simulation of expts.	Positive on learning experience, enjoyment, excitement, and teamworking
Portable experimental apparatus	No comments
Virtual power plant website	No comments
Multimedia engineering thermodynamics	No comments
Virtual assembly in compressors/turbin	No comments
Courseware in thermodynamics education	No comments
Simulation programs to perform virtual experiments	No comments

On active learning environment [1], students gave good to excellent remarks on interaction between lecturers and students, and on assessment. On computer-based active learning [6], 84% of the students commented that the materials presented were comprehensible. Two third of students interviewed commented that the discussion forum in blended learning [10] were useful. A number of the students interviewed identified the provision of more worked examples as the way to improve the module used in blended learning.

Students commented on cyclepad [11, 15, 27] as 'fun and exciting', 'the software is easy to learn', and 'they learn more because they do more'. Some students felt that by constructing and analyzing a complete cycle they had a better understanding of the cycle. Students also mentioned that cyclepad helped them see the relationship between parameters, gave them more accurate answers, and less time spent on calculations. Although most students felt cyclepad helped them to understand thermodynamics system better, however, a few students gave negative responses such as 'frustrating to work with computers and computers were too slow'.

Students comments on the interactivity and feedback from Physlets [14] as follows: 'Wow – this is the coolest thing that I've ever seen'. Over 70% of students surveyed either agreed or strongly agreed with the statement that 'the exercise helped me visualize and understand concepts presented'. Students also claimed that they can differentiate the different thermodynamic processes.

Online thermodynamics courseware [23] received overwhelming response from students. Students found it helpful to review notes from any missed classes and obtain solutions for homework assignments. Students also commented that the table wizard was very useful in obtaining thermodynamic properties.

Students' feedback on TEST™ software [24] has been very affirming. Some comments are as follows: 'I wish I had known about this software exists a year earlier', 'I will use the software in my workplace after I graduate', 'TEST™ has made my learning easier and I will continue to use it in my engineering practice', 'thanks for introducing me to such fantastic tool to solve thermodynamics problems', and 'the software guides your thinking on how to attack thermodynamics problems correctly and efficiently'. None of the 120 students introduced to TEST™ have said they disliked its use.

Students comments on thermodynamics cycle using HTML and JavaScript[21] include: 'I am very impressed', 'very helpful especially for students learning the material for the first time', 'increase my appreciation of computer programming', 'very interesting and could see its use in preparing for examination', 'informative, an excellent learning tool', 'an asset for examples to the situations we had in class', and 'had merit in enhancing the delivery of thermodynamics fundamentals'. However, a majority of students stated that such tools could not be a substitute for actual "hands-on" experience.

According to Lewis et al [26], students were remarkably positive about the use of the Notebook. On questionnaire given to students, 84% of students stated they liked using the notebook from 'medium' to 'a lot'. Students made comments such as 'excellent', 'great, a wonderful idea', 'it was fun and also a learning experience', 'a new kind of learning and I enjoyed it', 'fun, we learned a lot, but still had a good time', 'we liked the way the computer did the actual experiment based on real time experiment', 'easy to use, we liked predicting the result, making graphs, and finding out if we were right or not', and 'we liked the teamwork'. However, there were students who gave comment that they were bored with the program, although they had fun sometimes.

Methods that did not gave students comment were portable experimental apparatus, simulation programs to perform virtual experiments, instructional courseware in thermodynamics education, a virtual power plant website, multimedia engineering thermodynamics, and virtual assembly – a web-based student learning tool related to multi-staging in compressors and turbines [2, 5, 9, 12, 13, 16].

5. Conclusion

Many engineering students globally face difficulties in learning basic/introductory thermodynamics. This led to a numerous researches on developing and implementing various methods to enhance students' learning of thermodynamics. Most of the methods developed use computer technology and multimedia to give interactivity and visualization. The methods do improved students' performance and developed skill among students. The feedback and comments from students were positive and encouraging.

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