AC 2008-2251: TEACHING ENHANCEMENT IN UNDERGRADUATE THERMODYNAMICS II

X. Chang Li, Lamar University

Kendrick Aung, Lamar University

Jiang Zhou, Lamar University

Xuejun Fan, Lamar University

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Abstract

One of the core courses for most of the undergraduate students in Mechanical Engineering is Thermodynamics II, which, as an extension of the basic knowledge in Thermodynamics I, generally covers the typical cycles and processes for power generation, refrigeration, and air conditioning. To enable the students understand the fundamental concepts more easily, this paper discusses a list of enhancement in teaching this course. For example, there are many gas power cycles, such as Carnot cycle, Otto cycle and Diesel cycle. Presenting each cycle one at a time makes it very difficult for students to memorize the difference. However, it is seen that all the well-known reversible cycles (Carnot, Ericsson and Stirling) can be integrated into one T-s diagram (or a P-v diagram) so that the students can learn and remember these cycles by comparing them to each other. Similar integration can also be made for the standard ideal cycles, i.e., the Otto, Diesel, and Brayton cycles. Another example is that when the various air-conditioning processes are introduced, one point in the middle of psychrometric chart is usually selected as the reference point. An arrow from the reference point to the left is labeled as cooling and to the right as heating. An alternative is to make an arrow to the reference point from the left as heating and from the right as cooling. In this way, the reference point will represent the desired conditions, and all the arrows to the reference point will be the tasks to be done for different surrounding conditions. Different groups of students are surveyed to assess the improvement, and the students' feedback is included in this paper. Additional consideration to reinforce the teaching/learning process is also covered.

Introduction

Thermodynamics is an important curriculum for undergraduates in Mechanical Engineering, and it is often taught in two semesters: Thermodynamics I covers the basic concepts and principles while more practical items, such as different gas and vapor power cycles, the refrigeration cycles and air conditioning processes, are discussed in Thermodynamics II. As in many other subjects, instructors of thermodynamics have been searching a better way for the teaching/learning process. For example, Lype[1] in 1976 tried to incorporate more mathematical formulation in the fundamental Clausius-Thermodynamics, although the reversible processes, mechanical cycles, and the properties of specific substances were strictly classified into the area of applications. In recent years the discussion on this topic became even more active due to the modern Internet technologies and software development. New methodologies have been proposed and techniques on instructing some special concepts are also presented.

As a general instructional pedagogy to help students develop self-confidence and creativity, the problem-based learning (PBL) has been tested in the teaching of thermodynamics. Learning is implemented through asking and obtaining answers for questions that are open-ended and challenging. Carlson[2] applied the problem-based learning (PBL) approach to teach the first course in Chemical Engineering Thermodynamics. PBL approach was compared to an active learning approach and a traditional lecture in terms immediately before and after the PBL term by examining the student learning through traditional tests specifically structured to assess the first four levels on Bloom's scale of higher learning: knowledge, comprehension, application, and analysis. It was observed that PBL was at least as effective as the other teaching techniques. However, teaching ratings were significantly lower for the PBL course than for either straight lecture or active learning approaches. Nasr[3] presented the implementation of PBL curricular materials (modules) in Engineering Thermodynamics. Thermodynamics was restructured as teaching modules: Applications were talked first whereas principles were introduced just-in-time and as encountered. Theoretical information was presented to support the understanding of knowledge as students applied the inquiry-based learning. Steps and challenges in implementation were documented together with the assessment data. Alvarado[4] showed a case study on the problem-based learning approach, where course and laboratory activities were organized, aligned and coordinated so that the students could logically and actively participate in the learning process. The self-guided experimental task was used to encourage students to apply the concepts learned in the course. Knowledge of curve fitting, error propagation, electronic data logging and sensor calibration was introduced in the same time. Students were then required to apply the thermodynamic laws to experimental data analysis.

The past few years are marked with the significant advance in web and multimedia technologies. How to take advantage of this advance for teaching thermodynamics inspires many educators. Ngo and Lai[5] developed a web-based module for thermodynamics to present course materials in dynamic and interactive ways. The courseware also included a review section to help students in preparing the Fundamentals of Engineering (FE) Exam. The course materials delivered in a visually appealing way over the Internet could attract more students' attention. Favorable responses from students were reported. Baker[6] developed a web-based learning resource named ThermoNet for introductory Thermodynamic classes, including the use of interaction, animations, and movies. These functions are relatively difficult through the instructional techniques. Qualitative feedback on this technology obtained from both a questionnaire administered by the instructor and an evaluation conducted by an independent evaluator was reported. Huang and Gramoll[7] described the development, implementation, and functionality of an interactive multimedia online eBook designed to enhance the learning experience of students in studying basic concepts of engineering thermodynamics. The eBook was comprised of 42 case problems and each case covered a specific concept in engineering thermodynamics. The students could learn from each case the required concepts, procedures to solve the case problem, and variation of the problem through simulation. Graphics, diagrams, animations, sounds, and hypertext were used to exhibit these materials in an interactive and dynamic way.

Very similar to the web-based applications, software has also been developed for purpose of thermodynamics teaching. Jolls[8] created an interactive computer program to produce pictorial views of pure-fluid pressure-volume-temperature surfaces and to show the trajectories of the common thermodynamic processes as they appear in such surfaces. Karimi[9] discussed the benefits associated with the use of computer software in introductory thermodynamics courses. Available software tools were compared for their strengths and limitations. How to integrate the software tool into thermodynamics courses was also demonstrated through example software. Chavela Guerra et al.[10] discussed how to ask students to develop their own software before the gradual exposure to the commercial simulators, which are generally a black box to the students. In this way, the students can have an opportunity to understand the concepts and procedures involved in numerical solutions. Multi-years assessment showed that this approach could help students to expand and enrich the theoretical and practical understanding of classical Thermodynamics. More software applications are reported in other papers[11-13].

Except for the PBL and computer-based approaches discussed above, educators have also adopted many detailed and specific techniques in teaching thermodynamics. Falconer[14] discussed the impact of "conceptests" in thermodynamics course and the instant feedback from these tests. It was observed that students liked the conceptests as they got instant feedback on how well they understood the material. As a result, the students' conceptual understanding and performance were improved. The instructors also benefited from the conceptests to check how well the class understood the concept. John Dartnall and Reizes[15] outlined a model with simple particle, and the particle represented the thermodynamic fluid (gas) in a heat engine (exemplified by a piston engine). The model was used to demonstrate the connection between the Carnot efficiency limitation of heat engines and the 2nd law Kelvin-Planck statement. Foley[16] described a teaching approach whereupon a "catch all" general control volume was introduced as the primary tool as the course started. The change of any property within the control volume was shown as a result of three possible processes: direct transfer across a boundary, direct transfer in conjunction with "carrier" flows, and generation within the control volume itself. The generalized Reynolds Transport Equation was then formulized from this scenario. The paper also considered the property of entropy, which is conceptually more challenging. The approach was found beneficial for students learning. Bailey[17] discussed how to prolong and strengthen students' interest in thermodynamics by designing course projects. Two course projects were reported. The projects had been used for many years and were approved effective. The first project was to ask each student review a technical paper in writing and give an oral presentation in class; the second one was a team project for Advanced Thermodynamics, and each team was required to create and present a fifteen- to thirty- minute presentation/demonstration for a non-technical audience of their choice. More details about the projects feedback and assessment results were included in the paper.

Based on the literature review above, although not a complete one, it is observed that many of the papers are for the introductory thermodynamics. In addition, only few topics on how to improve instructional teaching are discussed. However, it is believed that the instructional teaching is still the most common approach in classes. In fact, the benefit of each methodology may be different from student to student and school to school. An integration of these approaches together with personal experience and students' feedback can be more suitable. This paper documents some of our experience in teaching Thermodynamics II for undergraduate, and effort has also been made to evaluate the efficiency of different methods.

Methodology

The items adopted to improve our classes are presented in this section. Most of the experience is from instructional teaching with a target for interactive and effective teaching/learning process. More specifically, it includes materials summarization and integration, interaction with students, and assignment of course projects. The authors maintain a regular discussion to keep the feedback updated and approaches adjusted. The popular textbook by Cengel and Boles[18] is used for the course.

1. Effective Integration and Summary

In general, the instructors know very well the course materials they teach, while it is difficult for the students to recognize the new “faces” and link them together effectively. In a certain degree, how to educate students in a way that they can understand easily may take the most time of the instructors. Rather than presenting the textbook item by item, it is always good to show the students all the relationship and summarize the materials in a creative way to promote the students’ understanding. An appropriate assessment is for sure needed.

1.1 Example 1

There are many gas power cycles, such as Carnot cycle, Otto cycle and Diesel cycle. In most cases, the textbook discusses each of them and shows the process in a P-v and/or a T-s diagram. The diagrams can help the student to understand and memorize these cycles. However, the students may become confused to remember these curves because all the curves are quite new to them. To help the students in learning these cycles, it is seen that all the well-known reversible cycles (Carnot, Ericsson and Stirling) can be integrated into one T-s diagram (or a P-v diagram). Figure 1 shows the individual diagrams of the three reversible cycles, which can be found in a textbook easily. Figure 2 shows the P-v and T-s diagrams after integrating these cycles into a single diagram. With the aid of different colors and symbols, it is expected that the integrated diagrams provide a help to the students. As shown in the figure, 1-2-3-4 is the Carnot cycle, 1-2-3’-4’ is the Stirling cycle, and 1-2-3”-4” is the Ericsson cycle. The lines with colors of red, blue and green are to differentiate the three cycles.

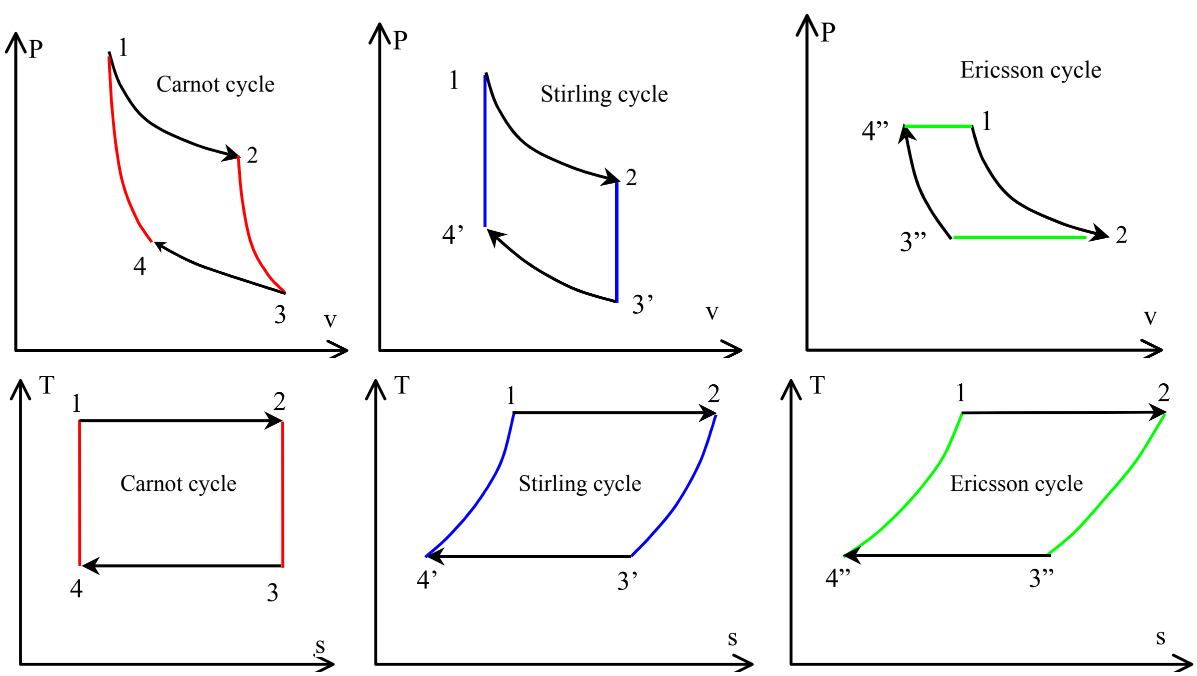

Figure 1 P-v and T-s diagrams for different reversible cycles

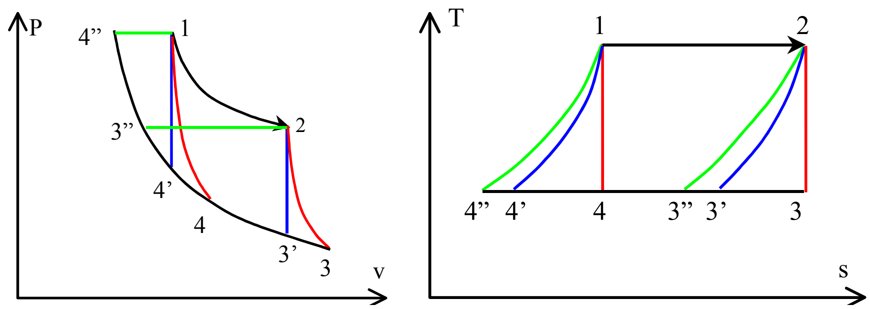

Figure 2 Integrated P-v and T-s diagrams for different reversible cycles

It is interesting to see that similar integration can also be made for all the common ideal cycles, i.e. the Otto cycle, Diesel cycle, and Brayton cycle. Figure 3 shows the case for these ideal cycles, where 1-2-3-4 is the Otto cycle, 1-2-3’-4’ is the Diesel cycle, and 1-2-3”-4” is the Brayton cycle. Unlike the reversible cycles, it is difficult to use lines in different colors for different cycles since some lines and points are overlapped. However, it is observed that the Diesel cycle occupies the smallest area in the middle. Adding one piece on the top changes the Diesel cycle to the Otto cycle, and adding one piece to the bottom makes the Brayton cycle. Note that the integration is just for learning purpose, and we are not seeking any physical meaning about it or any connection between these cycles.

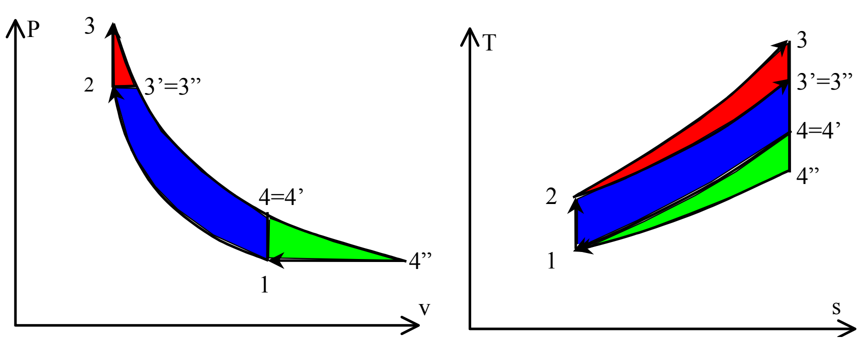

Figure 3 Integrated P-v and T-s diagrams for different ideal cycles

A simple questionnaire is designed to assess this modification, and Table 1 lists the questions as well as the survey result. Based on the survey, more than 69% of the students responded with a positive answer. In particular, the integrated diagrams can help the students to have a better understanding of the different cycles. These results show the success of this improvement.

Table 1 Questionnaire and survey result for the integrated cycle diagrams

Questions: Compared to the individual figure for each cycle, the integrated figure can help you	# of students	# of “Y” answers	% of “Y” answers
(1) Understand the different cycles better (Y/N)	29	23	79%
(2) Memorize the cycles easier (Y/N)	28	21	75%
(3) Make the cycle comparison easier (Y/N)	29	20	69%

1.2 Example 2

When the various air-conditioning processes are presented, a certain point in the middle of psychrometric chart generally serves as the reference point. Starting from the reference point, an arrow to the left is usually labeled as cooling and to the right as heating. Figure 4 shows the typical processes. An alternative is to make an arrow from left to the reference point as heating and an arrow from right to the reference point as cooling. In this way, the reference point will represent the desired conditions and all the arrows to the reference point will be the tasks needed for different ambient conditions. This concept is illustrated in the right panel of Figure 4. A survey was conducted on whether the proposed modification can help the students understand better the air conditioning concept. One third of the students responded with a "yes" answer. Another third of the students said that they could learn the concept from either of the two graphs, and the original graph is good enough for the rest of the students. Therefore, it is concluded that the new figure can benefit at least one third of the students, although not all of them.

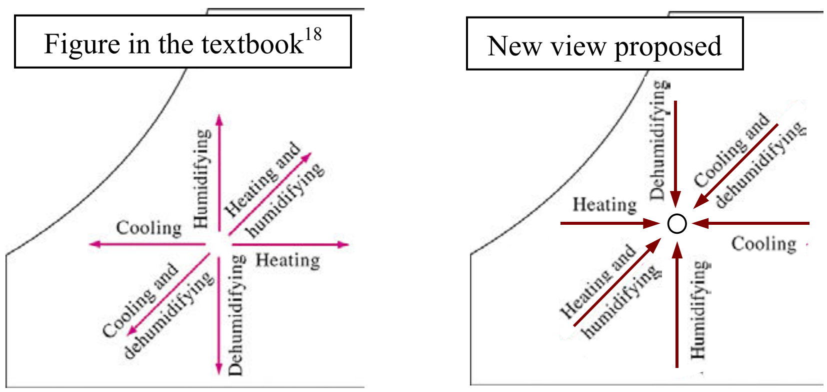

Figure 4 Different views of air conditioning processes on Psychrometric chart

2. Interactive Teaching with Multiple Feedback Channels

Computer-based approaches can easily implement interactive teaching by animation, movies, and simulation. In some degree, the interactive method can also be introduced to instructional teaching. The key issue is the on-time feedback from students and the quick response from the instructors. Appropriate adjustment needs to be made according to the feedback if necessary. Multiple feedback channels have been established for the authors' classes, which include weekly short quizzes (as called "conceptest" in [14]), class surveys, and working through examples in groups during class time.

Weekly short quizzes are designed for basic concepts with a form of either multiple-choice or true/false problems. There are usually 5 to 10 problems for each quiz, and it only takes about 5 to 10 minutes. Discussion on the answers is followed so that the students know why they are wrong or right. A survey showed that over 90% of the students consider the quiz a big help for their study. Although these questions are very simple, the students may still make mistakes. Below are two examples. It is obvious that the answers should be (F) and (d).

Example 1: Heat transfer is always accompanied with exergy transfer. In addition, the directions of heat and exergy transfers are always the same. (T/F)

Example 2: Which of the following **cannot** improve the gas turbine cycle?
(a) Increase T_{inlet} (or T_3) (b) Increase $\eta_{turbine}$ or $\eta_{compressor}$
(c) Apply regeneration (d) Preheat inlet air to the compressor.

There is no doubt that the instructor can get feedback from chatting with students. A well-designed class survey can collect more comprehensive information on the teaching/learning process. Survey problems can include how much the students like the course, how many hours the students spend on the homework, and whether the students prefer class power-point presentation or black-board presentation, etc. Based on the answers to the survey, the instructor can see the difference between his/her expectation and the student performance. For example, a survey result may show that the students only spend 0.5 hours in average to review the materials, which is much less than what the instructor expects.

Working through example problems during class time can also become fairly interactive. The students are asked to work in groups for a specific problem. Practice shows that many times their answers are different from each other so that they will actively discuss with their teammate and figure out the reason. Correct solutions need to be provided for students to validate their calculations. Based on the information from class survey, students are always expecting more examples in class, although the total class time is limited.

3. Open-end Course Projects

In the second half of the semester, students are required to work on an open-ended course project in a team. The project is usually to design one thermodynamic cycle and research the effect of all the parameters on power output as well as thermal efficiency. However, the students are strongly encouraged to fit the design into one of the actual cycles listed in the project sheet, for example, GE gas turbine. Certainly, any reasonable assumption can be made to complete the analysis if there is not enough information available. The open-ended project serves as an effective teaching approach in the following ways.

- The students need to review and have a good understanding on the cycle.
- Computer-based design tools can be applied, for example, the CyclePad software. They may also need to write their own code to complete the calculation.
- The students can learn how to gather related data by searching the Internet, calling vendors, and reading reference books.
- The project can foster students' creative thinking because they need to make their own assumptions. Unreasonable assumptions will lead to an unrealistic result.
- The students learn how to evaluate/criticize their results. For example, a student obtained a temperature of 5000K in the combustor chamber, which is obviously too high. He checked many different items before he could find his mistake.
- The project can also train the student for report writing and presentation.

All the items above will eventually help build the students' self-confidence and ability to face the real-world problems. Assessment shows that most of the students can achieve significantly by working on the project. As an example, one group of students studied the cycle of Chevy V8 325 engine and compared their analysis with the ideal Otto cycle under similar conditions. They found that the efficiency of the actual engine is about 30% while the ideal case has an efficiency of 56%. All the factors on thermal efficiency and potential losses were analyzed in their report. More surprisingly, the group listed 17 references, including on-line articles, engineering handbooks, and other textbooks. It is clear that the students worked hard on the project and they learned from the project.

Conclusions

With a focus on instructional teaching of Thermodynamics II for undergraduate, this paper discusses some practical approaches to enhance the teaching/learning process: Effective integration and summarization, interactive teaching with multiple feedback channels, and open-end course projects. Assessment results are also documented to evaluate the enhancement. The following conclusions can be reached.

(a) The integration of P-v and T-s diagrams of gas power cycles successfully helps the students understand and memorize both the reversible and ideal cycles, which are critical for Thermodynamics II.
(b) The interactive instructional teaching can be implemented through with multiple feedback channels. Short conceptual quizzes, class survey, and working on example problems in team during class time are approved effective.
(c) The open-end course project inspires the students and helps them build their ability and self-confidence to tackle real-world problems.
(d) An integration of different teaching approaches together with personal experience and students' feedback can be more promising.

Bibliography

1 Lype, E. F., "New Approach to the Teaching of Thermodynamics," Institute of Physics Conference Series, pp. 149-152, 1976
2 Carlson, Alfred, "Using problem based learning to teach Thermodynamics: The good, the bad, and the ugly paper 2005-2092," Proc. of ASEE Annual Conference and Exposition, pp. 15355-15367, 2005
3 Nasr, Karim J., "Implementation of problem-based learning into engineering thermodynamics," Proc. of ASEE Annual Conference and Exposition, pp. 7619-7635, 2005
4 Alvarado, Jorge, "Design your own thermodynamics experiment, a problem-based learning approach in engineering technology," 113th Annual ASEE Conference and Exposition, Chicago, IL, Jun. 18-21, 2006
5 Ngo, C.C. and Lai, F.C., "Teaching thermodynamics with the aid of web-based module," Proceedings of ASEE Annual Conference and Exposition, pp. 9635-9643, 2001
6 Baker, D., "Using ThermoNet, a web-based learning resource, for teaching thermodynamics," 31st Annual Frontiers in Education Conference- Impact on Engineering and Science Education, Reno, NV, Oct. 10-13, 2001
7 Huang, Meirong and Gramoll, Kurt, "Online interactive multimedia for engineering thermodynamics," Proceedings of ASEE Annual Conference and Exposition, pp. 10661-10671, 2004

8 Jolls, Kenneth R., "Teaching thermodynamics through interactive computer graphics: Announcement of a new computer program," American Institute of Chemical Engineers, National Meeting, New Orleans, LA, Mar 6-10, 1988
9 Karimi, Amir, "Use of interactive computer software in teaching thermodynamics fundamental concepts," ASME International Mechanical Engineering Congress and Exposition, Orlando, FL, Nov. 5-11, 2005
10 Chavela-Guerra, R., Alarcon-Garcia, A., and Rios-Casas, L.G., "Teaching thermodynamics through software development", AIChE Annual Meeting and Fall Showcase, Cincinnati, OH, Oct 30-Nov 4 2005
11 Lebiedzinski, K. and Bau, H. H., "Teaching undergraduate thermodynamics with mathematica," Winter Annual Meeting of the American Society of Mechanical Engineers, Atlanta, GA, Dec. 1-6, 1991
12 Uddin, M. and Kuntscher, J., "Simulation and data visualization of reversible and irreversible processes in thermodynamics classroom teaching," ASEE Annual Conference Anaheim, CA, Jun. 25-28, 1995
13 Rothberg, G. and Boytchev, P., "SoftLab virtual laboratory environment. Thermodynamics examples," Annual ASEE Conference and Exposition, Honolulu, HI, Jun. 24-27, 2007
14 Falconer, J. L., "Use of conceptests and instant feedback in thermodynamics," Chemical Engineering Education, v. 38, pp. 64-67, 2004
15 John Dartnall, W. and Reizes, J., "A novel approach to the teaching of thermodynamic cycles and the laws of thermodynamics," ASME International Mechanical Engineering Congress and Exposition, Orlando, FL, Nov. 5-11, 2005
16 Foley, A., "Applying the "catch all" general control volume and the Reynolds transport equation to improve thermodynamics instruction," Annual ASEE Conference and Exposition, Chicago, IL, Jun. 18-21, 2006
17 Bailey, M., "Enhancing lifelong learning and communication abilities through a unique series of projects in thermodynamics," ASEE Annual Conference and Exposition, Honolulu, HI, Jun. 24-27, 2007
18 Cengel, Y. A. and Boles, M. A., Thermodynamics: An Engineering Approach, McGraw Hill, 6th edition, 2007