120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013
ATLANTA

Paper ID #8096

Understanding the Continued Poor Performance in Thermodynamics as a First Step toward an Instructional Strategy

Prof. Nihad Dukhan, University of Detroit Mercy

Nihad Dukhan is an Associate Professor of Mechanical Engineering at the University of Detroit Mercy, where he teaches courses in heat transfer, thermodynamics, fluid mechanics and energy systems. His ongoing research interests include advanced cooling technologies for high-power devices with focus on metal foam as the cooling core, service learning and other engineering education pedagogies. Dr. Dukhan earned his BS, MS, and Ph.D. degrees in Mechanical Engineering from the University of Toledo.

Dr. Mark Schumack, University of Detroit Mercy

Mark Schumack is Professor of Mechanical Engineering at the University of Detroit Mercy, where he teaches courses in heat transfer, thermodynamics, fluid mechanics, and energy systems. His ongoing pedagogical interests include developing ways to teach energy conservation and sustainability principles. His research interests include thermal/fluid modeling using computational techniques, with applications in the automotive, manufacturing, and energy fields. Dr. Schumack earned his BS, MS, and Ph.D. degrees in Mechanical Engineering from the University of Michigan.

Understanding the Continued Poor Performance in Thermodynamics as a First Step toward an Instructional Strategy

Abstract

As a discipline, engineering thermodynamics is concerned with traditional and alternative sources of energy in terms of availability, movement and conversion. Practical issues such as efficiency of thermodynamic processes and systems are also studied. Stout understanding of thermodynamics by graduating engineers is indispensable for addressing the foremost global issue: the looming energy crisis and its related problems of pollution and global warming. Despite this monumental importance, engineering students continue to struggle with thermodynamics as indicated by the results of recent national US exams. Student's difficulties with thermodynamics have been also reported in several European countries, Australia and India. The current authors contend that understanding the root causes of problems with teaching/learning thermodynamics is an indispensable first step toward a design of an instructional strategy (and/or curricula and textbooks) geared at removing barriers to students' learning of thermodynamics. The purpose of this paper is to give a concise yet comprehensive account of the pertinent literature, and to analyze this literature in order to accurately describe the nature of problems of learning and teaching thermodynamics. The paper also describes the methods used for probing these problems, tried techniques for solving them and the degree of success achieved. In general, the literature points at two challenging problems. First, students do not properly learn thermodynamic concepts and principles; second, students have difficulty recognizing relevant concepts and principles, and putting them together in order to solve thermodynamic problems. The latter problem seems to not have received vital study and attention as the former. More details about these problems are given in this paper.

1. Introduction

The looming energy crisis, along with other issues of energy consumption, i.e., global warming and pollution, are arguably among the foremost challenges of our time and the near future. Thermodynamics is the science that deals with all types of energy- renewable and non-renewable- in terms of conversion, availability, transmission, efficiency and destruction (of free energy). Thermodynamics also governs important reactions such as combustion of fossil fuels in automobiles and power plants, and nuclear reactions in nuclear power plants. The field of heating, cooling and air-conditioning is part of thermodynamics.

Thermodynamics is taken by students in the majority of engineering majors- mechanical, chemical, civil and electrical, as well as by students majoring in physics and chemistry- albeit with some variations in the topics covered. In engineering, the first course in thermodynamics is taken early on by students, and is considered as a difficult course by students and as a "weed out" course by some instructors. Manteufel[1] described thermodynamics as the gateway course in mechanical engineering in the sense that student's performance in thermodynamics correlates well with how the student does in the rest of the courses in the curriculum. A recent study revealed the dire consequences of poor educational climate and negative student experience. Students who go through negative experiences and develop a negative perception of engineering as a field that contributes directly to society had a high risk of attrition.[2] The issue of retention in engineering is of vital importance in the US. Due to this importance, the American Society of Engineering Education (ASEE) has launched a national survey to benchmark the national retention rates in engineering.[3] Students' expressions of dissatisfaction and frustration with thermodynamics are very common.[4-6] There is even a sad culture of accepting the status quo: students often make comments like: "one cannot understand thermodynamics, only get accustomed to it."[6] Fuchs[7] stated that thermodynamics is considered to be one of the most difficult and abstract disciplines of the physical sciences.

2. National Statistics on Poor Performance

According to the National Council of Examiners for Engineering and Surveying (NCEES), which administers the Fundamentals of Engineering Exam, the national passing rates in the thermodynamics section are low for mechanical, electrical and civil engineering students.[8] National averages for the past ten years are given in Table 1 and the standard deviation (if available) is given in brackets. The table shows the lowest score recorded (27%) was for civil engineering students in 2004, while the highest score (71%) was that of mechanical engineering students in 2009. Figure 1 shows the trend in student's performance in graphical form. It is clear that there is not a clear improvement during the past ten years. For the most part, students' performance falls in the band from 40% to 65%. The figure shows that mechanical engineering students generally perform better than electrical and civil engineering students, most likely because thermodynamics is a major course in the discipline.

Table 1. National Average in the Morning Thermodynamics Section of the Fundamental of Engineering Exam. Source: NCEES.[8] The number between brackets is the standard deviation if available.

Year	Civil	Mechanical	Electrical
2002	43%(2.2)	63%(2.0)	44%(2.2)
2003	44%(2.0)	NA	NA
2004	29%(0.9)	57%(2.0)	NA
2005	44%	57%	NA
2006	48%(1.7)	62(1.8)	47%(1.7)
2007	51% (1.6)	63% (1.6)	NA
2008	49% (1.6)	61% (1.6)	50% (1.6)
2009	53% (1.8)	71% (1.7)	NA
2010	32% (1.3)	45% (1.8)	NA
2011	42% (1.7)	56% (1.9)	43% (1.8)
2012	58%(1.9)	70(1.8)	61%(1.8)

A specific example of students' performance is given for University of Texas at San Antonio. In their thermodynamics course, Manteufel[1] stated that, the percentage of students failing to earn a passing grade of C or better was 45% since the fall of 1994, and reached 52% in the spring of 1999.

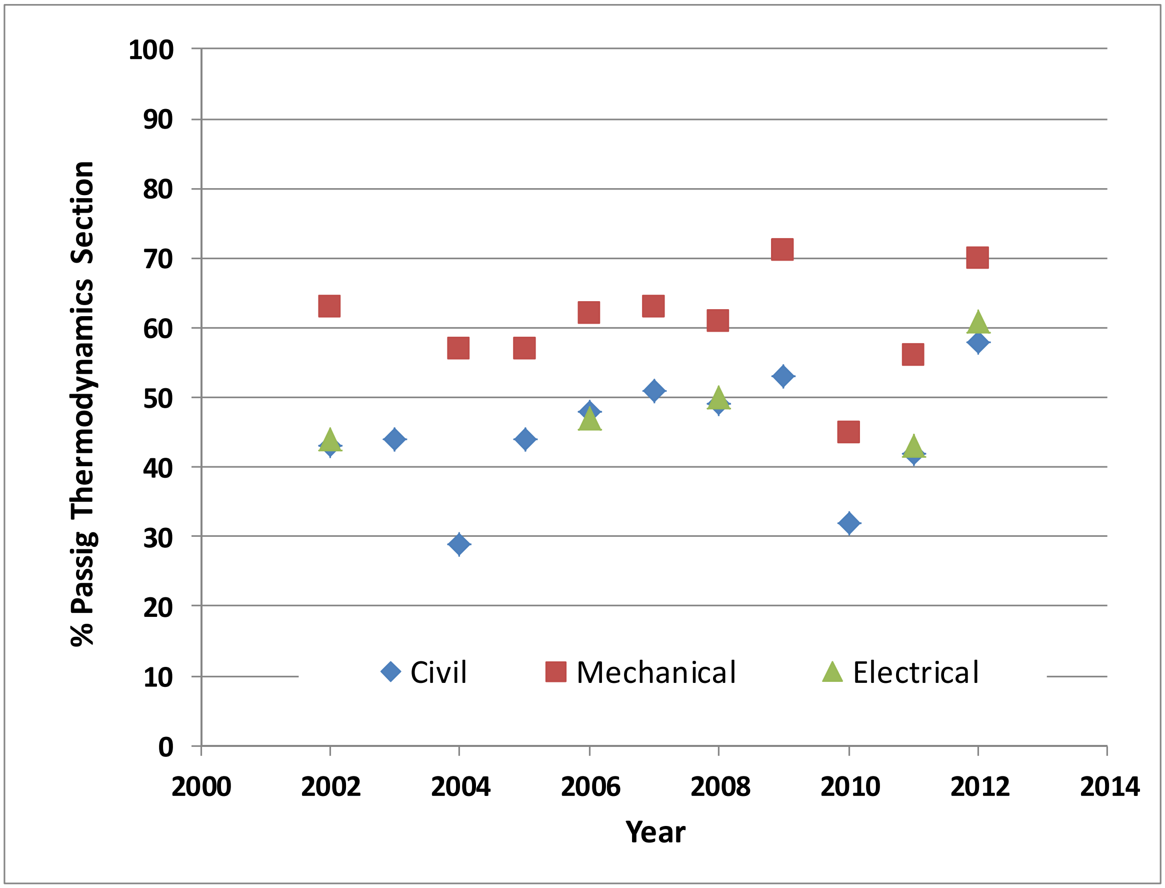

Figure 1. National performance of engineering students in thermodynamics

3. Specifics of Students' Difficulties

Many articles describe the widespread poor learning of basic concepts and principles of thermodynamics by college students.[5,9-21] Meltzer[5] said that students have difficulties with the concepts of heat, work, cyclic processes, as well as the first and second laws. In addition, engineering students were uncomfortable and unfamiliar with the need to provide explanations and reasoning in problem solving. Abulencia et al.[9] stated that students who can solve textbook problems may still give incorrect answers to conceptual questions in thermodynamics.

Prince et al.[11] presented misconceptions related to temperature, heat and energy; as well as 'rate' versus 'amount'. One of the common misconceptions reported was to think of temperature as a measure of the amount of energy contained in an object.[11] Loverude et al.[15] discussed students' misconceptions of temperature, heat, work and internal energy. Students in this study also failed to recognize the relevance of the first law and could not apply the ideal gas equation properly. In addition, they confused quantities associated with thermodynamic processes with those associated with states.

Hamby[18] described students' problems with using the first law in solving problems. Granville[19] documented misconceptions regarding the meaning of isothermal and spontaneous processes. Meltzer[21] asserted that the most prevalent misconception encountered during his investigation was that for a system going through a cyclic process, the net work done by the system or the net heat transferred to the system must be zero.

Several articles indicated that thermodynamics misconceptions are persistent and resistant to change.[5,11,22,23] Meltzer[5] stated that one out of eight students was able to apply the first law even after having studied the first law and related topics. Based on a sample of 373 from ten different universities, Prince et al.[11] showed that thermodynamic misconceptions did change through standard instructions. In a different study, Meltzer[21] indicated that only 20% or fewer of 653 students sample were able to effectively use the first law even after instructions.

Similar trends are present with pre-college students.[20,22-29] Arnold and Millar[22] indicated that pre-college students regarded temperature and heat as synonymous. This misconception was persistent and students regressed after showing some improvement. Clark and Jorde[23] reported misconceptions regarding thermal equilibrium by a hundred and twenty eighth-grade students. Ben-Zvi[24] reported that senior high school students confused the quality and quantity of energy. Viennot[25] reported difficulties experienced by adolescents in dealing with the temperature and heat concepts in heat transfer processes. de Berg[26] showed that 34% to 38% of students 17- to 18-years old from two colleges in England did not understand the concepts of volume and mass. Johnstone et al.[20] presented school students' misconception of entropy and its relation to disorder and chaos. Kesidou and Duit[26] reported that a sample of 15- to 16-years old students in Germany had severe difficulty in learning the energy concept and the distinction between heat and temperature. Students also rejected the conservation of energy principle because it contradicted their everyday experience. Pre-college misconceptions are likely to remain through college.[27,30] Kaper et al.[29] indicated that assuming that college students have no proper knowledge (or misconceptions) of some of the thermodynamics concepts may cause learning difficulties and impede the process of conceptual change in college.

Students' poor performance in thermodynamics is not a purely American phenomenon, it is international. Student's difficulties with thermodynamics have been reported in different parts of the world. Meltzer[21] reported on students difficulties in Europe. Viennot[25] talked about French students' difficulties, Kesidou and Duit[27] described misconceptions carried by German students, Roberts and Watts[28] presented problems with teaching thermodynamics in England and Kaper et al.[29,30] and Mettes et al.[31] discussed issues with thermodynamics learning in the Netherlands. de Berg[26] and Kavanagh et al.[32] talked about thermodynamics poor competency of entering students into the University of Queensland in Australia. Banerjee[33] discussed conceptual difficulties in thermodynamics of some undergraduate students in India.

4. Disagreement on Some Terminology

There are a few disagreements on some thermodynamics terminology.[28, 34-38] Roberts and Watts[28] suggested the use of 'heat energy' and 'heat energy transfer' instead of 'heat' and 'heat transfer', respectively. Moore[34] discussed general, restricted and misleading forms of the first law of thermodynamics, along with the meaning of various concepts, e.g., stored energy, heat, properties and the 'change' meant by Δ and δ, as well as the use of 'matter' versus 'substance'. Haber-Schaim[35] talked about the erroneous definition of energy as "the ability to do work," which confuses energy with free energy. Helsdon[36] argued that the traditional concept of heat as the random energy of atoms, molecules, etc. provided a reasonably satisfying explanation of the second law, while the newer concept of heat as an interaction was unable to do so.

Warren[37] indicated that the word 'heat' was used loosely in the early days of thermodynamics with several ill-defined meanings. He argued that traces of the caloric theory continued to be present with some textbook using 'caloric fluid' reasoning but renaming it 'heat energy'. He also contended that the use of the term 'heat capacity' is misleading. Fuchs[7] expressed similar notions and added 'latent heat' to the list of misleading terms that are connected to the caloric theory. These disagreements may lead to some confusion by students. However, the authors are inclined to think that the disagreements in terminology while unfortunate, remain minor, and are not among the major factors standing in the way of understanding thermodynamics by students.

5. Concept Inventories

Concept inventories are multiple-choice questionnaires in which common misconceptions (called distractors) are listed next to the correct answer for each question. Concept inventories are usually brief, require minimal or no computations and ideally, produce reliable results across broad and diverse student populations.[16] Many cycles of design, testing and redesign are necessary to develop calibrated inventories that lead to repeatable results.[12,16] Concept inventories lend themselves nicely to statistical analysis and are easy to score. Inventories have been very popular in probing students' conceptual understanding in engineering education. They have been effective in identifying trouble areas in engineering courses and in assessing the effectiveness of new instructional methods and educational reforms.

In thermodynamics, concept inventories that targeted properties and behavior of matter, work, heat and the first and second laws were described by Midkiff et al.[16] Olds et al.[12] presented an inventory that included the concepts of thermal equilibrium, mechanical energy, heat capacity and steady state among others. Prince et al.[11] developed the Heat and Energy Concept Inventory (HECI) to assess prevalent misconceptions related to temperature vs. energy, rate vs. amount of heat transfer and others. Using HECI on 373 undergraduate students from ten different universities, they demonstrated that student misconceptions are both prevalent and resistant to change.

6. Efforts and Techniques for Improving Students Learning

6.1 Real-life Examples and Experiments

Several real-life examples, hands-on experiments and projects have been constructed and used to help students in tackling thermodynamics concepts and principles, and to connect abstract ideas to accrual hardwere.[38-44] Flotterud et al.[38] for example described a micro-combined heat and power system sized for residential distributed power generation. The system has been used as a laboratory experiments in which students take measurements to complete an energy balance and perform second-law analysis. The real-life experiment enhanced students learning of some thermodynamics principles. Li and Zhou[39] described a thermodynamics project in which students had to select a commercial thermal cycle, analyze its performance and discuss the difference between the actual device and the theoretical model. Students were also required to build a small physical model of the device using straws, wires, plastic cups and paper. By doing that students could better visualize the device and its components.

Toro et al.[40] presented a desktop scale Rankine cycle with a solar-powered boiler for use as a hands-on laboratory experiment. Patterson[41] collected real-life thermodynamics examples in a booklet. The examples were intended to enhance teaching of thermodynamics by increasing the accessibility of thermodynamics principles, and to raise the appeal of thermodynamics to students. The examples were designed using the 5Es approach: Engage, Explore, Explain, Elaborate and Evaluate (part of the constructivist learning theory). Plumley et al.[42] presented hands-on demonstration units built from common laboratory components to enhance the learning in introductory thermodynamics, especially targeting conservation of mass, conservation of energy and boundary work.

6.2 Inquiry-Based Learning

Initiatives directed at enhancing thermodynamics learning include problem-based and inquiry-based learning techniques.[9-11, 44-49] In inquiry-based learning, students predict the outcome of an event or a process, conduct an experiment, watch a simulation, read or engage in discussion, and then critically compare their predictions to the correct results. Inquiry-based activities are known to cause conceptual change. Abulencia et al.[9] described an inquiry-based exercise in which students were required to develop an instructional video that could teach a concept in thermodynamics using common metaphors, and to watch (and critique) similarly constructed videos by peers. Prince et al.[11] presented results that showed the effectiveness of inquiry-based activities in addressing some thermodynamic misconceptions held be engineering students, i.e., heat, energy, temperature and entropy.

Field[43] described guided inquiry investigations of thermodynamic properties and cycles in a sophomore thermodynamics class. Students were required to modify a computer model to add features and new cycles, e.g., Stirling and Brayton cycles. No quantitative assessment was made, but anecdotal evidence pointed at improved learning by students.

6.3 Problem-Based Learning

Problem-based learning holds the promise of training students to tackle ill-defined, ill-structured problems and enhance the transfer of students' knowledge from the classroom to real-world design and analysis.[5] In this instructional pedagogy, learning occurs by asking and obtaining answers to open-ended and challenging questions. Studies have shown that this learning method results in more positive students' attitudes, a deeper conceptual understanding and improve retention of knowledge.[11] The success of problem-based learning depends to some extent on students' self-efficacy and the degree of collaboration among peers. In problem-based environments, learners practice higher order cognitive skills (analysis, synthesis and evaluation), and constantly engage in reflective thinking.[49] Students using problem-based learning can have a varied level of guidance form their instructors ranging from no to moderate guidance. If the guidance level is too low in problem-based learning, heavy cognitive loads may result during the learning process. Lape[10] presented tiered scaffolding techniques to bridge the gaps in high-cognitive-load problem-based learning in thermodynamics.

Alvarado[44] described a problem-based activity in which students were asked to design an experiment based on a thermodynamics device. Students were shown to benefit from the activity and to have an improved self-confidence, as compared to other students. Nasr and Ramadan[45] presented problem-based thermodynamic curricular materials, or modules, supported by simulations. The modules introduced practical applications first, whereas thermodynamic principles were introduced just-in-time and as encountered. The authors highlighted some challenges in the implementation of their technique, but stated that students benefitted from it.

6.4 Project-Based Learning

Wren[46] described a project in which students of thermodynamics were asked to determine the power and efficiency of the human body under various conditions-- the efficiency that an ergo trainer anticipated during calculation of energy consumption during exercise and the heat loss due to breathing when a person is resting and exercising. The activity was geared toward relating thermodynamic knowledge to practical applications outside textbooks. The project was found to be beneficial in terms of students' motivation and learning.

Krishnan and Nalim[47] presented a project in which students were required to apply key thermodynamic knowledge to designing a heating, ventilation and air-conditioning system, based on manufactures' specifications and actual climate data. It was stated that project-based instructions were an effective tool for introducing some of the abstract concepts of thermodynamics, while keeping students motivated and increasing their confidence.

Bailey[48] described a project in which students in a thermodynamics course had to prepare and deliver a presentation strongly related to thermodynamics to non-technical audiences, e.g., high-school students and college-level liberal-arts classes. Students were required to establish the relevance of thermodynamics to the audiences, and develop activities to keep them engaged. The project was designed to prolong and strengthen students' interest in thermodynamics.

6.5 Use of Electronic Media

Employing electronic media to facilitate thermodynamic learning is extensive.[4,49-61] These include on-line delivery, web-based instructions and software- sometimes with the use of multimedia (hypertext, sound, animation, simulation). Cobourn and Lindauer[4] described flexible, computer-controlled, interactive, multimedia thermodynamic modules that allowed instructors to implement different kinds of in-class and out-of-class activities. Students have responded favorably to the modules. Fridman and Shelangoskie[49] presented a web-based, multimedia, self-assessment tool that enabled students to become actively engaged in learning thermodynamics. The tool provided immediate feedback, which allowed students to recognize their weakness and gauge their own learning levels and needs.

Huang and Gramoll[50] described the development, implementation and functionality of highly interactive multimedia, online eBook designed to enhance students' learning of thermodynamics. The eBook was case-based (42 case problems), with each case covering a specific concept. Ngo and Lai[51] discussed how multimedia can be implemented to enhance the learning of thermodynamics. Their web-based module was interactive and visually appealing with animations and simulations- attributes that were intended to capture the attention of the wire-generation. The module included a tutorial session to help students in preparing for the FE/EIT exam; and it has received favorable responses from students.

Hall et al.[52] presented the use of various communication technologies from an on-line offering of a thermodynamics course. Asynchronous and synchronous technologies were employed for instructions and explication of feedback. In a previous study, Hall et al.[53] had presented findings of a study focused on useful advice regarding the design of on-line thermodynamics course. They discussed how students approached problem solving, the role of instructors and the role of peers, as well as students' use of technology as it related to accomplishing course work. Results showed that students relied heavily on the instructor to show them how to solve problems. The information was used to feed new course design in order to increase students' self-efficacy in problem solving through interactive engagement with peers and instructors.

Stanly and DiGiuseppe[54] presented a web-based animation software for thermodynamics that was linked to homework problems in a textbook. Students considered the software to be valuable, especially in explaining the transient nature of some thermodynamics concepts. Anderson et al.[55,56] described computer-based instruction for active-learning methods for thermodynamics. The instructional materials included interactive exercises, immediate feedback, graphical modeling, physical world simulation and exploration. Minor technical problems were sufficiently frustrating to discourage students from using the materials. There was no independent evidence that students comprehended the material in a deep fashion. However, in general, there was a positive correlation between time spent using the materials and test performance. Taraban et al.[57,58] developed a model of students' navigation in thermodynamics computer modules on a CD-ROM. Students' behavior and performance with interactive elements were used to infer students' reading patterns and metacognitive strategies- information that could guide changes to the implementation and delivery of the CD. It was indicated that the CD did not bring about active learning and that students needed a strong incentive to use the CD.

Kumpaty[59] introduced the expert system for thermodynamics (TEST) software for enhancing students learning of thermodynamics. TEST was visual, allowed parametric studies and followed closely the textbook of Cengel and Boles. TEST received positive remarks from students. Tebbe et al.[60] discussed the development and design of THERMOVIEW software within LabVIEW environment to help students learn thermodynamics.

Taraban et al.[61] described thermodynamics homework exercises that delivered to students via the Internet, and completed by students on-line. Collected data revealed students' patterns of software usage. The on-line homework, along with the immediate feedback, improved students' grades in the in-class tests. Baher[62] described a virtual laboratory (CyclePad) for constructing and analyzing thermodynamic cycles. Students found the software helpful in increasing their understanding.

6.6 Others

In a series of intriguing articles, Dartnall and Reizes[63-65] presented the use of simple molecular simulations to enhance thermodynamics learning. An easy-to-use software was developed to promote students' intuitive understanding of some thermodynamic concepts. One paper targeted the ideal gas law and the first law of thermodynamics.[63] In a different paper, one- and two-dimensional hard sphere simulations were used to demonstrate the ideal gas equation and to explain concepts such as temperature and pressure, and the way these two relate to a volume containing a specified number of molecules.[64] The simulations linked the microscopic behavior of matter to the macroscopic one. The third paper outlined a particle-mechanics model in which a single particle represented a gas in a heat engine.[65] the model demonstrated the connection between the Carnot efficiency and the Kelvin-Plank statement of the second law.

7. The Nature of Thermodynamics Learning Problems

It is critical to understand and to correctly frame problems associated with thermodynamics learning and teaching. It is also essential to identify the root causes of these problems. Doing this can form a foundation for eradicating these problems, and can guide curriculum and textbook design. It also can inform and positively influence new instructional strategies.

Close scrutiny of the literature outlined above reveals that in addition to conceptual difficulties, students have difficulty integrating concepts and principles and recognizing their relevance in solving problems.[10,15,22,32,47,66] While these two issues are intimately connected, they are often decoupled.[9] These problems remain intact, as evident by the continued poor performance of engineering students in thermodynamics, Fig. 1. This strongly suggests that either a) the attempted solutions did not address the problems, or did not treat the root causes, or b) the solutions that worked, or worked partially, were not adapted by a sufficiently wide population of university instructors such that a clear improvement in students' performance at the national level is achieved. None of the attempts seemed to be comprehensive- each targeted few certain concepts and/or principles.

Common engineering thermodynamics textbooks have not been affected by the incremental success of some of the attempted solutions described above. A review of thermodynamics textbooks[67-70] reveals that there is little variety in the approach- most organize topics in the same sequence and have similar word problems. These problems require students to calculate a numerical value and rarely ask students to link the answer to conceptual understanding, or to reflect on the implications of such answer. A typical sequence, which is followed by instructors, starts with basic thermodynamic definitions and concepts, e.g., system, surroundings, process, state, etc. This followed by presentation of various forms of energy, then properties of pure substances (ideal gas, refrigerants and steam) and property tables. This usually consumes the first three or four chapters of the textbook and the first few weeks of the semester. The rest of the sequence is shown in Fig. 2. In the first few weeks, the following issues are encountered.

1. During this presentation real-life applications are mentioned frequently, but not fully analyzed using the thermodynamic knowledge being presented. This is an issue because students do not experience thermodynamic knowledge in complete operational form. For example, an instructor may say that steam properties are needed for the analysis and design of steam power plants. However, students solve problems and see the instructor solve examples for the use of steam tables, but not a full analysis of a steam power plant. Full system analysis does not happen until the second course in thermodynamics. This is most likely why students generally do better in the second course of thermodynamics.
2. Another issue with textbooks, and the instructions that usually follow them, is that concepts and principles are presented in such an abstract way that students struggle with them. Connections to real-life devices, if presented, are superficial. Here are a couple of examples. Cengel and Boles:[67] define a control volume (or open system) as an arbitrary region in space through which mass and energy can pass across the boundary. The system's boundary is defined as the real or imaginary surface that separates the system from its surroundings. Balmer[68] states that "a thermodynamic process is the succession of thermodynamic states that a system passes through as it goes from initial and final state." At this junction, the reader of this article should reflect on what goes in the mind

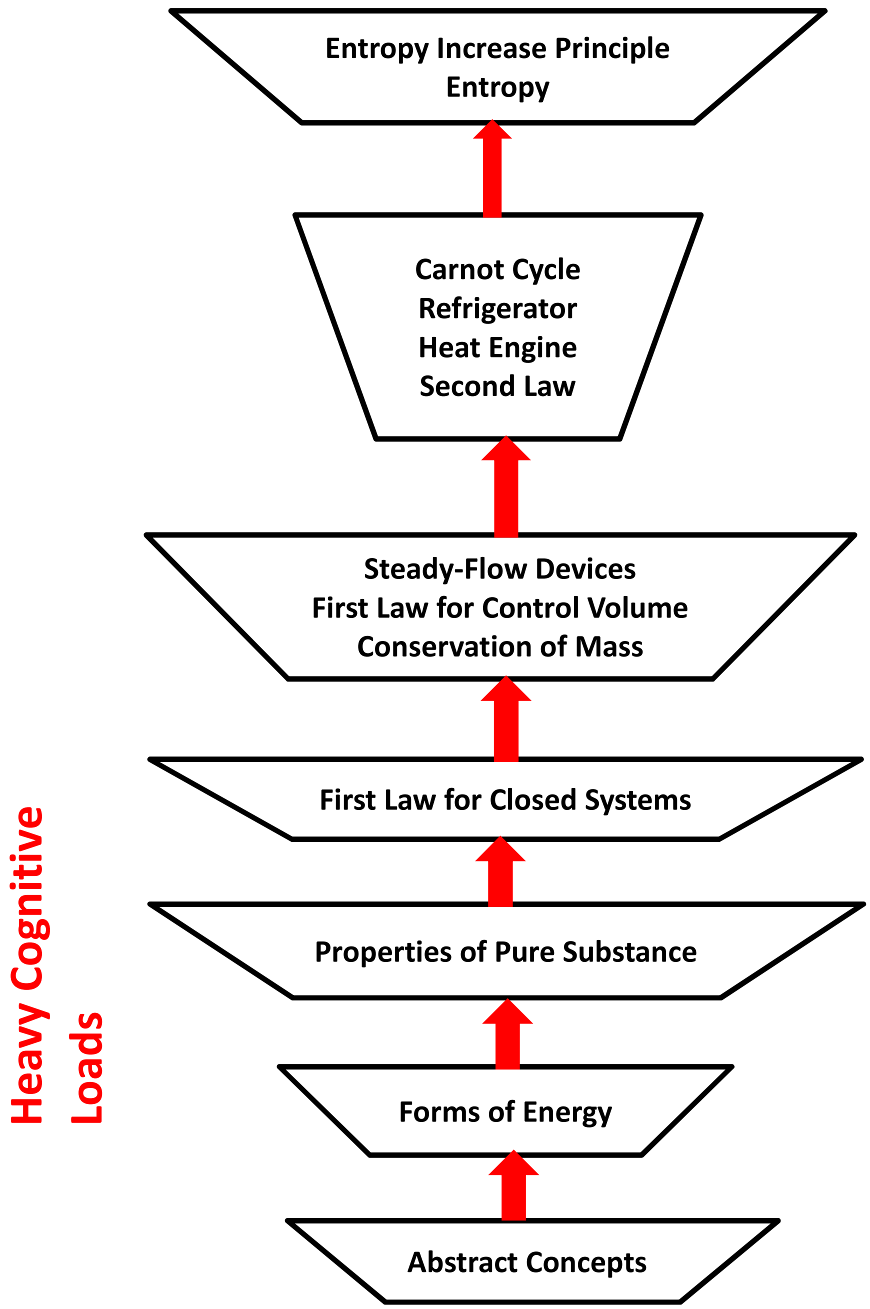

Figure 2. Typical thermodynamics knowledge presentation

of an entering engineering student. This student most likely chose engineering because of its applied nature and because "engineers design and build devices and machines that work and provide benefit to society"! To this novice, thermodynamic ideas seem rather aimless. Students develop learning difficulties and their frustration ensues. Haber-Schaim[35] stressed the importance of establishing a practical need for a new term before the term is introduced. This way the terms would have an operational meaning, and would be better integrated with the student's natural vocabulary. Due to all of this, one may conclude that current instructions and textbooks are riddled with heavy cognitive loads from the start.

In addition to understanding various thermodynamic concepts and principles, the process of learning is greatly influenced by how these are introduced, indexed and stored in memory so as to result in deep learning, and be available to the process of problem solving.[71,72] The mind itself is a pattern-making system.[73] Typical instructions and textbooks of thermodynamics do not seem to take this into account, as thermodynamic knowledge to fully analyze a practical system are spread over many chapters.

It is imperative for a comprehensive solution to the problem of the poor thermodynamics learning by engineering students must take into account the issues outlined above.

8. Conclusion

Engineering students' poor learning of thermodynamics is severe, widespread and on-going. Students continue to hold many misconceptions. Probing of students' misconceptions has been conducted using concept inventories, questionnaires and interviews. Many of these misconceptions are persistent, and may carry over from pre-college days. These issues are present in the US and in many other developed and developing countries around the world. Another difficulty students possess is that they fail to realize the relevance of thermodynamic principles in problem solving.

Many attempts have been made in order to improve students' learning of thermodynamics knowledge, including real-life examples and experiments. Some attempts employed various instructional techniques such as inquiry-, problem- and project-based learning. Electronic media in its varied forms have also been tried to enhance thermodynamics delivery and learning. These attempted solutions have not been comprehensive, and have not shown widespread improvement in students' learning at the national level. Students' performance in thermodynamics continues to be poor and unacceptable.

Any envisioned solution to the poor learning of thermodynamics by engineering students should address the issues outlined in this paper. Thermodynamics is often taken early in engineering curricula, and unfortunately is often perceived as an impediment to continuing studies. Instructional strategies for keeping students engaged and eliminating their frustration with thermodynamics will likely enhance retention in engineering.

Bibliography

1. Manteufel, R.D., (1999). A Spiral Approach for Mechanical Engineering Thermodynamics. *Proceedings of the ASME International Mechanical Engineering Conference, Nashville, TN, November 14-19.*
2. Litzler, E. and Young, E. (2012). At-Risk or Ill-Served? *PRISM*, 22(1), 49.
3. Yode, B. (2012). ASEE Develops a Database on Retention, Time to Graduation. *PRISM*, 22(1), 57.
4. Cobourn, W. G. and Lindauer, G. C. A. (1994). A Flexible Multimedia Instructional Material Module for Introductory Thermodynamics. *Journal of Engineering Education, 83, 271-277.*
5. Meltzer, D. E. (2006). Investigation of Student Learning in thermodynamics and Implications for Instruction in Chemistry and Engineering. *Proceedings of Physics Education Research Conference*.
6. Grigull, U. (1990). Students Views on Learning Thermodynamics. *Workshop on Second Law of Thermodynamics, Erciyes U.-T.I.B.T.D.27- Kayseri.*
7. Fuchs, H. U., (1987). Thermodynamics: A Misconceived Theory. *Proceedings of the Second Seminar on Misconceptions and Educational Strategies in Science and Mathematics*, July 26-29, Cornell University, Ithaca, NY, USA.
8. www.ncees.org, accessed April 2012
9. Abulencia, J.P., Vigeant, M. A. and Silverstein, D. L. (2012). Using Video Media to Enhance Conceptual Learning in an Undergraduate Thermodynamics Course. *Proceeding of the ASEE annual conference & exposition, San Antonio, TX, USA.*
10. Lape, N. K. (2011). Tiered Scaffolding of Problem-Based Learning Techniques in a Thermodynamics Course. *Proceedings of the ASEE Annual CONFERENCE & EXPOSITION, June 26-29, Vancouver, BC, Canada*
11. Prince, M. J., Vigeant, M.A.S. and Nottis, K. (2009). A Preliminary Study on the Effectiveness of Inquiry-Based Activities for Addressing Misconceptions of Undergraduate Engineering Students. *Education for Chemical Engineers, 4, 29-40.*
12. Olds, B. M., Streveler, R. A., Miller, R. L., et al., (2004). Preliminary Results from the Development of a Concept Inventory in Thermal and Transport Science. *Proceedings of the American Society of Engineering Education Annual Meeting and Exposition*, *Salt Lake City, UT, USA.*
13. Sozbilir, M. (2003). A Review of Selected Literature on Students' Misconceptions of Heat and Temperature. *Bogazici University Journal of Education, 20(1), 25 -40.*
14. Jasien, P. G. and Oberem, G. E. (2002). Understanding of Elementary Concepts in Heat and Temperature among College Students and K-12 Teachers. *Journal of Chemical Education, 79(7), 889-895.*
15. Loverude, M. E., Kautz, C. H. and Heron, P. R., (2002). Student Understanding of the First Law of Thermodynamics: Relating Work to the Adiabatic Compression of an Ideal Gas. *American Journal of Physics, 70 (2), 137.*
16. Midkiff, K. C., Litzinger, T. A. and Evans, D. L., (2001). Development of Engineering Thermodynamics Concept Inventory Instruments," *Proceedings of Frontier in Education Conference, October 10-13, Reno, NV, USA.*
17. Carlton, K. (2000).Teaching about Heat and Temperature. *Physics Education, 35(2), 101.*
18. Hamby, M. (1990). Understanding the language: Problem solving and the first law of thermodynamics. *J. Chem. Ed., 67, 923-924.*
19. Granville, M. F. (1985). Student misconceptions in thermodynamics. *J. Chem. Educ. 62, 847-848*.
20. Johnstone, A. H., MacDonald, J. J. and Webb, G. (1977). Misconceptions in school thermodynamics. *Physics Educ., 12, 248-251.*
21. Meltzer, D. E. (2004). Investigation of Student's Reasoning Regarding Heat, Work and the First Law of Thermodynamics in an Introductory Calculus-Based General Physics Course. *American Journal of Physics, 72 (11), 1432-1446.*

22. Arnold, M. and Millar, R. (1996). Learning the scientific 'story': A case study in the learning of elementary thermodynamics. *Sci. Educ., 80, 249-281*.
23. Clark, D. and Jorde, D. (2004). Helping students revise disruptive experientially supported ideas about thermodynamics: visualizations and tactile models. *J. Res. Sci. Teach,. 41, 1-23*.
24. Ben-Zvi, R. (1999). Non-science oriented students and the second law of thermodynamics. *International Journal of Science Education, 21, 1251-1267.*
25. Viennot, L. (1998). Experimental facts and ways of reasoning in thermodynamics: Learners' common approach. In: Tiberghien, A., Jossem, E., Barojas, J.: *Connecting research in physics education*. Ohio: ICPE Books, 1-10.
26. de Berg, K.C. (1995). Student understanding of the volume, mass, and pressure of air within a sealed syringe in different states of compression. *Journal of Research in Science Teaching 32(8), 871-884.*
27. Kesidou, S. and Duit, R. (1993). Students' conceptions of the second law of thermodynamics – an interpretive study. *J. Res. Sci. Teach.,* 30(1), 85-106.
28. Roberts, I. F. and Watts, D. S., (1976). The teaching of thermodynamics at preuniversity level. *Phys. Educ., 11, 277-284.*
29. Kaper, W. H. and Goedhart, M. J., (2002b). Forms of energy, an intermediary language on the road to thermodynamics? Part II. *Int. J. Sci. Educ., 24, 119-137.*
30. Kaper, W. H. and Goedhart, M. J., (2002a). Forms of energy, an intermediary language on the road to thermodynamics? Part I. *Int. J. Sci. Educ., 24, 81-95.*
31. Mettes, C.T., Pilot, A. Roosink, H.J. and Kramers-Pals, H., (1981b). Teaching and learning problem solving in science, part II: learning problem solving in a thermodynamic course. *J. Chem. Ed,. 58, 51-55.*
32. Kavanagh, L., O'Moore, L. and Samuelowicz, K. (2009). Characterizing the First Year Cohort Knowledge. *Proceedings of the ASEE Annual Conference and Exposition, Austin, TX, USA.*
33. Banerjee, C. (1995). Teaching chemical equilibrium and thermodynamics to undergraduate general chemistry classes. *J. Chem. Educ., 72, 879-887.*
34. Moore, G. S. M. (1993). General, restricted and misleading forms of the First law of thermodynamics. *Phys. Educ., 28, 228-237.*
35. Haber-Schaim, U., (1981). The role of the second law of thermodynamics in energy education. *Proceedings of the International Conference on Energy Education, University of Rhode Island, RI, USA, Office of Energy Education and College of Continuing Education, 97-99.*
36. Helsdon, R. M. (1976). Teaching thermodynamics. *Physics Education, 11, 261-262*.
37. Warren, J. W. (1976). Teaching thermodynamics. *Phys. Educ. Letters, 11, 388-389.*
38. Flotterud, J. D., Damm, C. J., et al. (2011). A micro-combined heat and power laboratory for experiments in applied thermodynamics. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 11-17, Denver, Colorado, USA.*
39. Li, X. and Zhou, J., (2011). Getting Hands-on Experience from Simple Experiments and Model Development in Thermal-Fluid Courses. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 11-17, Denver, Colorado, USA.*
40. Toro, X., Compere, M., Van Wie, B. and Dikici, B., (2011). A solar-powered direct steam generation boiler for an educational desktop Rankine cycle. *Proceedings of the ASME International Mechanical Engineering Congress & ExpositioN, November 11-17, 2011, Denver, Colorado, USA.*
41. Patterson, E. A., (2010). *Real Life Examples in thermodynamics*. East Lansing, MI: Department of Mechanical Engineering, Michigan State University.
42. Plumley, M., Foley, A. and Greene, E., (2000). Practical demonstration units, using common components, for an introductory thermodynamics course. *Proceedings of the American Society of Engineering Education Gulf Southeast Section Conference*, Las Cruces, NM, April 6-8.
43. Field, B. S. (2010). Guided inquiry learning in a thermodynamics class. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 12-18, Vancouver, British Columbia, Canada.*

44. Alvarado, J. (2006). Design your own thermodynamics experiment, a problem-based learning approach in engineering technology. *Proceedings of the Annual ASEE Conference and Exposition, Chicago, IL, June 18-21.*
45. Nasr, K. and Ramadan, B., (2005). Implementation of problem-based learning into engineering thermodynamics. *Proceedings of the ASEE Annual Conference and Exposition, 7619-7635.*
46. Wren, J. S., (2012). Engineering Thermodynamics in the 21st Century: Active Learning by Human Body Thermodynamics. *Proceedings of the American Society for Engineering conference, San Antonio, TX, USA.*
47. Krishnan, S. S. and Nalim, R. (2009). Project-based Learning in Introductory Thermodynamics. *Proceeding of the ASEE Annual Conference and Exposition, Austin, TX, USA.*
48. Bailey, M., (2007). Enhancing lifelong learning and communication abilities through a unique series of projects in thermodynamics. *Proceeding of the ASEE Annual Conference and Exposition, Honolulu, HI, June 24-27.*
49. Fridman, E. and Shelangoskie, S., (2005). Utilizing multimedia tools in undergraduate thermodynamics. *Proceedings of the ASME International Mechanical Engineering Congress and Exposition, November 5-11, Orlando, FL, USA.*
50. Huang, M. and Gramoll, K. (2004). Online interactive multimedia for engineering thermodynamics. *Proceedings of ASEE Annual Conference and Exposition, 10661-10671.*
51. Ngo, C.C. and Lai, F.C., (2001). Teaching thermodynamics with the aid of web-based module. *Proceedings of ASEE Annual Conference and Exposition, 9635-9643.*
52. Hall, S., Dancey, C., Amelink, C. T., and Conn, S. (2011). Our First Online Offering of Introduction to Thermal-Fluid Engineering. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 11-17, Denver, Colorado, USA.*
53. Hall, S., Amelink, C. T., Conn, S. and Brown, E. (2010). Online Course Design Informed by Students' Epistemic Beliefs: A Case Study of a Thermodynamics Course. *Proceedings of the ASME 2010 International Mechanical Engineering Congress & Exposition, November 12-18, Vancouver, British Columbia, Canada.*
54. Stanly, R. and DiGiuseppe, G., (2010). An Efficient Way to Increase the Engineering Students' Fundamental Understanding of Thermodynamics by Utilizing Web Based Animation Software. *Proceedings of the ASEE Annual Conference and Exposition, Louisville, KY, June 20-23.*
55. Anderson, E. E. and Traraban, R. (2005). Implementing and assessing computer-based active learning materials in introductory thermodynamics. *International Journal of Engineering Education, 21(6), 1168-1176*.
56. Anderson, E.E., Sharma, M.P. and Taraban, R. (2002). Application of Active Learning Techniques to Computer-Based Instruction of Introductory Thermodynamics. *Proceedings of the Annual ASEE Conference, Montreal, Canada.*
57. Taraban, R., Anderson, E.E., Sharma, M. P. and Weigold, A., (2003). Developing a Model of Students Navigations in Computer Modules for Introductory Thermodynamics. *Proceedings of the ASEE Annual Conf. and Exp., Nashville, TN, USA.*
58. Taraban, R., Anderson, E.E., Sharma, M. P. and Hayes, M. W. (2002). Monitoring Students Study Behaviors in Thermodynamics. *Proceedings of the ASEE Annual Conference, Montreal, Canada.*
59. Kumpaty, S. (2002). Learning Enhancement in Thermodynamics Classroom via use of TEST™ Software in Design Projects and Laboratory. *Proceedings of the ASEE Annual Conference, Montreal, Canada.*
60. Tebbe, P., Et al. (2001). Development of Software Applications for thermodynamics Related Courses: The THERMOVIEW Project. *Proceedings of the ASEE Annual Congress and Exposition, Albuquerque, NM, USA.*
61. Taraban, R., Anderson, E.E., Hayes, M. W. and Sharma, M. P. (2005). Developing On-Line Homework for Introductory Thermodynamics. *Journal of Engineering Education, 94(3), 339-342*.
62. Baher, J. (1999). Articulate Virtual Labs in Thermodynamics Education: A Multiple Case Study. *Journal of Engineering Education, 88(4), pp. 429-434*.
63. Dartnall, W. J. and Reizes, J., (2011). Molecular dynamic computer simulation models for teaching thermodynamic principles. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 11-17, Denver, Colorado, USA.*

64. Dartnall, W. J. and Reizes, J., (2010). Developing innovative teaching materials that use molecular simulations in engineering thermodynamics. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 12-18, 2010, Vancouver, British Columbia, Canada.*
65. Dartnall, W. J. and Reizes, J., (2010). A novel approach to the teaching of thermodynamic cycles and the laws of thermodynamics. *Proceedings of the ASME International Mechanical Engineering Congress & Exposition, November 12-18, , Vancouver, British Columbia, Canada.*
66. Beall, H. (1994). Probing student misconceptions in thermodynamics with in-class writing. *J. Chem. Educ., 71, 1056-1057.*
67. Cengel, Y. A. and Boles, M. A. (2011). *Thermodynamics, an Engineering Approach*. 7h Ed., New York: McRawHill.
68. Balmer, R.T. (2011). *Modern Engineering Thermodynamics*. New York: Academic Press.
69. Turns, S. R., (2006). *Thermodynamics, Concepts and Applications*. New York: Cambridge University Press
70. Moran, M. J. and Shapiro, H. N., (2000). *Fundamentals of Engineering Thermodynamics*, 4th Ed., New York: Wiley.
71. Turns, S. R. and Van Meter, P. N. (2011). Applying Knowledge from Educational Psychology and Cognitive Science to a First Course in Thermodynamics. *Proceedings of the ASEE Conference, Vancouver, Canada.*
72. Bhaskar, R. and Simon, H. A. (1977). Problem Solving in Semantically Rich Domains: An Example from Engineering Thermodynamics. *Cognitive Science, 1, pp. 193-215.*
73. deBono, E. 1970. *Lateral Thinking*. New York: Harper Perennial, 25-31.