Guest Editorial

What Motivates Your Teaching?

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"What Motivates Your Teaching?" is an invited article based on a lecture given by Dr. Turns at Auburn University on December 1, 2009. In it, he discusses the importance of motivation in teaching and presents several possible motivators using the example course of thermodynamics.

1. Introduction

Recently, I had the opportunity to reflect on my teaching and to spend some time examining why (and how) I teach the subjects that I do. As I found this a very useful exercise, the purpose of this essay is to share my findings with others with the hope that they may be inspired to similar reflection. At my institution, we generally have the luxury of requesting which courses we want to teach, and these requests are almost always granted. Why do we choose to teach any particular course? Before proceeding, let's dismiss reasons of expediency – although at times they may be compelling – and focus on reasons that keep us intellectually and affectively engaged in the joint processes of teaching and learning in specific subject areas.

By definition, the reasons we teach what we do must be domain specific, although some motivators may be more general. Therefore, we must have some domain to frame our discussion. Because I like to teach thermodynamics, that will be our subject. Although this domain is quite specific, I challenge readers to ask the same or similar questions about their courses that I asked of thermodynamics. Although the specifics of the reflection process will be quite personal, the idea of reflecting is domain neutral. My general contention is that when we deliberately reflect on why we teach a subject, we may reinvigorate our teaching with an active awareness of *why* we are doing *what* we are doing. Furthermore, we may be inspired to change the way we treat a particular subject to be more in line with what we discovered in our reflection.

2. How People Learn

Important in much of what follows is the understanding of how people learn. This topic is the subject of the masterful publication of the National Research Council, appropriately titled, *How People Learn: Brain, Mind, Experience, and School* [1]. The key findings of Bransford et al. [1] are the following:

> Prior Knowledge Plays a Key Role in Learning:
>
> *Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information that are taught, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom.*
>
> Knowledge Must Be Organized:
>
> *To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in way that facilitates retrieval and application.*
>
> Thinking about Thinking Is Useful:
>
> *["Metacognition" is the ability to monitor one's current level of understanding and decide when it is not adequate.] A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.*

These aspects of learning should impact how we organize and teach our classes, either consciously or unconsciously. I will point out how these findings explicitly can be taken into account as we look at what motivates us to teach a particular subject and the ways that we act on our motivation.

3. Some Motivators

Several general issues might motivate an individual to teach any particular subject. I would like to focus on four of these:

1. Potential to impact students
2. Historical context of the subject matter
3. Specific current relevance of the subject matter

Keywords: STEM pedagogy, engineering pedagogy, pedagogy, thermodynamics

4. New tools or approaches to teaching and learning

There certainly are more and, perhaps, you can add others that are important to you. Let's now explore these four in both general terms and in the context of the subject of thermodynamics.

3.1 Potential to Impact Students

Do you prefer to teach freshmen or seniors classes? Or are you equally motivated to teach either? Where the course falls within the curriculum will effect our treatment of the subject matter and our interactions with students. A course early in the curriculum has to deal with many very basic skills and affords the instructor an opportunity to affect a student's trajectory through the program—*just as the twig is bent the tree's inclined*. On the other hand, a senior technical elective offers a very different environment: this may be our last chance to affect our students. Consciously thinking about course timing in the curriculum will help us tailor a course to our students' needs and can provide the satisfaction and motivation that comes when we know we are addressing these needs.

In the mechanical engineering program at Penn State, thermodynamics is the first course with a mechanical engineering designation and a student's first exposure to mechanical engineering faculty members. Students usually take this course in their fourth semester after completing a course in statics and concurrent with a course in dynamics. This pattern is common in many mechanical engineering programs. Clearly, this timing of thermodynamics offers much opportunity for "twig bending." Because we get students early in their education, our instruction can have a large impact. Furthermore, we have the opportunity to create interest in the thermal-fluids branch of engineering, a branch that is typically less familiar to entering mechanical engineering students. This is important because so many of the challenges facing the world today are linked to energy and its use.

Let's look at some of the specifics related to timing that I find to be such compelling motivators for teaching thermodynamics. A thermodynamics course helps students:

1. Construct their knowledge and distinguish between important/less important and general/specific concepts.
2. Connect mathematics to the physical world.
3. Appreciate, understand, and use graphical information.
4. Develop sound problem solving skills.
5. Begin to "think like an engineer."

3.1.1 Constructing Knowledge

There are many opportunities in thermodynamics to help students construct their knowledge and distinguish between important/less important and general/specific concepts. When students are able to do this, important learning occurs. This is one of the three key findings of the National Research Council [1]. Figure 1 illustrates my attempt to help students to see the organization of thermodynamics from a big-concepts perspective, i.e., to see what the forest looks like before we start looking at the trees. Here we see the payoff of the course at the top – learning to deal with practical devices (pumps, turbine, heat exchangers, etc.) and systems (turbojet engines, power plants, etc.) is one reason students have elected to study mechanical engineering. All real devices and systems are made of stuff and operate with stuff. As a consequence, an understanding of the properties of matter and the interrelations among these properties form the base or bedrock of our study in thermodynamics. Connecting the top and the bottom are three fundamental principles: the two great conservation principles for mass and energy and the second law of thermodynamics. These connections are presented at the very beginning of the semester to foreshadow what is to follow. However, the real impact of this view occurs when we revisit it at the end of the semester. Students react very favorably to this with comments like "Why didn't you show this to

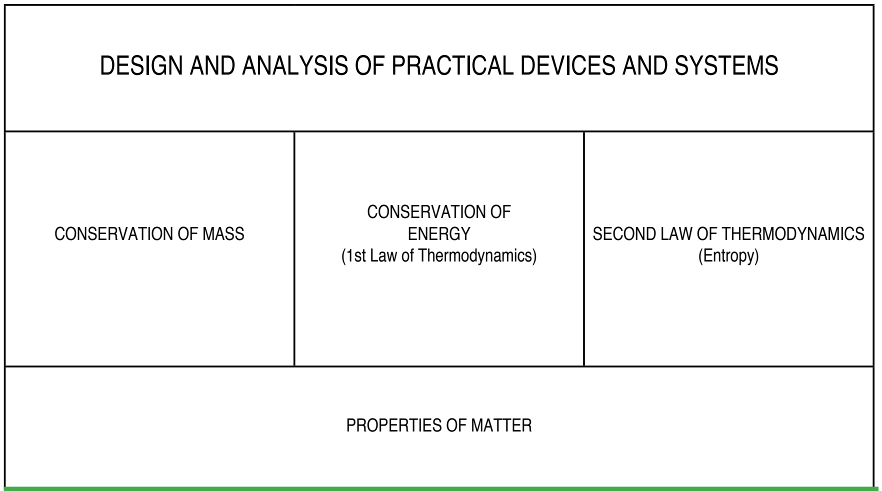


FIGURE 1. A conceptual organization of a thermodynamics course.

us before?" Such comments show that students armed with rich factual knowledge are eager to organize this knowledge into a coherent conceptual framework. Such organization is easy for thermodynamics – that's one reason I like to teach this course – however, organizing the big ideas of any course in a similar manner is a very useful exercise and pedagogical tool.

3.1.2 Connecting Mathematics

A second motivator related to the early timing of thermodynamics in the curriculum is the ability to help students connect mathematics with the physical world. Most students enter thermodynamics with 12 or more credits of formal mathematics instruction. For many students, their mathematical knowledge is abstract and not readily accessible to solve engineering problems. Thermodynamics offers wonderful opportunities to help students connect their mathematical knowledge to the physical world. Several examples illustrate these opportunities.

One such opportunity is teaching students that the behavior of the temperature of a system with time $T = f(t)$ is a concrete application of the notion of an abstract function $y = f(x)$. Although the simple replacement of concrete quantities (T and t) for the abstract mathematical quantities (x and y) is taken for granted by engineering students at some time in their study, this connection may not have taken place for some students entering thermodynamics. I and my colleagues have also observed that students have no problem evaluating the definite integral of a polynomial expressed as $y = a_0 + a_1x + a_2x^2 + a_3x^3 + a_4x^4$, but when requested to determine the enthalpy change associated with a change in state given a temperature-dependent specific heat $c_p = a_0 + a_1T + a_2T^2 + a_3T^3 + a_4T^4$ some students are at a loss. For them, the connection between abstract mathematics and its use to represent physical quantities has yet to be made. The application of partial derivatives offers a very similar example: Here the ability to connect the abstract $\partial f(x, y)/ \partial x$ with the concrete, for example, $c_p = (\partial h/\partial T)_p$, may be absent. Thermodynamics provides many opportunities for students to develop mathematical maturity. To see mathematical light bulbs turned on in the minds of students is a strong motivator for teaching thermodynamics. Again, we are seeing the application of the Bransford et al. [1] ideas that knowledge is both constructed and organized.

3.1.3 Appreciating, Understanding, and Using Graphical Information

Related to connecting mathematics to the physical world is the use of graphical information. Although students may enter thermodynamics with rudimentary skills in graphing, they have yet to appreciate how important graphical information is to engineering. Thermodynamics is replete with opportunities to help students appreciate, understand, and use graphical information. Figure 2 illustrates this idea. On the left, we see how the ideal gas law $Pv = RT$ can be exploited to plot pressure versus volume for processes in which either the volume, pressure,

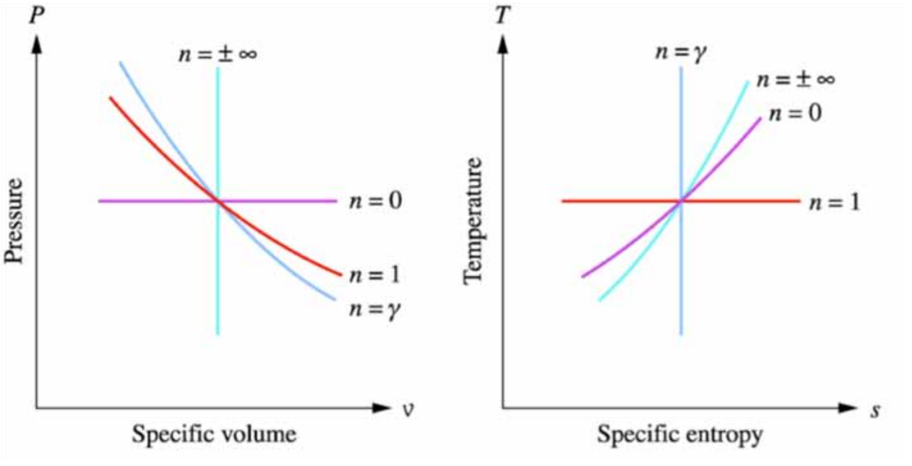


FIGURE 2. The use of pressure-volume and temperature-entropy diagrams helps to visualize thermodynamic processes. For an ideal gas, selected values of the polytropic exponent n allow the polytropic process $Pv^n = constant$ to be interpreted as a constant-pressure process (n = 0), a constant-temperature process (n = 1), a constant-volume process ($n = \pm\infty$), and a constant-entropy process ($n = \gamma = c_p/c_v$).

or temperature are held constant. By adding the ideal-gas relationships that express the entropy changes for changes in pressure, volume, and temperature, the graph on the right is obtained, as well as the P-v relation on the left for a constant-entropy process. Students also learn to use the graph on the left to evaluate the work (per unit mass) crossing the boundary of a system undergoing a reversible process as the area under the P-v line ($w = \int Pdv$). Similarly, the graph on the right can be used to evaluate the heat (per unit mass) crossing the boundary of a system undergoing a reversible process as the area under the T-s line ($q = \int Tds$).

Many students struggle at first to convert a word-problem specification of a process, or series of processes, into a graphical representation. Being able to make such transformations and extend this skill to other areas of engineering is an important step in an engineering student's education. Casting this in the Bransford et al. [1] framework, we see that we are helping students construct and organize their knowledge such that the physical, mathematical, and graphical interpretation of phenomena are integrated into a logical whole.

Before leaving the topic of using graphical information, I want to share a personal incident that reaffirms the idea that learning to interpret graphs can have far-reaching consequences. Conservation of energy for an adiabatic, constant-pressure combustion process is simply expressed by the statement that the enthalpy of the products equals the enthalpy of the reactants. On an enthalpy-temperature graph, this process is simply a horizontal line as shown in Fig. 3. As you can see, this graph illustrates how one might obtain the final temperature of the hot products (T_{ad}) if the reactants and products enthalpy curves were quantitative. As a student in an undergraduate thermodynamics course, this graph bowled me over! It was amazing to me that to determine the maximum temperature in a combustion process all I needed to do was draw a few lines. This one lecture set my career path. I've been a student of combustion ever since.

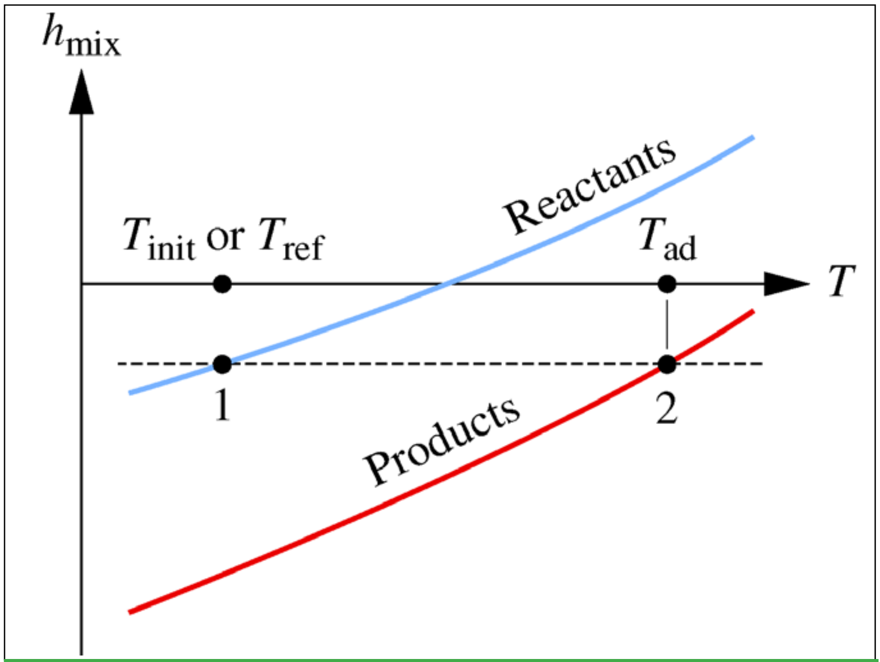


FIGURE 3. An adiabatic, constant-pressure combustion process can be represented as a horizontal line on an enthalpy-temperature graph. The final temperature of the hot products is easily visualized on the graph.

3.1.4 Developing Sound Problem-Solving Skills

The fourth motivator related to the early timing of thermodynamics in the curriculum is that we can help our students establish patterns of problem-solving skills that will serve them well in their upper-division classes, as well as throughout their careers. Figure 4 shows the set of problem-solving procedures I encourage my students to follow. To offer our students this heuristic, or one like it, is essential in a course like thermodynamics, or any other course that occurs early in the engineering major. Extrapolating from what is done at my institution, providing some formal guidelines for problem solving early on is a universal practice in engineering. As educators, we can take pleasure in this opportunity to help our students develop habits that will have such important and long-lasting benefits.

Inspecting Fig. 4, we see that item 3 on the list ties in directly with helping students to appreciate, understand, and use graphical information, as discussed earlier. In thermodynamics, many of the most useful sketches employed are process diagrams on pressure-volume and/or temperature-entropy coordinates. Other important sketches are those that define the system of interest. In thermodynamics, arrows can be added to such sketches to create mass and/or energy flow diagrams. These are quite analogous to free-body diagrams that are the bedrock of early engineering mechanics courses. Figure 5 illustrates this analogy. Creating sketches like these helps students to organize their knowledge; moreover, drawing a sketch guides thinking. For example, students can question whether or not they have added all of the correct arrows (forces for mechanics, energy flows for thermodynamics). In this sense, sketching has a metacognitive component.

Problem-Solving Method

For you to consistently solve engineering problems successfully (both textbook and real problems) depends on your developing a procedure that aids thought processes, facilitates identification of errors along the way, allows others to easily check your work, and provides a reality check at completion. The following general procedure has these attributes and is recommended for your consideration for most problems.

1. State what is known in a simple manner without rewriting the problem statement.
2. Indicate what quantities you want to find.
3. Draw and label useful sketches whenever possible. (What is useful generally depends on the context of the problem.)
4. List your initial assumptions and add others to the list as you proceed with your solution.
5. Analyze the problem and identify the important definitions and principles that apply to your solution.
6. Develop a symbolic or algebraic solution to your problem, delaying substitution of numerical values as late as possible in the process.
7. Substitute numerical values as appropriate and indicate the source of all physical data as you proceed.
8. Check the units associated with each calculation. The factor-label method is an efficient way to do this.
9. Examine your answer critically. Does it appear to be reasonable and consistent with your expectations and/or experience?
10. Write out one or more comments using step 9 and the following questions as your guides. What did you learn as a result of solving the problem? Are your assumptions justified?

FIGURE 4. A typical set of procedures given to students to develop their problem-solving skills.

Note that the last two items of the problem-solving procedure of Fig. 4 explicitly attempt to help students integrate their knowledge and develop metacognitive strategies; step 9 requires students to perform a critical evaluation of their result, a very important metacognitive step; and step 10 encourages the students to step back even further, asking them to write out what they've learned from solving the problem. I have found that students at first do not want to spend the time thinking about the problem they've just solved; they are eager to move on. By assigning point values to the comments in the grading of homework, students will reflect and provide constructive comments. These comments often offer insights on a student's progress. Before exploring Fig. 4 in more detail, we introduce the final motivator on our list.

3.1.5 Thinking Like an Engineer

The final motivator related to the early timing of thermodynamics in the curriculum is that we can help our students to begin "to think like an engineer." Based on our individual experiences and understandings, each of us could come up with a different definition of what it means to think like an engineer. However, it is most likely that there will be many common elements. My list includes the following:

- Make, question, and validate assumptions.
- Be able to work with incomplete knowledge.
- Use a variety of resources as necessary.
- Go beyond "plug and chug."
- Use units as your friends.
- Work from integrated knowledge.

Let's take a look at a few of the items on this list and see how they relate to or expand some of the ideas we have already discussed.

Making, Questioning, and Validating Assumptions. Making, questioning, and validating assumptions is a complex skill. (Note that the problem-solving procedure (Fig. 4) explicitly deals with assumptions.) Although a wide array of assumptions are involved in solving problems in previous courses, e.g., physics and engineering mechanics, thermodynamics is probably the first course where students must focus on assumptions. For example, deciding if a working fluid can be treated as an ideal gas, if a process can be considered adiabatic, or if kinetic energy changes can be neglected offers challenges for students, the mastery of which results in students beginning to think like engineers. Justifying assumptions based on a calculated result is both a higher-level skill and part of the metacognitive regulation of the problem-solving process. Furthermore, confronting assumptions contributes to conceptual understanding.

Using a Variety of Resources. Thermodynamics is also likely to be the first course where students bring together information from various sources such as stand-alone tabulations of properties, online resources and databases, and software. I was not aware that this aspect of my thermodynamics course made students feel like they were beginning to work, or think, like engineers until it was pointed out by a perceptive student in response to the question “What did you like best about this course?” on the end-of-semester course evaluation.

Using Units as Your Friends. This is a mantra recited throughout the engineering curriculum. In engineering, nearly all quantities have units associated with them, and reconciling the units in an equation is as important as the equation itself. Getting students onboard with this idea is the job of early courses in the curriculum – and there is no better place to drive this message home than in thermodynamics. Ideal-gas-law and energy-balance computations offer nontrivial opportunities to deal with units. Furthermore, using units to check algebra is a step towards thinking like an engineer.

Whatever may be on your list, helping students to begin to think like an engineer is a motivating challenge for anyone teaching a course that is located early in the curriculum.

3.2 Historical Context of the Subject Matter

All subjects have a history. And, in all likelihood, some aspects of this history can motivate our teaching of the subject. Students’ misconceptions and beliefs about the physical world often mimic the historical development of a field. In mechanics, fundamental understanding of force and motion took centuries to develop. The misconception that a force is necessary to maintain motion is longstanding and may be a belief held by beginning engineering students [2]. Discussing historical breakthroughs, such as Newton’s three laws of motion, may help students construct their knowledge. Dispelling the notion that heat is a material substance with some strange properties was a major breakthrough in thermodynamics. Adiscussion of the canon-boring experiments of Benjamin Thompson, Count Rumford, can illuminate this break-through.

Introducing historical personages also can provide a welcome human element along with the technical content of a course. Thermodynamics is replete with interesting personalities, among them the previously mentioned Rumford, along with Sadie Carnot, Ludwig Boltzmann, Rudolf Clausius, Rudolf Diesel, and Max Planck. Every subject is sure to have an interesting

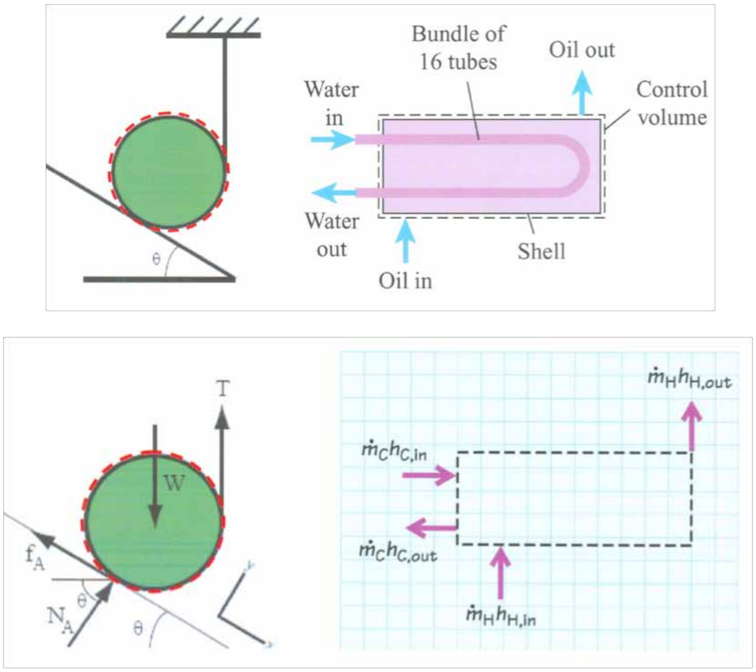


FIGURE 5. Learning how make useful sketches is an important skill to be developed early in the curriculum. (a) Identifying the system of interest and separating it from its surroundings is essential to most engineering problems. (b) Having identified the system, forces can be added to create a free-body diagram used in a static equilibrium analysis (left), or energy flows can be shown to assist in writing conservation of energy (right).

cast of characters. Helping students to see the historical context of what they are learning can be motivating to an instructor. Learning a little history to share with our students also can be part of our own lifelong learning experience.

3.3 Specific Current Relevance of the Subject Matter

One answer to the question of what motivates your teaching is often to help students understand the relevance of the subject matter. Most engineering students hunger for and thrive on an understanding of the relevance of what they are learning. All engineering courses have relevance or they would not be part of the curriculum, although the relevance of some subjects may be much more immediate or obvious than that of others. In all of the courses I teach, I try to illustrate clearly and concretely the current relevance of the subject matter. This is similar to continuing the historical context to the present and projecting it into the future – the future in which our students build their careers. Showing relevance, which may sometimes be somewhat hidden, is a strong motivator for me.

For example, with energy and climate change issues continually in the headlines (see Fig. 6), illustrating the relevance of thermodynamics is easy: at the core of the global warming problem is an energy balance; understanding and applying energy-conservation measures to mitigate climate changes or decrease dependence on foreign oil clearly require the use of both the first and second laws of thermodynamics, and estimating the amount of carbon dioxide emitted per kilowatt hour of electricity generated in a power plant requires a host of concepts learned in a thermodynamics course. Adding to this list is not difficult. With such motivation, it is easy to answer the question “Why teach thermodynamics?” Energy and climate change issues are relevant to a host of STEM subjects and can motivate the teaching of chemistry, physics, geography, geology, and many others. What connections can you make with your subject matter to these issues?

3.4 New Tools or Approaches to Teaching and Learning

New research problems can sustain our interest in and enthusiasm for research. Are there similar motivators that can sustain our interest in and enthusiasm for teaching? I answer in the affirmative; however, like ideas for research, we must seek these out. In the past several years, three things have added excitement to my teaching of thermodynamics:

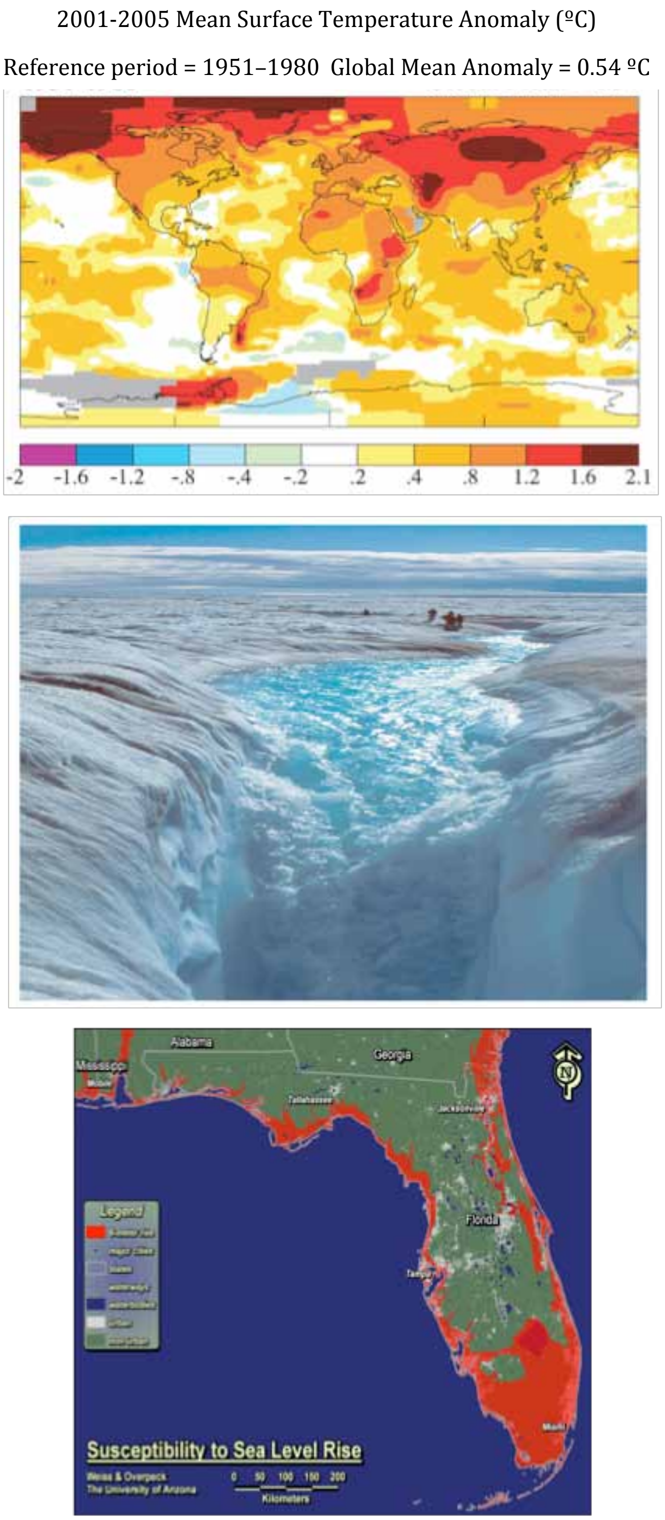
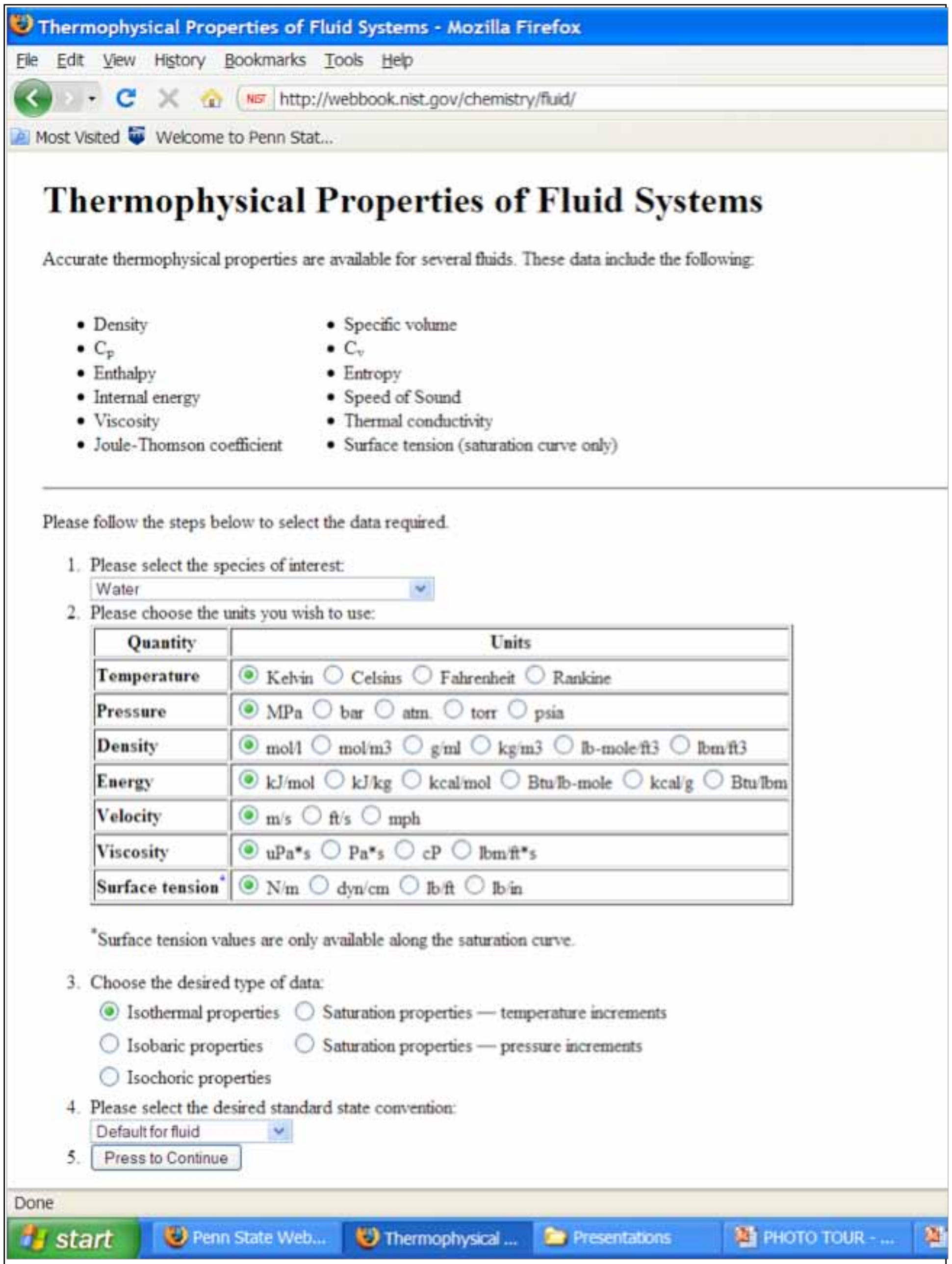


FIGURE 6. Arctic regions (dark red) have been warming at a greater pace than in lower latitudes (top). From [3]. Melt waters on the Greenland ice sheet cascading into moulins (crevasses) affect the dynamics of ice sheet breakup (middle). Photograph courtesy of Roger Braithwaite, University of Manchester, UK. Low lying coastal areas are at risk to sea level rise associated with both ice sheet melting and ocean water thermal expansion (bottom). Courtesy of Jeremy Weiss and Jonathan Overpeck, University of Arizona. See also [4].



Thermophysical Properties of Fluid Systems

Accurate thermophysical properties are available for several fluids. These data include the following:

- Density
- C_p
- Enthalpy
- Internal energy
- Viscosity
- Joule-Thomson coefficient
- Specific volume
- C_v
- Entropy
- Speed of Sound
- Thermal conductivity
- Surface tension (saturation curve only)

Please follow the steps below to select the data required.

1. Please select the species of interest: Water
2. Please choose the units you wish to use:

Quantity	Units
Temperature	● Kelvin ○ Celsius ○ Fahrenheit ○ Rankine
Pressure	● MPa ○ bar ○ atm. ○ torr ○ psia
Density	● mol/l ○ mol/m3 ○ g/ml ○ kg/m3 ○ lb-mole/ft3 ○ lbm/ft3
Energy	● kJ/mol ○ kJ/kg ○ kcal/mol ○ Btu/lb-mole ○ kcal/g ○ Btu/lbm
Velocity	● m/s ○ ft/s ○ mph
Viscosity	● uPa*s ○ Pa*s ○ cP ○ lbm/ft*s
Surface tension*	● N/m ○ dyn/cm ○ lb/ft ○ lb/in

*Surface tension values are only available along the saturation curve.

3. Choose the desired type of data:
   ● Isothermal properties ○ Saturation properties — temperature increments
   ○ Isobaric properties ○ Saturation properties — pressure increments
   ○ Isochoric properties
4. Please select the desired standard state convention: Default for fluid
5. Press to Continue

FIGURE 7. The user interface for the NIST online thermophysical property database.

First, the use of the National Institute of Science and Technology (NIST) website and software for thermodynamic properties; second, the use of a tablet PC as a blackboard; and third, a much greater use of active and collaborative learning in the course. Of these three, only the first is truly specific to thermodynamics. The other two certainly can be applied to any subject; however, they have indeed motivated my teaching of thermodynamics.

Discovering the National Institute of Science and Technology (NIST) website and software for thermodynamic properties has transformed the way I teach thermodynamics. My students still learn to use property tables, which they use in examinations, but their learning to access the NIST database provides them with a powerful tool that they can use in subsequent courses (fluid mechanics, heat transfer, and others) and throughout their careers. The online database [5] provides both thermodynamic and transport properties for a large number of fluids, including modern refrigerants. The website permits the user to select the fluid of interest, to select the units desired (one can mix and match SI and U.S. customary units), and to create individualized tables for isothermal properties, isobaric properties, isochoric properties, and

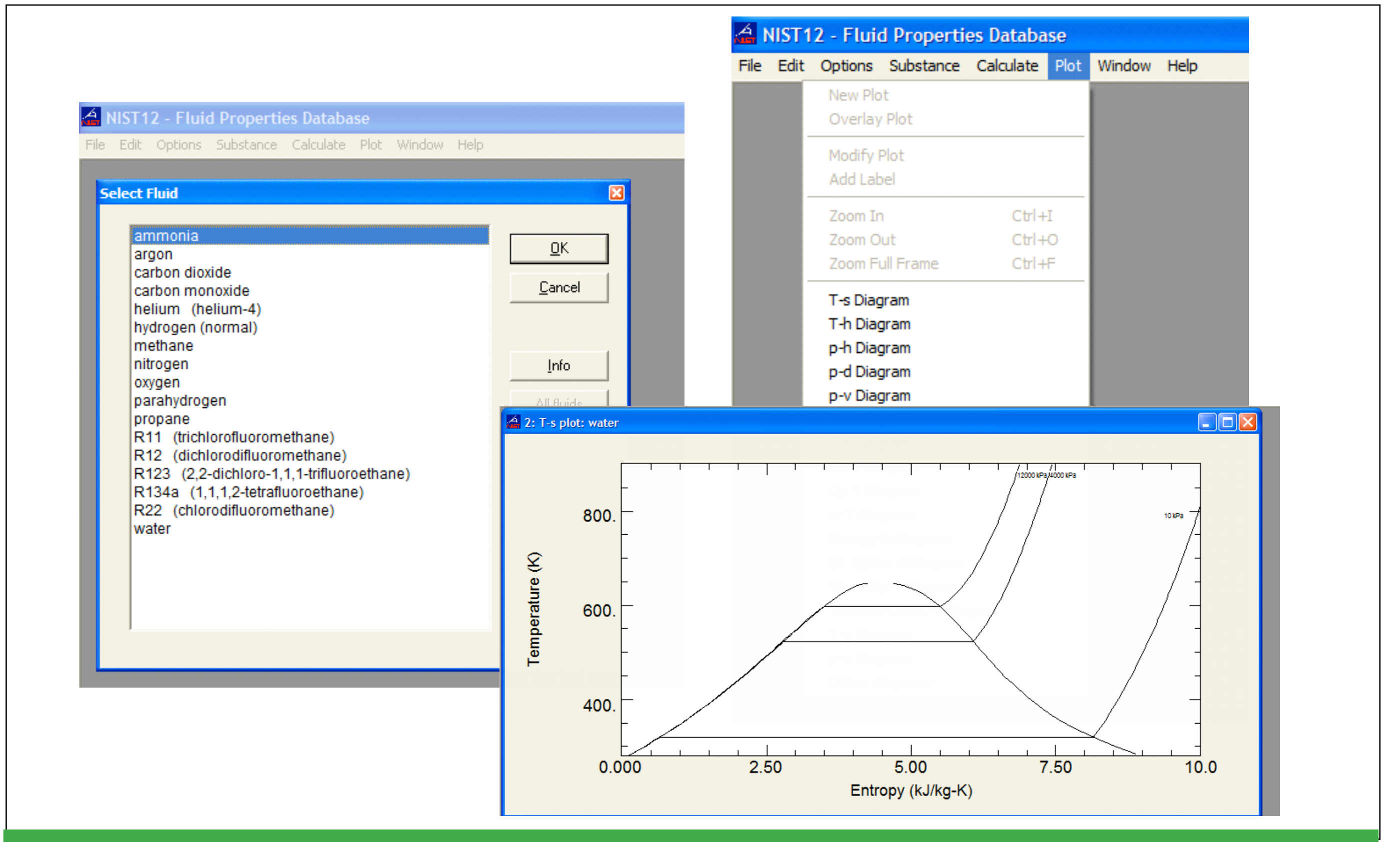


FIGURE 8. The NIST software allows sophisticated plotting and other options not available with the online database. The full REFPROP software provides properties for dozens of fluids.

saturation properties in either temperature or pressure increments (see Figure 7). The NIST software [6] is even more powerful, with many more options, including the ability to make a variety of plots (see Figure 8).

The tablet PC has allowed me to develop a lecture in the same manner as using the blackboard, while simultaneously eliminating the time-wasting and distracting occasional use of other media in conjunction with the blackboard. Before using the tablet PC, I felt after some class periods that I had just ring-mastered a three-ring circus: writing on the board, lowering a screen to project a transparency, raising the screen and going back to writing on the board, lowering the screen once again, etc. Now, with the tablet PC loaded with blank PowerPoint slides, I use the tablet stylus just like chalk on the board. Not only do I have multiple colors and line widths available for writing, but I am always facing my students. Any visuals or links to the internet can be interspersed among the blank slides, so their use is seamless, with no raising and lowering of screens. Figure 9 illustrates the use of the tablet PC in a discussion of throttles, one of the several steady-flow devices normally discussed in a thermodynamics class.

The third factor that has recently invigorated my teaching is a much greater use of active and collaborative learning. Educational research has found that both active and collaborative learning can enhance learning. The following quotation from Felder [7] encapsulates these findings:

> *In the traditional approach to college teaching, most class time is spent with the professor lecturing and the students watching and listening. The students work individually on assignments, and cooperation is discouraged.*
>
> *Such teacher-centered instructional methods have been found inferior to instruction that involved active learning, in which students solve problems, answer questions, formulate questions of their own, discuss, explain, debate, or brainstorm during class, and cooperative learning, in which students work in teams on problems and projects under conditions that assure both positive interdependence and individual accountability.*

My approach to active learning is multi-faceted. Very simple exercises, such as asking students to write down their answer to a question I put to the class, may take only 30 seconds, whereas some exercises involve small-group efforts that can require 20 minutes

Tablet PC allows seamless use of visual materials

Here's a throttle. A really big throttle!

Tablet PC provides a modern blackboard with multi-colored chalk AND the instructor always faces the class.

Some theory:

THROTTLE - SSSF

$$\cancel{\dot{Q}_{net,in}}^{\approx 0} - \cancel{\dot{W}_{net,out}}^{0} = \dot{m}\left(h_2 - h_1 + \cancel{\frac{V_2^2 - V_1^2}{2}}^{\sim 0} + g\,\cancel{(z_2 - z_1)}_{0}\right)$$

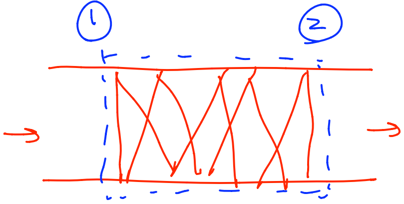
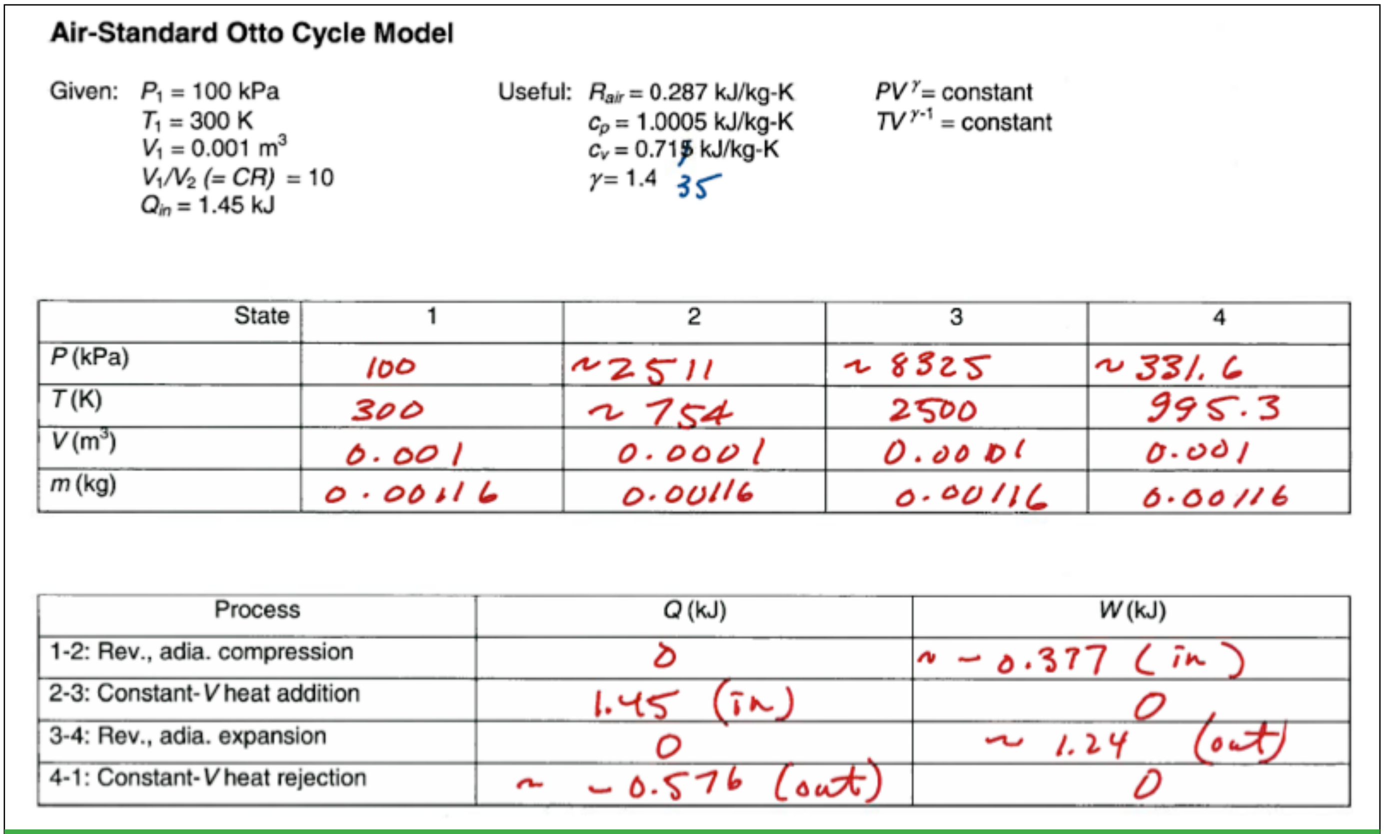


FIGURE 9. The use of a tablet PC allows the easy integration of visual materials (top) into a lecture developed in the old-fashioned way (bottom). Photograph courtesy of General Electric Company.

or more. Adding active learning to a traditional lecture course can be relatively painless [8]. For example, most instructors ask their classes questions and sometimes students will volunteer to answer these questions. However, asking every student to write a response engages nearly everyone, unlike the free-floating question that students can either choose to think about or ignore. Similarly, examples that we work for our students might be better worked by the students themselves. I often ask students to work in pairs or groups of three to work an example problem, which we then discuss. Such discussions are usually lively as students are now engaged and may have very specific questions. Such longer activities usually involve, first, a mini-lecture on some topic, for example, the air-standard Otto cycle. This is followed by giving the students, who work in groups of three, a challenging but doable task. For the Otto cycle example, students are asked to define all of the state points and determine the heat transfer and work associated with each process. Figure 10 shows the handout students complete for this exercise. I also provide some guidance at the outset and/or during the exercise. For the Otto



Air-Standard Otto Cycle Model

Given:
$P_1 = 100$ kPa
$T_1 = 300$ K
$V_1 = 0.001$ m^3
V_1/V_2 (= CR) = 10
$Q_{in} = 1.45$ kJ

Useful:
$R_{air} = 0.287$ kJ/kg-K
$c_p = 1.0005$ kJ/kg-K
$c_v = 0.71$~~5~~7 kJ/kg-K
$\gamma = 1.4$ 35

$PV^{\gamma} =$ constant
$TV^{\gamma-1} =$ constant

State	1	2	3	4
P (kPa)	100	~2511	~ 8325	~ 331.6
T (K)	300	~ 754	2500	995.3
V (m^3)	0.001	0.0001	0.0001	0.001
m (kg)	0.00116	0.00116	0.00116	0.00116

Process	Q (kJ)	W (kJ)
1-2: Rev., adia. compression	0	~ −0.377 (in)
2-3: Constant-V heat addition	1.45 (in)	0
3-4: Rev., adia. expansion	0	~ 1.24 (out)
4-1: Constant-V heat rejection	~ −0.576 (out)	0

FIGURE 10. In this exercise, students work in groups of three to analyze an air-standard Otto cycle. Students determine values for the properties at the four state points along with the heat transfer and work associated with each process connecting the state points.

cycle, I write out the ideal-gas law, the first law of thermodynamics, the definition of reversible work, and a few calorific property relations, e.g., $dh = c_p dT$, and some isentropic-process property relations. For this exercise, students will often work past the end of class, even after they have been reminded that the class is over. Now that's motivation (for the instructor)! The exercise concludes with an opportunity for students to ask questions and for me to probe to make sure that everyone understood how to do the exercise.

The use of new tools and approaches – new, at least, to the instructor – is a possibility for any course. Finding ways to improve instruction and learning can be very rewarding.

4. Concluding Remarks

This essay attempts to answer the question of what motivates us as engineering educators to teach any particular course. Why is this question important? I believe that by consciously asking this question, and others like it, that we can improve our teaching and concomitantly add enthusiasm and joy to the process. I chose to answer this question using thermodynamics as an illustration. Although thermodynamics is one of my favorite courses to teach – and after reflecting I now have a better understanding of why – I could have chosen any other course in my repertoire. By focusing on the particular attributes of a course – its potential impact on students, its historical context, its current relevance, and new tools associated with it – we can see what makes any course special. Discovering this specialness can motivate us to do new things and to make our courses better and, as a result, derive greater satisfaction from our teaching.

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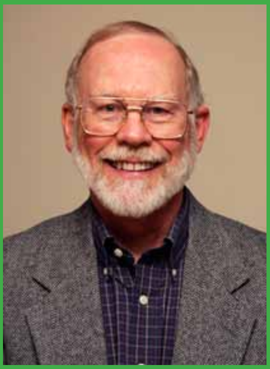
References

1. Bransford, J. D., Brown, A. L., Cocking, R. R., Donovan, M. S., and Pellegrino, J. W., *(Eds.), How People Learn: Brain, Mind, Experience, and School*, Expanded Edition, National Research Council, National Academies Press, Washington, DC, 2000.
2. Clement, J., "Students' Preconceptions in Introductory Physics," *American Journal of Physics, 50*(1): 66–71 (1982).
3. Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D. W., and Medina-Elizades, M., "Global Temperature Change, *Proceedings of the National Academy of Science, 103*(39): 14,288–14,293 (2006).
4. Hansen, J., "High Sea Level Rises Are Coming – Unless We Act Now," *New Scientist*, Issue 2614, 28 July, 2007.
5. Linstrom, P., and Mallard, W. G. (Eds.), NIST Chemistry Web Book, Thermophysical Properties of Fluid Systems, National Institute of Standards and Technology, Gaithersburg, MD, 2007, http://webbook.nist.gov/chemistry/fluid/.
6. NIST Reference Fluid Thermodynamic and Transport Properties Database (REFPROP): Version 8. See http://www.nist.gov/srd/nist23.htm.
7. Felder, R. M., URL: http://www4.ncsu.edu/unity/locker/users/f/felder/public/. Accessed 2/25/2008.
8. Turns, S. R., Pauley, L. P., and Zappe, S. E., "Active and Collaborative Learning in a First Course in Fluid Mechanics: Implementation and Transfer," *International Journal of Engineering Education, 25*(5): 979–997 (2009).



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