Teaching Core Concepts in Thermal and Fluid Sciences Using Devices Familiar to the Student

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Abstract

Students often struggle with core concepts in thermal and fluid sciences courses. Through a National Science Foundation funded project we are developing a suite of experiments designed to expose student misperceptions about core concepts, and to hopefully improve the students' understanding of the basic principles. The experiments use common devices that the students are familiar with. By using such devices the students can concentrate on learning the underlying principles rather than getting lost in understanding how the device works. There are seven experiments currently being developed using a hair dryer, a blender, a toaster, a bicycle pump, a computer power supply, a pipe with a sudden expansion, and a water container with a hole in it. These will be implemented over the next two years at the authors' campuses to determine the effectiveness of each.

These experiments are used as part of a three step approach to teaching the core principles. First, before the relevant lecture on the material, the students are exposed to a demonstration of one of the device. This is done to expose misconceptions they may have, and to try to increase their interest in the material. A traditional lecture is then presented on the material. The students should be more prepared for the lecture, and may have questions they may not otherwise have. Finally, the students go into the lab and run a more extensive test using the same equipment.

This paper presents a pedagogical framework for these types of exercises and an overview of the seven experiments that are under development.

Introduction

This paper outlines a suite of seven laboratory exercises intended to be used in undergraduate classes in thermal and fluid sciences. The exercises are designed to make the students confront their misperceptions about the core principles involved, and to ultimately improve the students' understanding of those core principles.

The experiments have several characteristics in common. They are all designed around devices that are familiar to the students. This helps to reduce or eliminate confusion about the operation of the devices so that the students can focus on the underlying principles. The devices include a hair dryer, a blender, a toaster, a bicycle pump, a computer power supply, a pipe with a sudden expansion, and a water container with a hole in it. Most of these devices are inexpensive and easy to obtain. One notable exception is the computer power supply experiment which involves the use of an air flow bench. An air flow bench can be purchased commercially or can be built at a much lower cost. A key feature of these exercises is the use of low cost, USB based data acquisition (DAQ) devices. Many companies are beginning to offer these types of devices, and prices are getting to the point where students may be able to obtain one for about the cost of a textbook to use throughout their college careers and beyond.

Before outlining the suite of exercises, we take a look at the pedagogical framework which provides the basis for them. Most undergraduate engineering courses that have laboratory components involve a series of structured exercises that employ preconfigured devices that yield predictable results. The students are usually required to follow a particular procedure to run the test, record data, analyze data, and compare the results to the theory that was learned in class. This type of experiment is designed to demonstrate theory that is given in an earlier lecture. Certainly there is a place for these types of exercises in a laboratory curriculum. Unfortunately, these types of exercises often do not confront the students with a real learning experience, simply a demonstration that the theory given in their lecture is correct. Also, these types of exercises often require the use of equipment that is unfamiliar to the students forcing them to concentrate on the operation of the device rather than the underlying principles. A good example of this is a refrigerator that is commonly used for thermodynamics experiments. The device generally has no resemblance to a refrigerator the students are familiar with, so it can be difficult for them to relate to the device on a practical level. We recognize that many of the laboratory exercises at our own institutions are of this type, which is part of the motivation for this work.

The seven exercises outlined in this paper are intended to be used in several undergraduate courses. No attempt is being made to entirely replace traditional lab exercises in these courses with our own, but to supplement them. A key difference between our exercises and traditional exercises is that ours are designed to teach core principles rather than to demonstrate them. This type of learning will be discussed later in this paper as the pedagogical framework for these exercises is explored.

Pedagogical Framework

Cognitive science research is recognizing that methods other than traditional lectures can result in improved student learning. The National Research Council report "How People Learn"[(1)] summarizes research done in this area. This report discusses the differences between experts and novices, and methods each use for organizing knowledge. It recognizes that students bring pre-conceived ideas with them, some of which contain misperceptions about core principles. Teachers need to realize that these misperceptions exist and confront them. It is becoming increasing well recognized that teachers need to do more than convey knowledge. They must also develop methods for instilling an understanding of core principles.

Knowledge and problem solving abilities can get students through a traditional course, but understanding of core principles is needed for them to be able to apply their knowledge to unique problems. Two approaches that are currently popular for confronting misperceptions and trying to develop understanding are project-based learning and inquiry-based learning.

Project-based learning involves open ended projects, often with ill defined constraints designed to challenge the students to think and hopefully develop a better understanding of the principles involved. Clearly, capstone projects fall into this category, particularly those that are industrially sponsored. Examples abound of these types of projects [(2-6)]. Others are using open ended projects to enhance student learning in other undergraduate courses. There are many examples. Nasr and Ramadan [(7)] report on their approach to employing problem-based learning into a thermodynamics course. Dukhan and Jenkins [(8)] discuss an interesting approach in a heat transfer course where students become the teachers in designing an experiment for the heat transfer lab to demonstrate the principles of thermal resistance and thermal resistance networks. Other examples are abundant.

Our exercises fall more into the category of inquiry-based learning. Inquiry-based learning involves the students in a different level of learning than traditional information or knowledge transfer. In this type of learning students are often asked to pose questions, develop experiments to try to answer those questions, analyze information obtained from those experiments and draw conclusions. Others have implemented this approach to one degree or another in their engineering courses. For example, Ross and Venugopal [(9)] describe several experiments used in a physics laboratory to teach electrical concepts using inquiry-based learning as described by McDermott [(10)].

Our approach is a variation often referred to as guided-inquiry in that the questions are generally posed by the instructor. Simple equipment is provided for the students to use. Observations are made by the students and they are challenged to make sense of the observations based on their past experiences. We propose a three step approach: demonstrate-lecture-experiment. First, a demonstration of a common device is made. The students take a short pre-demonstration survey to help expose misconceptions they may have about the concept. They make observations about the demonstration and try to reconcile the observations with their notions of what is going on. The whole process only lasts about 15 minutes, and challenges the students to think about the underlying principles. This is followed by a traditional lecture on the concept. By using the demonstration first the students can be stimulated to think about the core concepts involved and ask very meaningful questions during the lecture. After the lecture the students are asked to conduct a more detailed lab exercise using the same equipment to help them gain the deeper understanding they may not have otherwise obtained through the lecture alone.

It is important to recognize that there are different types of learners. Kolb [(11)] describes four learning styles: concrete active (activists), concrete reflective (reflectors), abstract reflective (theorists), and abstract active (pragmatists). Each of these types of learners has their own methods for gaining knowledge and understanding. No single style of teaching is right for everyone. It is important to balance class-room activities to be able to reach everyone. Tuan, et.al. [(12)] have looked at the effect of inquiry-based learning methods on the motivation of students with different learning styles, indicating that the incorporation of at least some inquiry-based learning exercises into the classroom may help improve the learning of the students.

The remainder of this paper briefly describes each of the seven experiments. Examples are given to illustrate the core concepts involved in each exercise and of questions that may be posed to the students for each. Each is in a different state of development, but most of them have been at least prototyped, and preliminary tests have been run using the equipment. Work is just beginning on deploying these exercises into classrooms. Early prototype deployment at Portland State University has shown promising results, but it is too early to draw any conclusions. We welcome any feedback.

Hair Dryer Exercise

The motivation for this exercise first came from an experiment that has been regularly used and reported on by Edwards [13]. The original exercise described in that paper involves the measurement of the energy terms involved in a first law analysis of an open system – the hair dryer. Since it falls into the category of demonstration rather than teaching, it has been modified to become an inquiry-based learning exercise. The hairdryer is a good example of the first law of thermodynamics for an open system. Students are asked questions about energy terms that are needed for an energy balance analysis. They are asked to predict the effect on outlet temperature if the fan speed is changed without changing the power to the heaters. The hairdryer has separate power and speed controls so an interesting result when the students try to change the fan speed without changing the power setting is that the outlet temperature does the opposite to what is expected (if the fan speed is increased the outlet temperature rises instead of drops). This occurs because the hairdryer is wired to cause power to the heaters to vary with the fan speed. Students are allowed to ponder this dilemma. Will they recognize that something is wrong or will they try to rationalize the observed results? A second demonstration is made using a device that has the fan and heater elements wired independently. Students who did not immediately recognize that something was not right about the first exercise are now given conflicting information to think about. The final result should be a better understanding of the underlying principles. Figures 1 and 2 show the equipment used for this exercise.

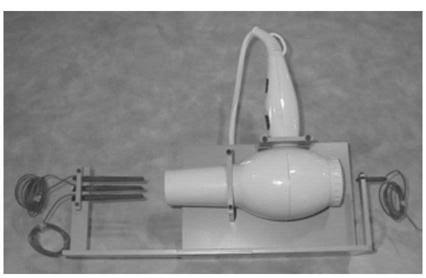

Figure 1 – Hairdryer Apparatus

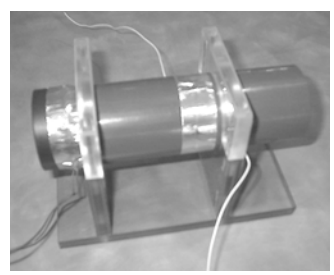

Figure 2 – Heater in Tube Apparatus

Blender Exercise

The blender exercise is designed to teach the concept that work can be converted into other forms of energy. In the case of a blender the electric work entering the system is converted to internal energy of the water. This is a demonstration of the first law of thermodynamics for a closed system. Water is put in the blender and the system is allowed to reach equilibrium. The students are asked questions to get them to predict what will happen to the water once the blender is turned on. A particularly revealing question is to ask them to explain why the water will do what they predict. Their answers can lead to an enlightening discussion about energy conversion and the first law of thermodynamics. Figure 3 shows a schematic of the test set-up, and figure 4 shows the actual devise that is used.

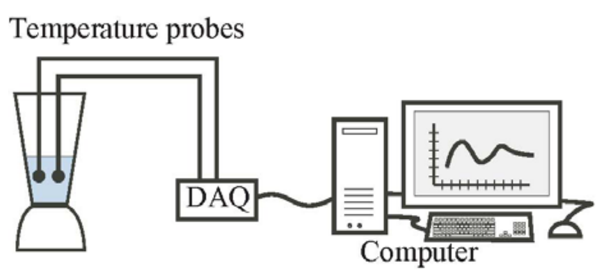

Figure 3 – Blender Schematic

Figure 4 – Blender Apparatus

The test would normally be ended when the water has warmed up sufficiently to demonstrate the principle, but while this data was being taken the students asked what would happen if the speed were changed, and then if the blender were to be shut off. The plot immediately changed when the conditions changed. This lead to a discussion of the core principles involved, and is an example of the type of student interaction that we expect from this set of experiments. It demonstrates that the students are thinking about the principles rather than just watching a demonstration.

Toaster Exercise

The toaster exercise is used to teach radiation heat transfer concepts. Simulated “toast” made of stainless steel sheet is used as a test sample. Some of the “toast” is polished and some is painted black. A polished sample is placed in one side of the toaster and a black sample is placed in the other side. The toaster is depressed causing the heating elements to turn on. The “toast” is allowed to warm up for approximately 1-1/2 minutes at which time the toaster is then turned off. The “toast” is removed and allowed to cool in air. The students can easily see the dramatic difference in heating and cooling between the two test samples. Figure 5 shows the test setup for this exercise, and figure 6 shows typical results. Notice that the black “toast” not only warms up faster, but also cools down faster than the shiny one. Many students predict that the black "toast" will cool slower than the shiny one. This can lead to further discussion of radiation concepts.

Figure 5 – Toaster Hardware

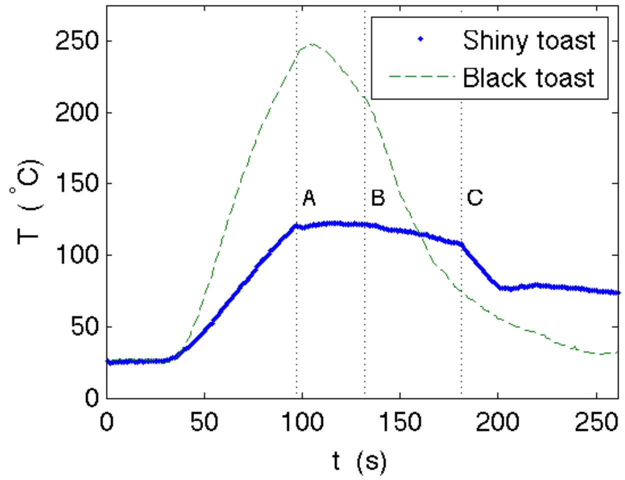

Figure 6 – Typical Toaster Results

As with the other experiments, the toaster is first run as an in-class demonstration before radiation is introduced in the course to stimulate discussion about the topic. After radiation is introduced the students return to the lab for a more extensive investigation using the toaster. The final form of the extended lab portion of this test is under development, but some of the ideas being considered include a comparison of other surface properties and effects of cooling in and out of the toaster.

Bicycle Pump Exercise

The core principle involved in the bicycle exercise concerns the direct conversion of work to internal energy of the working fluid – air in this case. What happens when the pump handle is depressed, compressing the air into a closed cylinder? How does this compare with the results of leaving the cylinder open, allowing air to escape as the plunger is depressed? Students are asked to create P-V and T-V diagrams for each case. The principles that are involved are fairly advanced, making this exercise appropriate for both undergraduate and graduate level courses.

Figure 7 – Bicycle Pump

Figure 7 shows a prototype of the apparatus that will be used for this exercise. This is one of the least developed exercises at this point, so this will be the focus of much of our effort.

Computer Power Supply Exercise

Many mechanical and electrical devices operate according to characteristic curves that are dependent on some parameter. A fan does not deliver a fixed amount of air. The amount of air that can be expected from a fan is dependent on the back pressure of the system the fan is attached to. However, a system has its own characteristic curve showing how much back pressure there is for a given flow rate (Figure 8). To determine the actual flow rate one needs to find the intersection of these two curves. Students should be able to understand how to interpret and use this information in design.

A computer power supply is a device familiar to the students and readily available. In this exercise the students are asked to plot the fan curve for the fan in the power supply. They then plot the flow impedance curve for the power supply housing. Using this information they predict how much air actually flows through the device when the fan is on. After they make their prediction they marry the fan and housing and measure the actual flow rate. Figure 9 shows typical results obtained during the exercise.

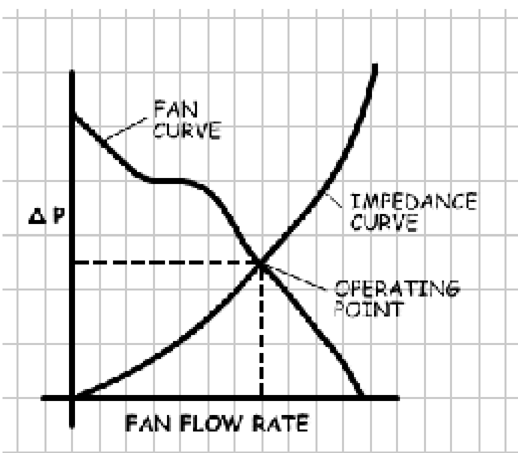

Figure 8

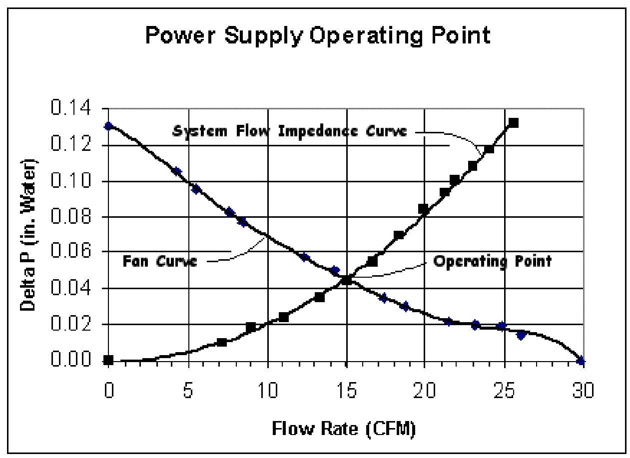

Figure 9

This exercise requires the use of an air flow bench to make the measurements, making this the most expensive of the suite of exercises. Commercial versions of this type of flow bench can be purchased, however, both Portland State and Penn State Erie have built their own at a greatly reduced cost. Plans for building a flow bench will be part of the final report for this project.

<u>Sudden Expansion Exercise</u>

The sudden expansion experiment was deployed in an introductory fluid mechanics course for third year Mechanical Engineering and Civil Engineering students during Fall 2007. Figure 10 shows a schematic of the laboratory apparatus. A blower draws air through a duct constructed from tubing of two diameters. The transition between diameters is abrupt.

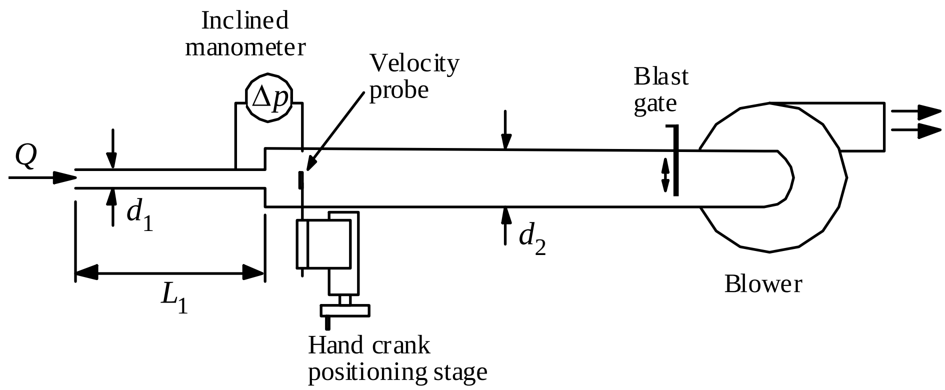

Figure 10 - Schematic of sudden expansion apparatus

This exercise introduces the concept of head loss. Two common misperceptions that students might have about flow through a duct like this are: a.) the fluid pressure must always decrease in the direction of the flow due to friction and b.) the smaller tube must be at higher pressure.

The students are asked to predict both the sign and magnitude of the pressure change across the sudden expansion before they make any measurements. Direct measurement shows that the pressure immediately downstream of the sudden expansion is higher than the pressure immediately upstream of the sudden expansion. This goes against many of the intuitive ideas the students may have. However, the pressure rise across the sudden expansion is much less than that predicted by the Bernoulli equation. This fact is used to stimulate discussion about flow coefficients, the Bernoulli equation, and flow in ducts in general. This apparatus can also be used to plot the flow profile across the cross-section of the duct. Recktenwald(13) has reported fairly extensively on this exercise. Please refer to this paper for more information.

Tank Draining Exercise

This exercise is designed to stimulate interest in the hydrostatic equation and to expose misperceptions about the effects that the shape of the container has on the results. The concept of quasi-equilibrium can also be introduced through this demonstration. Figure 11 shows a schematic of the apparatus used for this exercise. Both tanks have a small hole in the side. The hole is plugged and the tank is filled. The stopper is removed and the water flows from the tank into a catch basin. A pressure transducer is located opposite of the hole to measure the pressure due to the high of the water column.

Again, Recktenwald(13) has reported fairly extensively on this exercise. Please refer to this paper for more information.

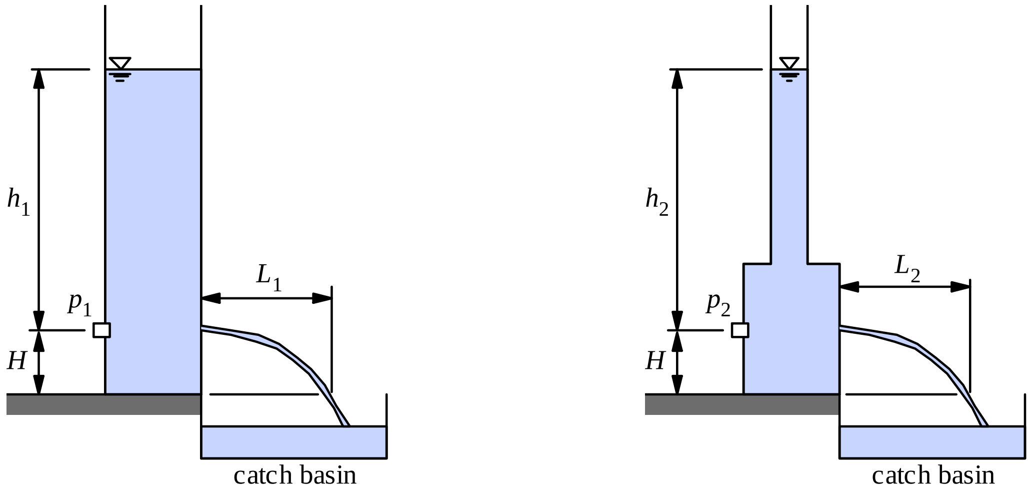

Figure 11 – Tank Draining Experiment

Conclusions

This paper gives an outline of a suite of experiments we are developing in the areas of fluid and thermal sciences. The experiments are at various stages of development. The hair dryer, blender, sudden expansion, tank draining and toaster are substantially complete. The bicycle pump has been prototyped, but work needs to be done on the hardware. The computer power supply exercise can be run as a regular lab exercise at this point, but work needs to be done to modify it to fit into this suite of experiments. More information about any of these experiments can be obtained by contacting either of the authors. A website has been started to disseminate information about these experiments at http://eet.cecs.pdx.edu/. As of the publish date of this paper there is only information on the blender and toaster experiments at this web site. More will be available soon.

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References:

[1] National Research Council. How People Learn: Brain, Mind, Experience, and School, National Academy Press, Washington, DC, 2000.

[2] A.E. Jackson, “An Industry-Centered Capstone Experience for Aeronautical Management Technology Students at Arizona State University East,” ASEE/IEEE Frontiers in Education Conference, 1998.

[3] D.E. Roth, J. Bandstra, “Problem and Expectations of Industrial Sponsored Undergraduate Senior Engineering Technology Projects using FEA,” Proceedings of 1992 International ANSYS Conference, Pittsburgh, PA, pp 3.53-3.58, 1992

[4] R.C. Edwards, “Mechanical Engineering Technology Senior Projects – Partnering With Industry to Enhance the Students’ Capstone Experience,” Technology Interface, Fall 2006.

[5] C. Luongo, C. Shih, J. Sturges, D. Bogle "Senior Design Projects in Mechanical Engineering – Active Involvement of Industry Partners and Advisory Council," Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition, 2007.

[6] T.E. Dwan, G.E. Piper, C.E. Wick, B.E. Bishop, "Systems Ball – A Creative Capstone Design Experience," ASEE/IEEE Frontiers in Education Conference, 2001.

[7] K. Nasr, B. Ramadan, "Implementation of Problem-Based Learning into Engineering Thermodynamics," Proceedings of the 2007American Society for Engineering Education Annual Conference & Exposition, 2007.

[8] N. Dukhan, M. Jenkins, "Student/Teacher Role Swap in Heat Transfer," Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition, 2007.

[9] R. Ross, P Venugopal, "Inquiry-Based Activities in a Second Semester Physics Laboratory: Results of a Two-Year Assessment," Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition, 2007.

[10] L.C. McDermott, et.al., "Physics by Inquiry," John Wiley & Sons, 1996.

[11] D.A. Kolb, "Experiential Learning," New Jersey, Prentice Hall, 1984.

[12] H. Tuan, C. Chin, C. Tsai, S. Cheng, "Investigating the Effectiveness of Inquiry Instruction on the Motivation of Different Learning Styles Students," International Journal of Science and Mathematics Education, 3: 541-566, 2005.

[13] R.C. Edwards, "A Simple Hairdryer Experiment to Demonstrate the First Law of Thermodynamics," Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition, 2005.

[14] G. Recktenwald, R.C. Edwards, "Using Simple Experiments to Teach Core Concepts in the Thermal and Fluid Sciences," Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition, 2007.

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