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Using a Blender to Teach Qualitative Reasoning with the First Law of Thermodynamics

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Engineering of Everyday Things

The *Engineering of Everyday Things* project aims to develop laboratory exercises to enhance learning of core concepts in the thermal and fluid sciences. Students perform experiments on everyday technology such as a hair dryer, a bicycle pump, a blender, a computer power supply, and a toaster, or on very simple hardware such as a tank of water with a hole in it, or a pipe section with a change of area. The laboratory exercises are designed to engage students by showing the everyday application of their coursework, to teach them qualitative reasoning, and to expose their misperceptions about core concepts.

Qualitative Reasoning

Qualitative reasoning is the use of engineering models to predict system response when all terms in the model are not fully specified and when time and other resources are not available for detailed quantitative analysis. Qualitative reasoning involves manipulating an analytical model with one of the following

- Forming ratios;
- Neglecting all but the dominant terms;
- using common sense.

This poster describes a relatively simple thermodynamics experiment that gives students practice with qualitative reasoning.

Blender Apparatus

Figure 1 is a photo of the equipment used to demonstrate the equivalence of work and energy—a modern version of Joule's experiment. The apparatus includes an ordinary kitchen blender, thermocouples mounted on rigid wooden supports (chopsticks!), a four channel data acquisition device (NI USB-9211), a computer running LabVIEW, and a power meter (Watts Up? Pro).

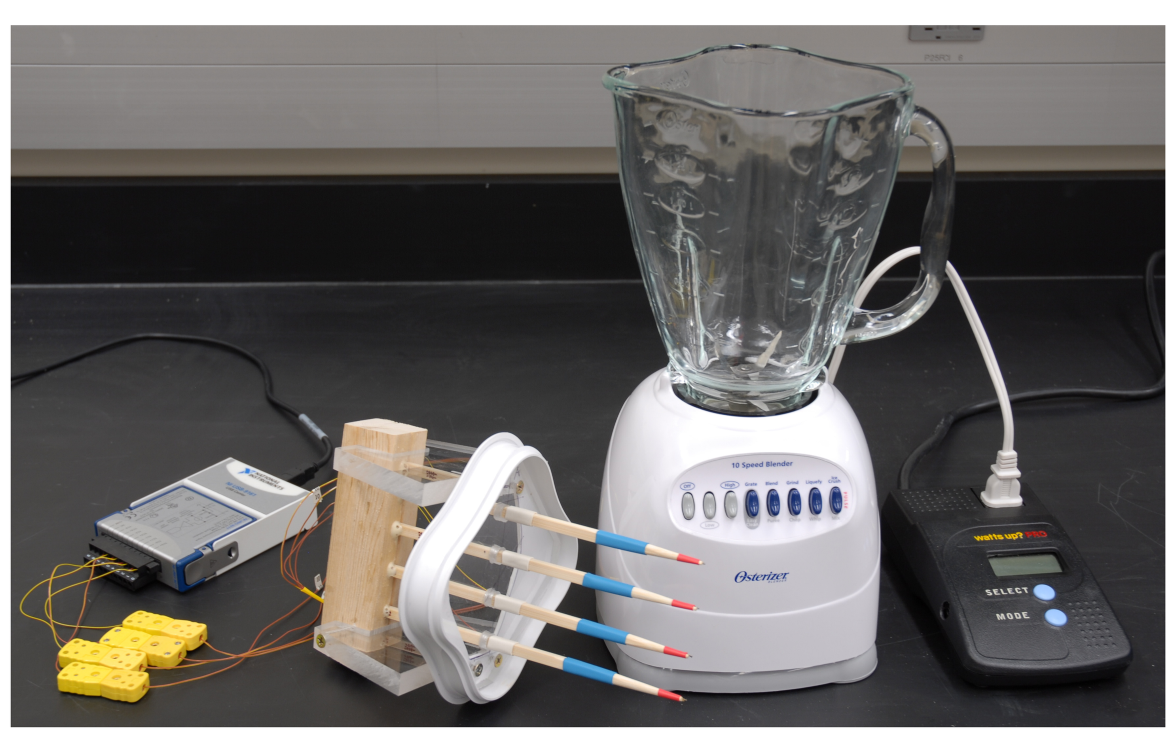

Figure 1: Equipment used in the blender experiment.

In-class Demonstration

The in-class demonstration is given *before* the students have attended lectures on the rate form of the first law. The blender is half-filled with water. Before turning on the blender, students are asked to complete a one page worksheet with the following questions.

1. When the blender is turned on, will the water temperature increase, decrease, or stay the same?
2. Will the change in temperature be obvious, barely noticeable, or non-existent?
3. Why will the temperature of the thermocouples change the way you predicted?
4. What formula can be used to explain how the water temperature is related to the action of the spinning blades?
5. What course, learning experience, or life experience is most responsible for your ability to answer the preceding questions?

The entire demonstration, including completion of the worksheets, takes fifteen minutes. As shown by Crouch et. al [1], having the students make a written commitment to their thinking is more effective than having them passively witness the demonstration.

Formative Assessment

The blender demonstration has been used in a first thermodynamics course for mechanical and civil engineering students. Table 1 shows categorically grouped responses to the third question of the worksheet for the in-class demonstration.

Table 1: Categorized responses to the question, *Why will the temperature of the thermocouples change the way you predicted?*.

	Spring 08		Fall 07	
Aggregate Response Category	N	(%)	N	(%)
First law or energy balance for system	31	(59%)	28	(41%)
Mechanistic view: kinetic energy & friction	7	(13%)	25	(37%)
Heat transfer	3	(6%)	8	(12%)
Other, not relevant to explain system behavior	12	(23%)	7	(10%)
Total	53		68	

The data in Table 1 show that a significant fraction of students (13% in Spring 2008 and 37% in Fall 2007) have a mechanistic view of the role of shaft work. The mechanistic model explains the temperature change of the water as resulting from dissipation of the kinetic energy of water molecules, or on friction between the blender blades and the water. This perspective reflects the way that the first law is taught in introductory physics classes. Students also need to learn to use the first law as a macroscopic energy conservation principle for systems.

It is important to note that the instructors in both Thermodynamics sections were not part of the research team. For the Spring 2008 section, the instructor had discussed the role of shaft work before the blender demonstration. That is likely to account for a larger fraction of students (59% versus 41%) who explained the temperature change with the first law of thermodynamics.

Guided Inquiry Laboratory Exercise

Students perform a laboratory exercise that takes one and a half hours. The laboratory exercise uses guided-inquiry to lead students to discover how the energy storage and shaft work are manifest in the behavior of the blender. Data from the DAQ is displayed with a LabVIEW VI and post-processed with a MATLAB program. The focus of the exercise is on manipulating hardware and collecting data, not on the details of data acquisition.

Because qualitative reasoning is a new skill for students, and because (in our approach) the students have only recently been reintroduced to the first law of thermodynamics, the lab exercise begins with warm-up questions on the rate form of the first law, and on possible choices of control volumes for the system. Figure 2 shows possible definitions of the control volumes for the system.

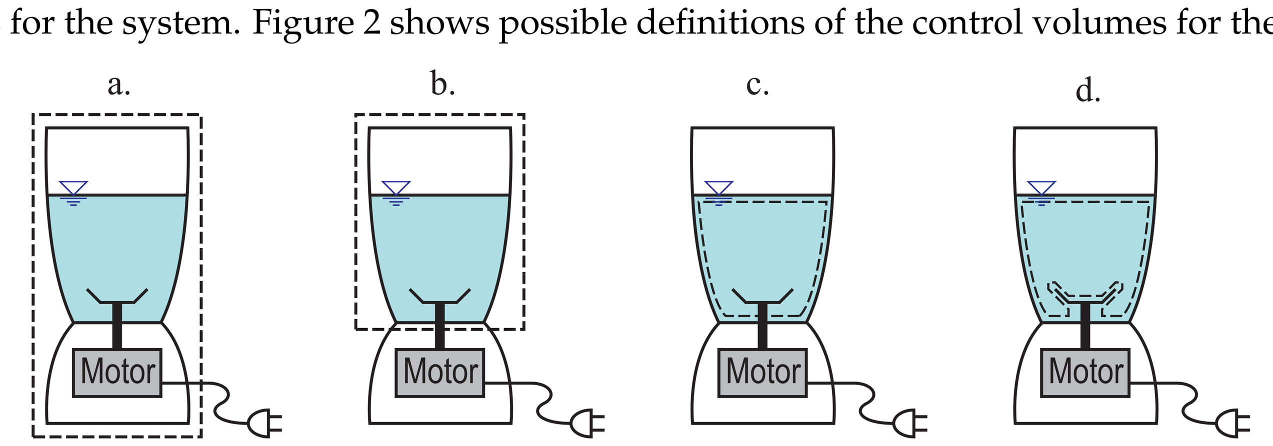

Figure 2: Definitions of system control volumes used in the scaffolding exercise.

Qualitative and quantitative analysis of the blender involves manipulating the rate form of the first law for a closed system

$$mc\frac{dT}{dt} = \dot{Q} - \dot{W} \quad (1)$$

where m is the mass of the system, c is the specific heat, T is the temperature, $\dot{Q}$ is the rate of heat gain by the system, and $\dot{W}$ is the rate at which work is done by the system on its the surroundings.

Role of Energy Storage

The first experiment investigates the effect of varying the amount of water in the blender. The First Law for two different masses of water is

$$m_1 c\dot{T}_1 = \dot{Q}_1 - \dot{W}_1 \qquad m_2 c\dot{T}_2 = \dot{Q}_2 - \dot{W}_2 \quad (2)$$

where $\dot{T} = dT/dt$. Take the ratio of those two instances of the energy equation and simplify by assuming that $\dot{Q}_2 - \dot{W}_2 \approx \dot{Q}_1 - \dot{W}_1$, that $\dot{Q}$ is small, and that $\dot{W}$ does not change when m changes since the speed is constant. Under these assumptions the ratio of the two formulas in Equation (2) can be rearranged as

$$\frac{\dot{T}_2}{\dot{T}_1} = \frac{m_1}{m_2} \quad (3)$$

The values of $\dot{T}_1$ and $\dot{T}_2$ are easily be determined from the measured $T(t)$ data.

Measurements show that the trend predicted by Equation (3) is correct, but the measured data are not in quantitative agreement with the formula. The work input, $\dot{W}$, depends weakly on the mass in the blender. Also, energy is stored in the blender pitcher material as well as the water. Students are lead through qualitative reasoning exercises to show that these are plausible explanations for the failure of Equation (3) to match the measured data. In the spirit of inquiry-based pedagogy, students can quickly show how $\dot{W}$ depends on m.

Role of Shaft Work

A second experiment is performed with the amount of water held constant and the speed of the blender varied. Figure 3 shows typical measurements of the $T(t)$ curve at two blender speeds. Forming a ratio, and performing simplifications analogous to those that lead to Equation (3) gives

$$\frac{\dot{T}_2}{\dot{T}_1} = \frac{\dot{W}_2}{\dot{W}_1} \quad (4)$$

which agrees well with the data from Figure 3: $\dot{W}_2/\dot{W}_1 = 2.49$ and $\dot{T}_2/\dot{T}_1 = 2.72$.

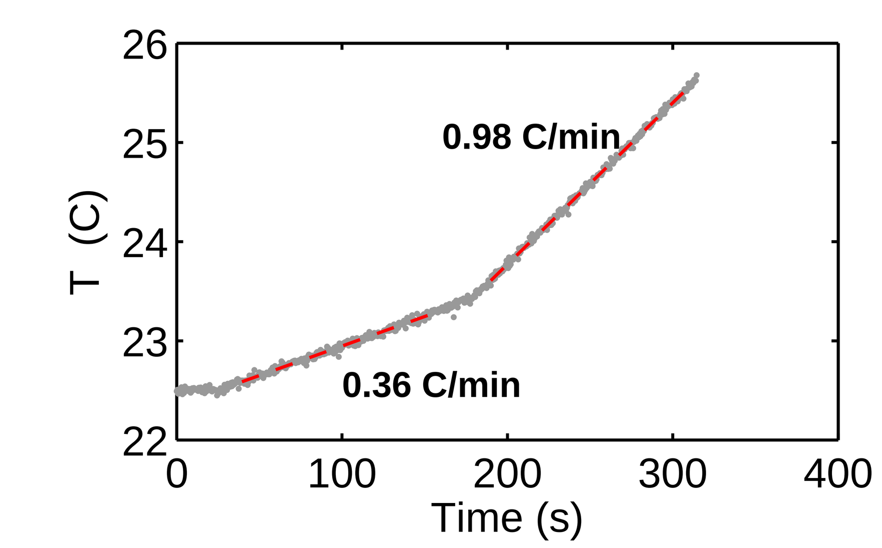

Figure 3: Average thermocouple temperatures as the blender speed increases from *puree* to *liquify* with one liter of water in the pitcher. Nominal power consumption is 113 W during puree and 281 W during liquify.

Summary

- The Blender is a simple apparatus that is familiar to students.
- The in-class demonstration is used for formative assessment.
- The laboratory exercise is a guided-inquiry learning experience.
- Qualitative reasoning focuses attention on appropriate definition of the control volume.
- Students gain experience manipulating the rate form of the first law.
- Use of ratios and the first law demonstrates qualitative reasoning, and it allows analysis of the roles of energy storage and shaft work, while using minimal quantitative data.
- Analysis and measurements help students shift from a mechanistic model, as taught in introductory physics classes, to a macroscopic system view that is required for engineering design.

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References

[1] Catherine H. Crouch, Adam P. Fagen, J. Paul Callan, and Eric Mazur. Classroom demonstrations: Learning tools or entertainment? *American Journal of Physics*, 72(6):835–838, June 2004.