An Exercise to Teach the First Law of Thermodynamics for an Open System Using a Simple Hair Dryer

by

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Abstract: *A wide range of active learning methods are being employed in today's modern classroom to enhance the learning experience. One type is known as guided inquiry. This method requires the students to be actively involved in discovering a concept or basic principle. Questions are posed which are intended to keep the students on task, but the students are required to make predictions about physical phenomenon, test their ideas and make sense out of the results of their tests.*

In a traditional engineering classroom, students focus on quantitative problem solving skills, which are certainly needed. However, that alone may not give the students the type of understanding of basic concepts that is needed. The exercise described in this paper attempts to address this possible lack of understanding through a guided inquiry approach using a common physical device – a hair dryer. The traditional lecture and the guided inquiry exercise complement each other nicely. In the lecture, the students get a quantitative background of the material while in the exercise the students get a qualitative understanding of the underlying concept.

The exercise described in this paper involves the use of a hair dryer to teach the first law of thermodynamics for an open system. The pedagogical basis for this exercise is discussed, along with a look at why a hair dryer is a good teaching tool. The bulk of the paper describes the exercise in some detail. The first attempt at assessing the effectiveness of this exercise is also explored.

Keywords- Guided inquiry, first law of thermodynamics, qualitative reasoning, active learning.

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I. Introduction

The first law of thermodynamics is traditionally taught through a lecture as part of a first course in thermodynamics. However, modern pedagogical research is showing that lectures alone may not be the most effective way to teach these kinds of concepts[1][2]. Lectures need to be complimented with demonstrations and hands-on experiences. Even in-class demonstrations are not necessarily an effective way to increase student learning. Mazur, Fagen, et al[3] took a look at the effectiveness of classroom demonstrations and concluded that students that simply observe a demonstration during class show no significant improvements in learning compared to those who do not observe the demonstration. However, they further noticed that when the students are actively involved in the exercise there is definitely a significant improvement in learning.

Traditional laboratory experiences are certainly hands-on and get the students actively involved. These labs typically involve the use of preconfigured hardware and procedures designed to demonstrate or “prove” the theories that are being taught in class. They usually call for the students to set-up the experiment, run a set procedure, take data and tear down the equipment. Students then typically have one to two weeks to do any necessary calculations and produce a report. Even though they are actively involved physically during the lab period, they are often not actively engaged mentally. There is often very little need for them to understand what they are doing during the lab period, and often they do not recognize if the data they are gathering is good or bad. They are accustomed to it being good, so they are unlikely to question it. One consequence of this is that the students come away with the impression that the purpose of any laboratory experiment is to verify or demonstrate a theory. Newer, active methods for laboratory exercises are attempting to move the lab experience beyond just demonstrating a theory into actually teaching it.

Active methods have been widely incorporated into science classrooms. More recently they have been finding their way into engineering classrooms. A brief overview of some of these methods is given in the next section. The bulk of this paper describes an exercise designed to teach the concept of the first law of thermodynamics for an open system using a guided inquiry approach. The exercise described in this paper uses a hair dryer as the thermodynamic system. The general procedure asks the students to make predictions about the properties of the outgoing air stream as various hair dryer parameters are changed, test their ideas and try to make sense out of what seems to be conflicting data. This process requires the students to think on a deeper level than they normally would during a laboratory exercise, hopefully leading to a better understanding of the concept.

II. Overview of Active Learning Methods

There are several active learning methods that are being used in classrooms today. Malicky, Huang and Lord[4] have compiled an overview of many of these methods. These include problem-based learning, project-based learning, cooperative and collaborative learning, service learning, and inquiry based learning. They also review some mixed methods. Several other methods are in use, but those listed here are sufficient to get the sense of what active learning is about.

In problem-based learning the course is centered around a set of open-ended problems which are selected to lead the students toward the desired course outcomes. Students are motivated to learn the associated material because it is needed to solve the assigned problems. Montero and Gonzalez[5] describe their experience incorporating problem-based learning into a first year class for electronic engineering students. They use this method to help teach them heat transfer basics with a focus on the cooling of power electronics and on electrical maintenance.

Project-based learning is similar to problem-based learning except that one or more projects are used rather than a series of shorter problems. This method is generally used to reinforce the theory that is being taught instead of providing a motivation to learn the material. Cooper[6] describes how this approach was applied to a course in an introductory thermal sciences course. She incorporates a semester long project with deliverables due throughout the semester. She lists several projects that she has used in her class. Interestingly, one of the projects is a thermal analysis of a hair dryer. Roy, Nasr and Berry[7] describe a thermodynamics course that is driven entirely by the project based learning approach.

Cooperative and collaborative learning are somewhat different, but similar enough to be treated as the same here. These methods usually involve the formation of temporary small groups, often during the class period, to work on a problem assigned in class. It might also be applied to a group homework assignment or other similar short term problems. An example of this method can be found in a paper by Ulasir, Carpenter, et al[8]. In this paper they describe how they incorporated cooperative learning into a fluid mechanics laboratory course.

Service learning is similar to project-based learning in that it is usually centered around one or more projects. In the case of service learning the project is usually something that benefits some community organization such as a school or community center. Jawaharial, Fan and Monemi[9] discuss adding service learning to engineering courses. They incorporate a year-long multidisciplinary project into their curriculum, and list many possibilities for community partnerships.

The exercise discussed in this paper uses a guided inquiry approach to active learning. In this approach students are asked to pose questions, develop experiments to try to answer those questions, analyze information from those experiments, and draw conclusions[10]. In a pure inquiry based exercise the students are left on their own to discover the relevant concept. Guided inquiry recognizes that in the context of letting students "discover" principles on their own many students can lose focus and move off target. To assist in keeping students on the right path, a set of open ended questions is provided. The wording of these questions is critical in keeping the students on track while not leading them to a specific conclusion. A good example of this is given by Buch and Wolff [11]. A question intended for a course in construction materials might be posed two different ways:

"How would the presence of fibers affect concrete toughness?"

or "How would you improve concrete toughness properties?"

The first question clearly suggests an answer while the second is more thought provoking.

Ross advocates for students spending more time thinking about and writing down explanations for things than in actually doing calculations[12]. Students are asked to make predictions about the behavior of an apparatus or process with no penalties for wrong predictions. If the behavior of the device does not match the prediction then students need to make sense of the results. This is quite different from traditional engineering courses in which students spend large amounts of time on the calculations, and not necessarily as much time on making sense of results. In the exercise described below the results seem to be contradictory and confusing. By going through the process of trying to make sense of these conflicting results the students should get a deeper understanding of the first law of thermodynamics for open systems then they would through a lecture alone.

III. Hair Dryers as a Teaching Tools

Using a familiar device for an experiment has two advantages. First, the students do not need to spend time and mental effort trying to figure out what the device is intended to do or how it works. This frees them to concentrate on the basic principles that are involved in the exercise rather than on the operation of the equipment. Secondly, it has been shown that the use of a familiar device to demonstrate an unfamiliar principle can help to add relevance to a lecture[13].

Hair dryers, which are familiar to most students, have commonly been used as teaching tools. Alvarado has students design their own thermodynamic experiment using a hair dryer[14]. Weltner uses a hair dryer in an experiment to determine the specific heat of air[15]. Shakerin makes use of a hair dryer to demonstrate both the first and second laws of thermodynamics[16]. As mentioned earlier, Cooper makes use of a hair dryer as part of a project based course in thermodynamics[6]. Edwards has long used a hair dryer in an experiment where students perform a comprehensive first law analysis[17]. One thing many of these experiments have in common is that they incorporate traditional or “cook book” type laboratory exercises in which there is a well defined procedure and usually a successful, predictable result. The exercise described in the remainder of this paper is different in that it uses a hair dryer within the context of guided inquiry pedagogy. The focus of the hair dryer exercise described below is to teach a qualitative relationship between mass flow rate and temperatures of fluids crossing the boundary of an open thermodynamic system using a guided inquiry approach.

IV. Equipment

Figure 1 shows a schematic of the test set-up used for this exercise. The apparatus consists of a hand-held hair dryer mounted in a custom bracket, thermocouples to sense both upstream and downstream temperatures, a data acquisition unit (DAQ) for digitizing the thermocouple output and a computer running a LabView VI to display the thermocouple output. Not shown on the schematic is a wattmeter used to measure the total power that is consumed by the hair dryer. The hair dryer is simply plugged into the wattmeter to get the reading.

Notice the various hair dryer settings. There are two switches on the handle. One controls the fan setting, with off, low and high options. The other controls the heater setting, with cool, warm and hot options. When the hair dryer is set on the cool setting there is no power directed to the heaters. It is important to recognize this because it factors into the results of the exercise.

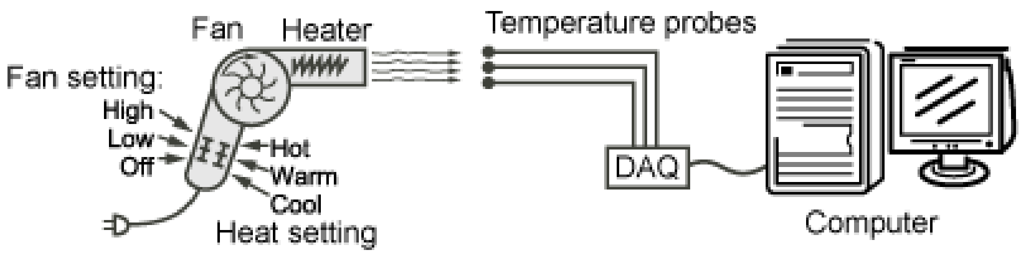


Fig. 1: Schematic of the exercise set-up

Figure 2 shows a photograph of the actual apparatus used for the exercise.

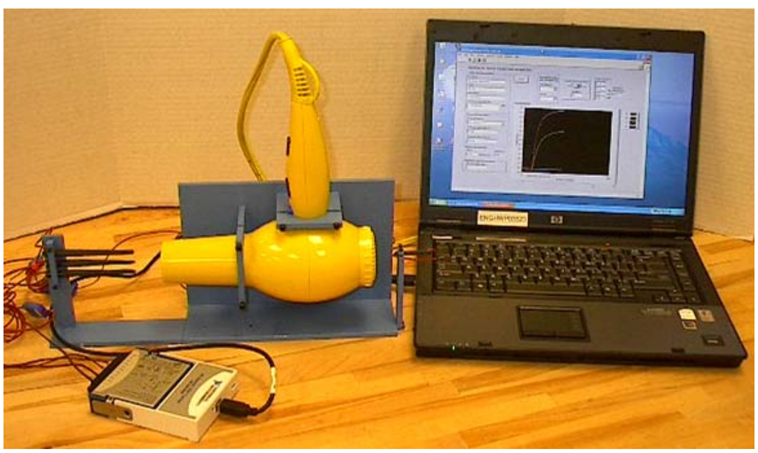


Fig. 2: Apparatus used for the hair dryer exercise

V. Theory

A simple schematic for a hairdryer is shown in Figure 3. It is made up of three basic parts: a resistance heater, a fan and an enclosure. Most of the energy consumed by the hair dryer is used by the resistance heater while a smaller amount is used by the fan. As air is blown across the heater it gains energy from the heater causing the temperature to increase. A small amount of the temperature increase can also be attributed to the power consumption of the fan motor. Even though the power consumed by the fan is small, it is interesting to note that the effect of this small increase is observed later as part of the exercise. It turns out to be an important part of the analysis of the data.

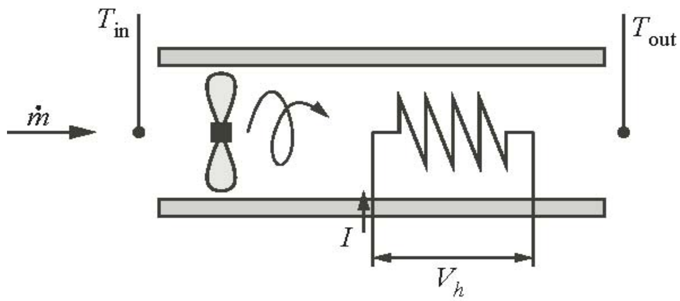


Fig. 3: Simplified schematic of a hair dryer

The first law of thermodynamics for the hair dryer can be written as shown in Equation 1[18].

$$\dot{W}_{elec} - \dot{Q} + \dot{m}_{in}\left(h_{in} + \frac{V_{in}^2}{2} + gZ_{in}\right) - \dot{m}_{out}\left(h_{out} + \frac{V_{out}^2}{2} + gZ_{out}\right) = 0 \qquad \text{Equation 1}$$

Where:
$\dot{W}_{elec} = Electric\ work\ input\ (watts)$
$\dot{Q} = Heat\ loss\ from\ the\ housing\ (watts)$
$\dot{m}_{in} = Mass\ flow\ rate\ of\ the\ incoming\ air\ (\frac{kg}{sec})$
$\dot{m}_{out} = Mass\ flow\ rate\ of\ the\ outgoing\ air\ (\frac{kg}{sec})$
$h_{in} = Specific\ enthalpy\ of\ the\ incoming\ air\ (\frac{joules}{kg})$
$h_{out} = Specific\ enthalpy\ of\ the\ outgoing\ air\ (\frac{joules}{kg})$
$v_{in} = Velocity\ of\ the\ incoming\ air\ (\frac{m}{sec})$
$v_{out} = Velocity\ of\ the\ outgoing\ air\ (\frac{m}{sec})$
$g = Acceleration\ due\ to\ gravity\ (9.81\ \frac{m}{sec^2})$
$Z_{in} = Elevation\ datum\ for\ the\ incoming\ air\ (m)$
$Z_{out} = Elevation\ datum\ for\ the\ outgoing\ air\ (m)$

This is an equation the students should already be familiar with, having been exposed to it during a lecture before the exercise is conducted. In order to successfully complete this exercise the students must be able to apply qualitative reasoning to this equation and make predictions about the effects of changing certain parameters on the outlet temperature. They first need to recognize that certain of the terms can be neglected, then manipulate the equation to find the necessary relationships.

VI. Pre-Exercise Predictions

Prior to the exercise they are asked to predict two relationships. The main one is to predict what effect changing the flow rate of the air (switching to a higher fan setting) has on the outlet temperature if the power setting remains unchanged. Their choices are shown in Figure 4. The correct answer is d, as the flow rate goes up the temperature should go down linearly.

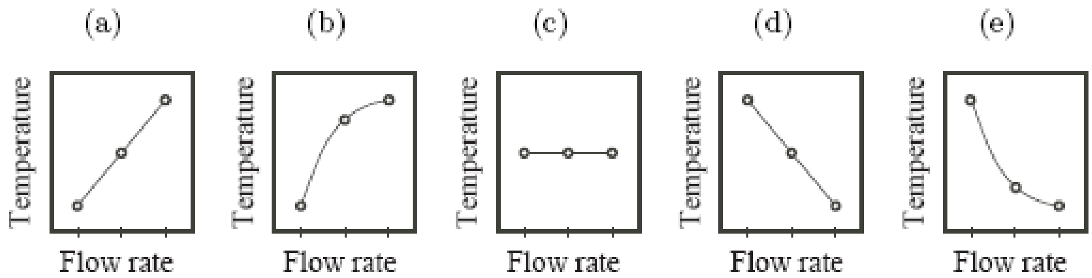


Fig. 4: Effect of air flow rate on outlet temperature

There are three ways they might arrive at an answer to this: guess, rely on prior experiences and preconceived ideas or by applying the theory to the problem.

They might simply guess. Some students take this approach because they really do not know what the answer should be, and do not understand enough about the theory to apply it to this situation. Obviously this is not the most desirable approach, but can still result in learning gains.

The second method is to rely on prior experience with a hair dryer or similar device. They may have noticed that the temperature tends to go up or down when they change the fan speed. Everyone brings preconceived ideas based on prior experiences to any problem. These preconceived ideas might be right or wrong. A successful laboratory exercise must engage and challenge these preconceptions[19]. Therefore, it is desirable to have the students initially take this route in predicting the outcome of the experiment.

Most of the students do not rely on the theory at this point. After they have made their initial prediction, the entire group works through a qualitative reasoning exercise to make predictions based on the theory. Qualitative reasoning has several possible meanings. In general, it is the use of engineering models to predict system response when not all of the terms in the model are fully specified. It involves making estimates through simplifying the model by concentrating on the dominant factors and neglecting the minor ones. Several techniques might be applied to a qualitative reasoning problem. The method used in this exercise is analytical simplification. The application of this method involves the use of scale or order-of-magnitude estimates to obtain simple formulas from more complex equations. Experience and common sense are important in determining what the dominant factors are.

For this exercise students need to recognize that heat transfer from the housing, kinetic energy changes and potential energy changes are small so they can be neglected from Equation 1. Arriving at this conclusion might be difficult for the students. They tend to try to include everything in their equations, and often feel uncomfortable when terms are eliminated. An instructor led discussion can lead them through the following thought process.

Hair dryers typically have ratings in the 1200 watt range. If an ordinary hair dryer is turned on the housing does not get very hot. Since the temperature difference between the housing and the surrounding air is small, the rate of heat transfer is small. It is certainly not of the same order of magnitude as the total power consumption. In fact, experimentation by the author has shown that the heat loss from the housing comprises less than .01% of the total power consumption[17]. Therefore, heat transfer can be safely neglected. Next are the kinetic energy terms. Since the inlet and outlets of most hair dryers have similar areas, the velocities are similar, minimizing any kinetic energy differences. These terms can also be neglected. Moving on to potential energy, the hair dryers used in this exercise have the center line of the inlet and the center line of the outlet horizontally in-line with each other which gives a potential energy difference of zero. Even if the hair dryer were tilted or mounted vertically the potential energy difference is extremely small, therefore it can also be neglected. Equation 1 then reduces to Equation 2.

$$\dot{W}_{elec} = \dot{m}_{out}h_{out} - \dot{m}_{in}h_{in} \qquad \text{Equation 2}$$

Since the mass flow rate in has to equal the mass flow rate out based on the continuity equation, Equation 2 can be rewritten as Equation 3.

$$\dot{W}_{elec} = \dot{m}(h_{out} - h_{in}) \qquad \text{Equation 3}$$

The assumption used for the prediction is that the input power is not changed. In Equation 3 the enthalpy difference reflects a temperature difference. For a given electric work input, an increase in the mass flow rate results in a decreased temperature difference to maintain the equality in Equation 3. Since the inlet temperature remains constant, this means that the outlet temperature must decrease. Furthermore, the relationship is linear making d the correct choice over e.

After this discussion the group as a whole makes a prediction, based on the theory, which is used for comparison purposes with the actual test results. For warm and hot heater settings the students can now readily see that the outgoing air temperature should decrease if the fan speed increases when the heaters are held at constant power. Those predictions for the two possible heater settings are shown as the top two lines on the plot in Figure 5. This leaves one final scenario to be discussed. When the heaters are set on cool there is no power going to the heaters. The group generally predicts that the incoming and outgoing air temperature will be the same, and that it will not change if the air is moving faster. This prediction is displayed as the bottom plot in Figure 5. Note, however, that when the fan motor is turned up there will be more power consumed by the fan, so the theory actually predicts that the outlet air temperature should rise. This point is usually not made at this stage of the exercise. It is left for the students to discover it when they run the hair dryer. As data is taken the students then plot actual results which will later be compared with this group prediction.

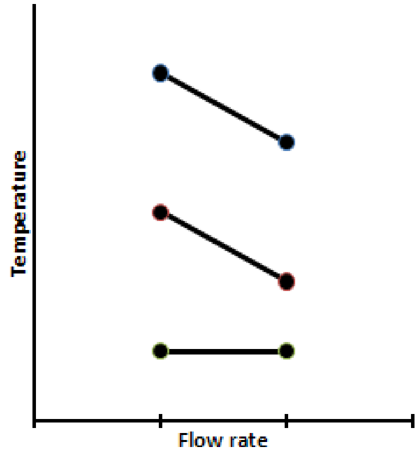


Fig. 5: Group prediction of air temperature changes when input power is held constant and fan speed is changed

The second prediction they are asked to make is what should happen if the inlet temperature and mass flow rate are held constant and the heater power (electric work) is changed. Again, they are given five choices (Figure 6). The correct answer is a, as the heater power is increased the outlet temperature should go up linearly.

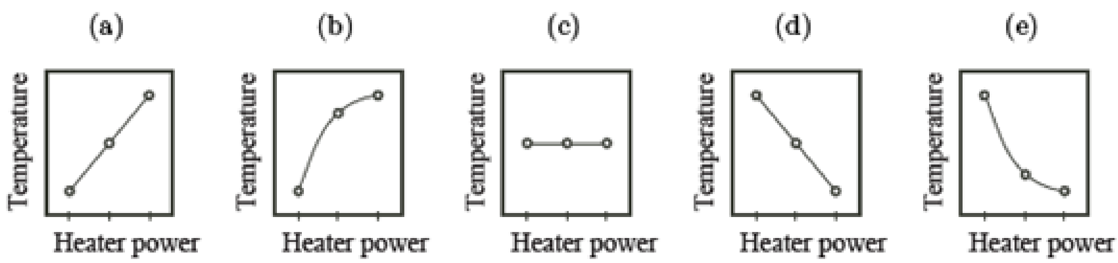


Fig. 6: Effect of electric work on outlet temperature

Once again, Equation 3 shows the reason. If the mass flow rate remains constant then the enthalpy change must go up when the electric work term goes up. Also note that it is a linear relationship making a, not b, the correct answer. However, this is pretty much a common sense prediction since it is fairly obvious that the temperature should go up if a heater is turned on. It might not be quite so obvious that the relationship is linear.

After the students make their own predictions the group once again makes a prediction to use for comparisons with actual data. Figure 7 shows that prediction.

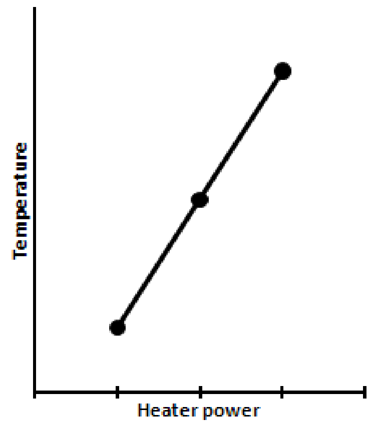


Fig. 7: Group prediction of air temperature changes when fan speed is held constant and input power is changed

VII. Hair Dryer Exercise

The laboratory exercise consists of taking data for two hairdryers and then making sense of the data based on the first law of thermodynamics. Data collection is quite simple. The electric power to the hair dryer is read from a wattmeter and the outlet temperature is read from the LabView screen. There are three downstream thermocouples and one thermocouple for the ambient temperature. All four thermocouple readings are plotted. The downstream thermocouples show different readings due to the placement of the heaters inside the nozzle. The LabView VI calculates the average downstream temperature and displays that value. The average value is the one that is recorded. Data is recorded for every combination of heater and fan settings. Two hair dryers are tested to ostensibly verify that the readings are consistent. In reality, the two hair dryers behave quite differently.

Figure 8 shows a series of data plots for the first hair dryer. The figure only shows the plot portion of the screen and not the calculated average value. The data in Figure 8a is for a power setting of cool. The first jump in the outlet temperature shown on the plot happens as soon as the hair dryer is turned on. The second jump occurs when the fan setting is changed from low to high. This is not what the students predicted (Figure 5), and often surprises them. Why did the temperature go up when there is no power to the heaters? This is a question for the students to ponder after all the data is taken.

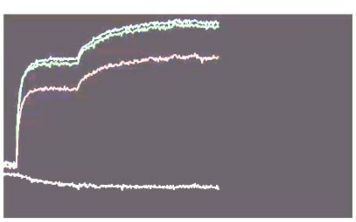


Fig. 8a – Heater setting Cool

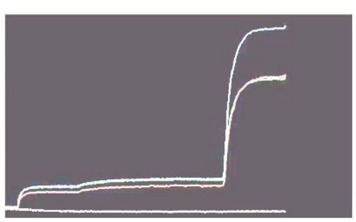


Fig. 8b – Heater setting warm,

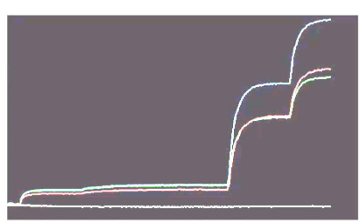


Fig. 8c – Heater setting warm,

fan setting low fan setting high

Figure 8b shows what happens when the fan is returned to low and the heater power is turned on warm. The temperature goes up significantly, which is exactly what one would expect since there is now a heater turned on. While it is running at this level the students are reminded that the prediction for the outlet temperature when the fan is turned up is that the outlet temperature should go down. Figure 8c shows what actually happens. At this point the fan is on high and the heaters are still on warm. A similar trend occurs for a heater setting of hot. The students are now confronted with something they do not often encounter in the lab. The results are exactly opposite of what they predicted and would expect based on the theory. The graphs appear to violate the first law of thermodynamics. Since the results are dramatically different from the prediction, not just slightly different, the students cannot simply write off the differences as experimental error. Later they will be asked to make sense of this data.

The second hair dryer is run to verify the results from the first. Results for the same sequence of runs are shown in Figure 9.

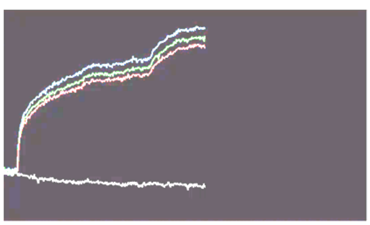


Fig. 9a – Heater setting Cool

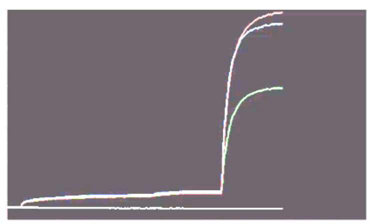


Fig. 9b – Heater setting warm, fan setting low

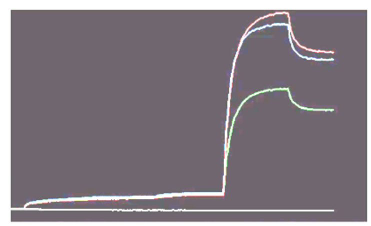


Fig. 9c – Heater setting warm, fan setting high

Notice that the first two plots are very similar, however there is a marked difference in the third one. This time the temperature goes down when the fan speed is increased, which is according to the original prediction. Now the students really have a dilemma. Can they make sense of all of this? To help with their analysis they are asked to collect data along the way. Table 1 shows a typical data table that they produce. The table would also include data for the hot heater setting. It does not add anything to the discussion here, so that data is omitted for clarity.

Hair Dryer		Low	High
1	Cool	70	110
	Warm	422	875
2	Cool	67	108
	Warm	555	597

Table 1 – Typical data table (All values are in Watts)

VIII. Data Analysis

The results are very surprising based on the predictions. First, note that the temperatures go up for both hair dryers when the heaters are set on cool. Usually the group prediction is that there will be no change in the temperature for that setting. This needs to be discussed and understood by the students. Figure 11 shows an energy diagram for a hair dryer. The first law of thermodynamics states that for steady state the energy in has to equal the energy out. Neglecting heat loss, the energy leaving with the air has to equal the sum of the energy coming in with the air and the electrical work input. Therefore the temperature of the outgoing air will be higher than that of the incoming air. Additionally, when the fan speed is increased it requires more power, increasing the outgoing temperature even more. This is exactly what is shown in Figures 8a and 9a. Most students eventually recognize this relationship on their own.

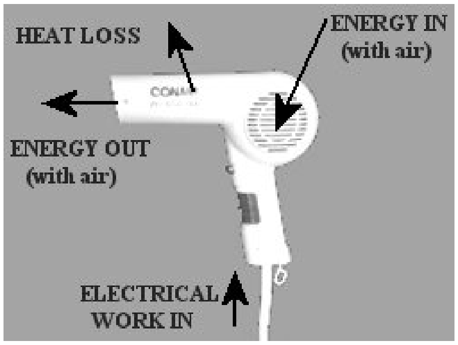


Fig. 11 – Energy diagram for a hair dryer

Now the students are left with the bigger problem. When the heaters are turned on (warm or hot), the hair dryers not only behave differently from each other, but one of them appears to violate the first law of thermodynamics. They need to consider the data (Figure 10) to resolve this issue. Notice that for both hair dryers, the power required to change the fan speed from low to high is around 40 watts. (This can be determined by looking at the cool power setting, because no power is going to the heaters.)

Looking at the warm setting, you can see that it takes about 450 watts to increase the fan speed for the first hair dryer while the second hair dryer it takes only about 40 watts. Eventually the students notice that the power for the first one is significantly higher than for the second one, and conclude that it must have some effect on the results. They rarely notice that the power to increase the fan alone is 40 watts. Eventually, through discussing this dilemma as a group, the students begin to understand why the hair dryers act differently in terms of the outlet temperature characteristics.

It is interesting to note that even after the discussion period there is still confusion about how this all relates to the first law of thermodynamics. The students are asked which of the hair dryers obeys the first law. The majority say that the second one does because it follows the predictions, whereas the first one does not. It must be explained to them that the variations from the predictions are not caused by a failure to obey the first law but by the fact that the first one does not follow all of the assumptions that went into the prediction. Specifically, the heaters are not held at constant power. It needs to be emphasized at this point that everything has to obey the first law of thermodynamics, and that apparent violations must have some type of explanation behind them.

At the end of the exercise the students are told that one of the hair dryers has been modified. They are asked which one they think was changed. Most students assume that the first one was modified because it does not follow their first law predictions. In reality, it was the second one that was modified. Several hair dryers were tested by the author, and all of them behaved like the first one. Some of the students have suggested that one reason the manufacturers might design them that way is because if the temperature of the outgoing air were to go down when the fan is turned up that many users would assume the unit was broken.

IX. Why are the Hair Dryers Different?

The hair dryers are different because one of them has been rewired to make it different. After testing several brands of hair dryers it appeared that they all perform in a similar way. When the fan is turned up without changing the heater power setting the temperature of the air leaving the hair dryer increases. This does not demonstrate the basic principle that says it should go down, therefore using only a standard hair dryer for this exercise risks confusing students. However, it does show that one needs to be aware of the assumptions that are made and whether or not they apply to a given situation. It also helps in stressing the point that everything obeys the first law, even if it does not appear to do so. The authors wanted to have a model that performs according to the predictions in order to enhance the exercise.

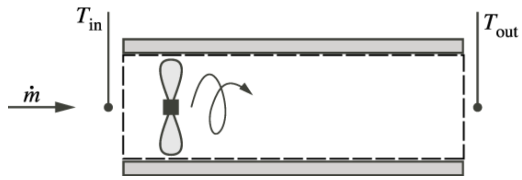
The first attempt to provide that model took the form of a fabricated tube with a heater inside and a fan to blow air through it. Figure 12 shows a picture of that model. A DC power supply was used to power both the fan and the heater independently. This does a nice job of demonstrating the principle, but it does not look very much like a hair dryer. Also, the exercise using this device was significantly different than the one using the actual hair dryer, causing confusion rather than clarity among the students. It was decided to try to modify an actual hair dryer to demonstrate the same thing. The internal wiring was re-done to make the switches operate independently. Appendix A shows the original schematic and the modified schematic for the hair dryer. The modifications that were made cause the hair dryer switches to operate independently. Safety was of utmost during the modifications. All of the standard safety features including the ground fault switch and the thermostatic heater controls remain in the circuit. Additionally, the modification includes one additional safety feature, the heaters cannot be turned on if the fan is not running.

Fig. 12 – Model of hair dryer

X. Assessment of Results

The most recent implementation of this exercise was with a group of Mechanical Engineering Technology (MET) Students. The course was broken into two sections with only one of them doing the exercise. Four multiple choice questions were added to an exam in both sections to test the understanding of the principles covered by this exercise. The questions were:

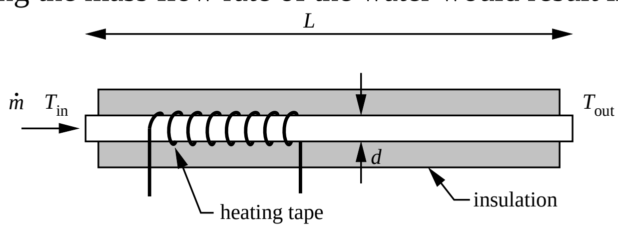
1.) The sketch below depicts a fan pushing air through a duct. When the fan is turned on the temperature probes indicate that T_{out} is 0.2^0 C higher than T_{in}. This measurement is an indication that:



a. There is a measurement error because the temperatures should be the same
b. There is a measurement error because T_{out} should be lower than T_{in}
c. We should ignore the small temperature difference as negligible
d. The fan work is causing the temperature increase.

This question is a direct application of the results of the exercise. The correct answer is d.

2.) Water flows through a well insulated pipe as shown below. The heating tape supplies a constant heat transfer rate of Q watts. The inlet temperature is fixed. Decreasing the mass flow rate of the water would result in:



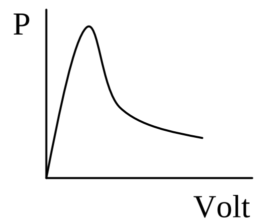
a. A decrease in T_{out}
b. An increase in T_{out}
c. No change in T_{out}
d. Not enough information is given to determine the effect on T_{out}.

This is a slight variation of the hair dryer exercise with the energy in coming from heat transfer rather than electric work (although it could also be looked at as electric work going to the heating tape). The correct answer for this one is b.

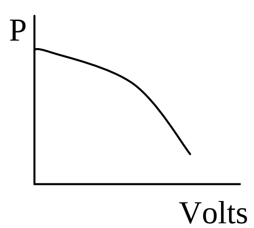
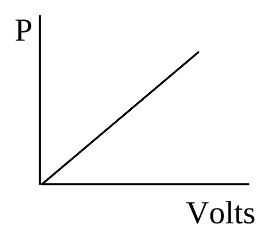
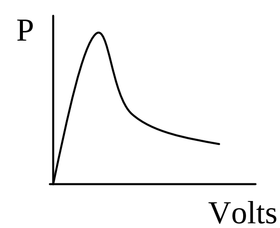
3.) A heat exchanger is used to cool the exhaust gases from a machine using water as the cooling medium. If the rate of heat transfer to the water, and the water inlet temperature remain constant, what would happen to the water outlet temperature if its flow rate is increased?
a. Remain the same
b. Increase
c. Decrease
d. It depends on the gas temperature.

This is extending the hair dryer exercise into a different application, but still is very similar. The correct answer to this one is c.

4.) After doing a thorough analysis of a new device an engineer determines that an increase in voltage to the device would result in the curve shown below.



The engineer builds three of the devices and the tests yield the three different curves shown below:

		
A (Device 1)	B (Device 2)	C (Device 3)

Which of these actual devices obeys the First Law of Thermodynamics?

a. A
b. B
c. C
d. All of them.

This question was designed to determine if the discussion of the first law of thermodynamics relating to the two hair dryers had any effect on student learning. The correct answer to this is d, all of them, because everything obeys the first law. It does not matter that the curves do not match the prediction.

Table 2 shows the results from the exams given to the two sections. Section 1 students ran the exercise and section 2 students did not. The values on the table are in percentage of students who selected a particular answer for each question. The values in red are the percentages in each section who answered the question correctly.

The results are mixed. Section 1 did better on two of the questions (1 & 3) and Section 2 did better on two of the questions (2 & 4). The most surprising result was for question 4. The point that everything obeys the first law was made quite strongly during the exercise yet only 38.5% of the responses from Section 1 got this answer correct. It was better than Section 2, but should have been much higher. Another surprising result from question 4 was that the largest number of responses for both sections was answer b. Answer c would seem to be the more logical response since the diagram matches the one that is given in the original wording of the question.

		Section 1 results				Section 2 results			
Ques.	Ans.	a	b	c	d	a	b	c	d
1	d	0.0	7.7	3.8	**88.5**	5.3	2.6	0.0	**92.1**
2	b	19.2	**76.9**	0.0	3.8	7.9	**86.8**	2.6	2.6
3	c	3.8	38.5	**58.8**	3.8	21.1	28.9	**47.4**	2.6
4	d	3.8	46.2	11.5	**38.5**	2.6	47.4	26.3	**23.7**

Table 2 – Percentage of answer selections by section

The results of this assessment are inconclusive. Informally, many students said that they felt they learned a lot from the exercise, but the exam results do not verify that. There are some factors which may have affected the outcomes which will be addressed in future trials. The main area of concern for comparison purposes is that the sections were taught by different instructors. There is no way of knowing how the in-class treatment of the topic compared between the two sections. It is possible that this topic was stressed more in Section 2 than in Section 1. Another factor that might affect the outcomes was that students from different sections may have talked with each other about the exercise. There was no way to control this, and there is some indication that this did happen to a certain extent. These results highlight the need for improved assessment instruments and controls. This will be a major focus for future work.

One major disappointment in these results is with question 4. Since this exact point was covered thoroughly during the exercise, it was expected that the percentage of correct answers in Section 1 would have been significantly higher than 38.5%. These results highlight the fact that students do not seem to be clear on the point that everything obeys the first law of thermodynamics. It is good feedback in the sense that instructors can modify their delivery of the topic to stress this point.

XI. Summary

This paper discusses a guided inquiry exercise designed to teach the concept of the first law of thermodynamics for an open system. It requires students to use some qualitative reasoning to make predictions about the outcome of the exercise. In the process of gathering and plotting data they encounter conflicting results, which they are not accustomed to getting in other traditional laboratory experiments. The final step of making sense of the data causes them to have to think on a deeper level than they would normally have to if they were simply making calculations as part of a traditional lab. While the quantitative assessment results to date are inconclusive, qualitative feedback suggests that the students feel they have enhanced their understanding of the topic by doing the exercise. Future work is planned to make some further refinements to the exercise. The main area where improvements are needed is in the assessment of the educational benefits of the exercise.

This exercise is part of a suite of exercises that have been developed by the authors called the Engineering of Everyday Things. This work is supported by the National Science Foundation under Grant No. DUE 0633754. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. For more information on this, or any of the other exercises you may go to the project website at: http://eet.cecs.pdx.edu.

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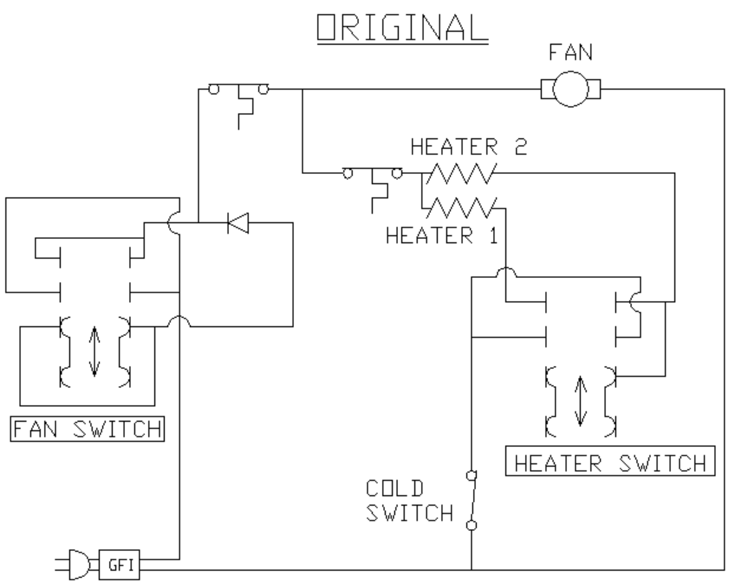
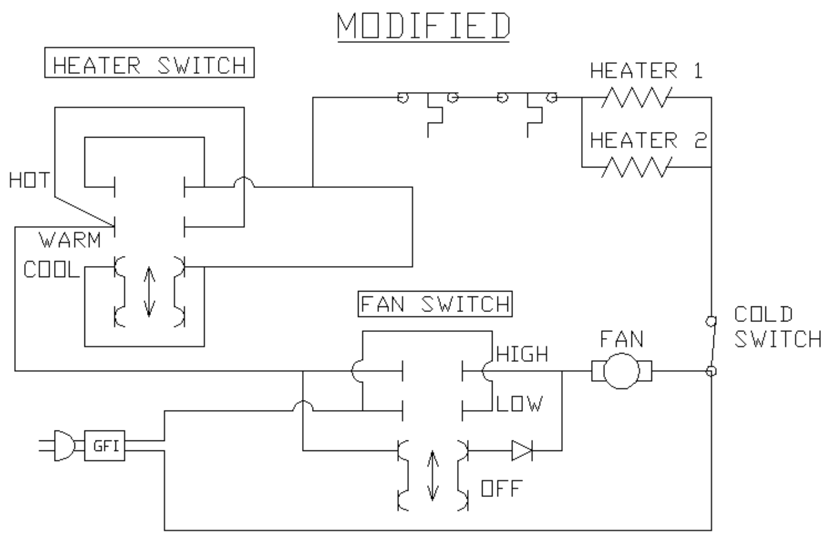
Appendix A – Hair Dryer Schematics





Biography

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ROGER KUNTZ is an instructor of engineering at Penn State Erie, The Behrend College in the Electrical and Computer Engineering Technology program. His teaching specialties are in the areas of circuits, semiconductors and programmable logic controllers. He is a registered professional engineer in the state of Pennsylvania, and is a member of SPE, IEEE and ASEE.

ROBERT MICHAEL is a lecturer in engineering at Penn State Erie, The Behrend College. He joined the faculty at Penn State Behrend in 1999. Prior to Penn State Behrend, Bob spent several years in industry where he worked as an industrial product designer and aerospace product designer for Lord Corporation and general manager for National Tool and Equipment. He is currently working toward doctorate at Case Western Reserve.