

AC 2008-293: GUIDED INQUIRY IN AN ENGINEERING TECHNOLOGY CLASSROOM

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Guided Inquiry in an Engineering Technology Classroom

Abstract

Active learning methods are becoming increasingly popular in science classrooms, and are beginning to move into engineering classrooms. One of these methods is called guided inquiry. This method of teaching involves the students in a different level of learning than traditional lectures involving a 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. Guided inquiry tries to focus the discussion a little more narrowly through questions posed by the instructor.

One goal of guided inquiry is to help the students to develop a deeper understanding of core principles. This is in contrast to a traditional classroom where problem solving skills are often the focus. The two are not mutually exclusive, but compliment each other. A better understanding of core principles gives the student a better foundation for solving problems than just problem solving skills alone.

The approach suggested by this paper is a three step process. The first step is to make a simple and short in class demonstration designed to 1) expose student misperceptions about the topic, and 2) get the students' interested in the topic. The second step is to deliver a traditional lecture on the material where the students can learn the theory and basic problem formulations. The third step is a more extensive lab experience with the same equipment that was used for the demonstration. Questions are posed during the exercise designed force the student to think about core principles instead of just typical problem solving. These lab exercises are not graded. This takes the pressure off the students to be "right", and gives them more freedom to let you know what they are really thinking about.

This paper describes the guided inquiry approach to learning and gives one example of this approach using a hair dryer to teach core principles of the first law of thermodynamics for an open system.

Introduction

Many active learning approaches are being incorporated into today's modern classrooms. Papers by Maliky, Huang, and Lord and Prince and Felder take a look at several of these methods including inquiry based pedagogies, and give some suggestions for evaluating when it might be appropriate to incorporate them in a classroom^{1,2}. Kanter, Smith et al describe an inquiry based laboratory exercise for biomedical students designed to teach core concepts and promote understanding of the material³. Teaching core principles about the first law of thermodynamics for an open system is a key goal of the exercise described in this paper. Others have looked at the use of process workshops⁴, various types of projects⁵, experiential learning⁶, and various uses for interactive tutorials⁷. An interesting comprehensive program for teaching physics using a hands-on interactive environment in large classes has been developed by North Carolina State University⁸. Known as SCALE-Up (Student-Centered Activities for Large Enrollment

University Physics), it is being incorporated in schools around the country including Arizona State, Massachusetts Institute of Technology, and the authors own school, Penn State Behrend⁹.

One of these approaches which is growing in popularity is inquiry-based 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 conclusions¹⁰. While this approach is very popular there is the question of how focused the students will be if they are left completely on their own to find answers to their questions. It is easy for them to stray off on tangents that not only cost time but also can lead to incorrect notions about the topics.

A variation of this approach is referred to as guided inquiry. This approach 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 Wolff¹¹. A question intended for a course in construction materials might be posed two different ways:

“How would the presence of fibers affect concrete toughness?”
and “How would you improve concrete toughness properties?”

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

The overall intent of guided inquiry is to instill an understanding of a basic principle or concept. To that end, it is not necessary to spend a lot of time doing calculations. Ross advocates that more time be spent thinking about and writing down explanations for things rather than doing calculations¹². Students are asked to make predictions about the behavior of an apparatus or process with no penalties for wrong predictions. If the behavior does not match the prediction then students need to make sense of the results based on their preconceived ideas. This should lead to a deeper understanding of the principles involved.

The hair dryer exercise described later in this paper uses this guided-inquiry approach. The implementation of this approach for this exercise is threefold: demonstration, lecture, and subsequent lab exercise. First, a brief (15 minute) demonstration is made using the hair dryer apparatus. Students receive a worksheet asking them to predict certain behaviors of the system and to think about any differences they observe compared to their preconceived ideas. The demonstration is intended to be immediately followed by a lecture on the topic. In the case of the hair dryer the topic is the first law of thermodynamics for an open system. The third step is for the students to meet in the laboratory for a more extensive exercise using the same apparatus. Each of these steps is described in more detail below.

Use of a Hair dryer as a Teaching Tool

The use of something that is familiar to the students for a demonstration can add relevance to an unfamiliar process that is being described in a lecture¹³. There are many examples of the use of simple devices being used as teaching tools in the literature. Jodl and Eckert give many examples of these types of experiments being used in physics classes¹⁴. In fact, the use of a hair

dryer, which is a simple, common device familiar to most, if not all students, is not unique to this exercise. Hair dryers have frequently been used as teaching tools. For example, Alvarado asks students to design their own thermodynamic experiments, one of which is based on a hair dryer¹⁵. Weltner uses a hair dryer as part of an experiment to determine the specific heat capacity of air¹⁶. Shakerin describes an experiment to demonstrate both the first and second laws of thermodynamics¹⁷, and Edwards discusses an experiment to perform a thorough first law analysis of a hair dryer¹⁸. Most of these experiments involve data collection and subsequent calculations similar to most of the common “cookbook” experiments in use today. Experiments of that type have a place in engineering lab curricula, and they can provide the students with good insight into the topic. The guided inquiry approach discussed in this paper is being suggested for use as part of an overall lab course, not as a replacement. The exercise described later in this paper does not require the student to do any analysis, but is designed to demonstrate first law principles for an open system.

None of this exercise is graded. It is only used to help enhance learning for the students. By not grading the exercise the pressure is taken off the students to provide “right” answers. Students feel free to explore and make mistakes along the way. It can also foster an environment much more conducive to discussions and interactions between students or between students and the instructor.

The Apparatus

Figure 1 shows the apparatus that is used for this exercise. It consists of a bracket to hold the hair dryer and four thermocouples. One of the thermocouples is positioned to measure the inlet air temperature while the other three are spaced across the outlet. The bracket is constructed entirely from ¼” thick aluminum plate. The thermocouples have heat shrink tubing holding them onto the ends of chop sticks. Any wooden dowels would work fine. The thermocouples are type T, but type K or others would be just as good.



Figure 1 – Test Apparatus

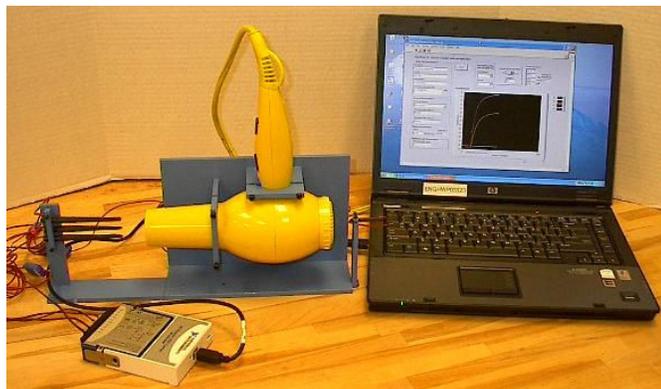


Figure 2 – Test Set-up

Figure 2 shows the entire test set-up. The thermocouples are connected to a low cost USB based data acquisition unit shown in the foreground which is connected to the laptop computer. The screen shows a LabView virtual instrument (VI) designed to collect and display the data from the exercise.

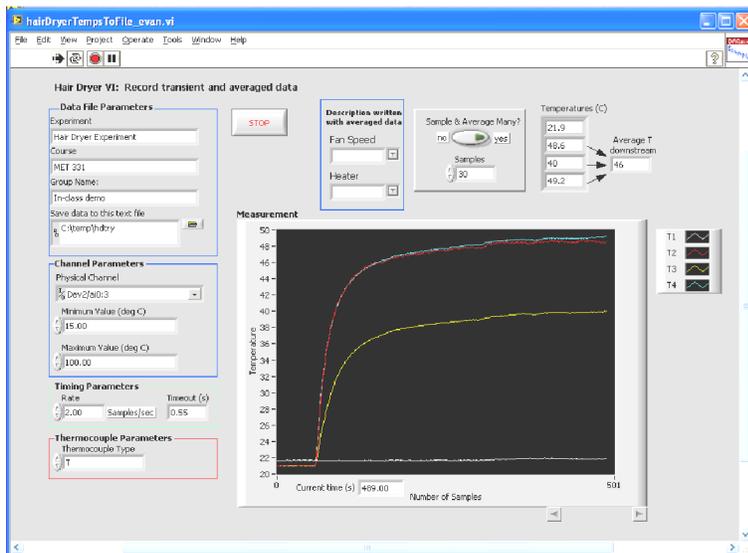


Figure 3 – LabView Data Acquisition Screen

Figure 3 is a close-up of the LabView screen. The temperature at each of the thermocouple locations is plotted. Data is being stored in a text file as long as the system is running. The data can then be used later if it is needed. The information down the left side of the screen is header information for the text file, and various parameters such as thermocouple type, file name for storing data, and sampling rate.

Theory

The basic first law of thermodynamics for the hair dryer can be written as:

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

If the heat transfer rate and the kinetic energy and potential energy terms are assumed to be negligible then equation 1 is simplified into equation 2.

$$\dot{W}_{\text{elec}} = \dot{m}_{\text{out}} h_{\text{out}} - \dot{m}_{\text{in}} h_{\text{in}} = 0 \quad (\text{Equation 2})$$

The enthalpy terms (h_{in} and h_{out}) depend on the air temperature. The mass flow rate in has to equal the mass flow rate out (continuity equation). Also, the inlet temperature remains constant, so the inlet enthalpy remains constant. The variable parameters are the input power and the mass flow rate. If the input power increases the outlet enthalpy or air temperature would have to increase for a constant mass flow rate to maintain the equality in equation 2. If the mass flow rate increases for a constant input power then the outlet enthalpy or air temperature would have to decrease to maintain the equality.

The exercise described in this paper is designed to encourage the students to discover these qualitative relationships on their own, and by doing so increasing their understanding of the underlying core principle.

In-Class Demonstration and Lecture

The first step is to present a short (15 minute) demonstration in the classroom prior to any lecture on the first law of thermodynamics for an open system. The classroom instructor is likely to be different from the person administering the demonstration, so some coordination is needed for scheduling the demonstration. The apparatus is set-up and the data acquisition unit is started. Both the heater control and the fan control are set to low or medium. The plot is observed until the system reaches steady state. When steady state is achieved, the fan speed is increased while the heater control is left unchanged.

Students are given a worksheet that asks two basic questions that they must answer before the demonstration starts:

- 1) How do you expect the temperatures to change, if at all, when the fan speed is increased without changing the heater control, and why? The worksheet could be multiple choice with the choices being increase, decrease, or stay the same.
- 2) Will the three downstream thermocouples show approximately the same values or will they be different, and why?

Remember that these questions are being asked before they have had a lecture on the topic. The first question in particular is designed to get a sense of their preconceived ideas about this type of process. Answers vary, as might be expected. The instructor should pay close attention to the reasoning the students used to arrive at their conclusion, even if the conclusion is wrong. This gives insight to the instructor which could be used to help fine tune future lectures on the topic. The demonstration is then run and the students are left to ponder why they were right or wrong with their answers. This leaves them with questions in their minds. Anecdotal evidence suggests that the demonstration tends to stimulate discussion during the ensuing lecture on the topic.

It is important to point out here that the first time this demonstration was run the results were opposite from what one should expect. As the air speed was increased the temperature should have dropped, but the temperature actually increased significantly. By checking the power consumption with a wattmeter it can be seen that the power level increases by much more than would be needed for just increasing the fan speed. It turns out that the controls of the hair dryer automatically increase power to the heaters when they boost the fan speed. This does not appear to be unique to the hair dryer shown above. Several makes and models were tested giving the same type of response. This created an awkward situation since a test should demonstrate the principle without a need for an explanation.

To remedy this a separate “model” hair dryer was built using a power resistor as a heater and a small DC fan to force the air through the tube (see figure 4). This device yields the correct trends in the data, but it does not look much like an actual hair dryer. A second attempt was made to devise a solution using an actual hair dryer that looked exactly like the original. The controls were modified so that the hair dryer reacts as expected... the power to the heaters does not increase when the fan speed increases. This modified hair dryer can be used exclusively for the exercise, or both the modified and unmodified hair dryers can be used to try to stimulate

discussion and the thought process. It is probably best to use the modified hair dryer for the initial demonstrations in order to avoid having to explain why it is not reacting as one might expect.



Figure 4 – Model Hair Dryer

After the initial demonstration has been completed it is followed by a traditional lecture or lectures on the first law for open systems.

Post-Lecture Exercise

Students are asked to participate in a voluntary small group exercise outside the regular class. This exercise involves the use of both the modified hair dryer and the model shown in figure 4, but is intended to be deeper and more thought provoking than the initial demonstration. The time involved is between one and two hours. Again, nothing is graded. The intent is to get them to think about the core principles involved to enhance their learning experience. The hope is that they will go away with a better understanding of those core principles.

The students are asked to do several things on a worksheet before any testing is conducted:

- 1) Write the steady flow energy equation and rearrange the terms to find a formula for the outlet temperature as a function of inlet temperature, mass flow rate, specific heat, and input energy (electric work).
- 2) Derive a formula for the temperature of the heater as a function of the inlet temperature, surface area of the heater, rate of heat transfer from the heater to the air, and the convection coefficient. (This part is only for students who have had some background in heat transfer).
- 3) Using the modified hair dryer, plan a sequence of measurements to measure the outlet air temperature for every combination of heater and fan settings on the hair dryer. What are the independent and dependent variables? What trends would you expect as you make changes to the settings?
- 4) Make a plot of the outlet temperature versus the fan setting at a constant power setting, and a plot of the outlet temperature versus the heater setting for a constant fan setting. Do these curves match your predictions? If not, why do you think they are different?

The second part of the exercise uses the model hair dryer for the test apparatus. There are two reasons that the model is used instead of the actual hair dryer. First, the fan and heater are independently powered by two channels of a DC power supply rather than by discrete switch setting on the handle. A second reason is to see if students recognize that the model follows the same principles as the actual hair dryer. This gives some indication if the students are learning principles rather than just how a hair dryer works. Again, a worksheet is provided for making predictions and recording results.

- 1) Devise and carry out an experiment to determine a relationship between the air velocity and the fan input voltage.

- 2) Devise and carry out an experiment to determine a relationship between the outlet air temperature and the air velocity. The velocity is small so it is measured using a hot wire anemometer. The students are asked to determine an appropriate location at the outlet to take the velocity measurement.

If these exercises are done in a small group the learning experience can be further enhanced through the discussion of questions that come up along the way. Questions might come from the students, or additional points might be brought up by the instructor.

- 1) One thing that is interesting to look at is what happens to the outlet temperatures if the fan is running but all of the power to the heaters is shut off. Will the students recognize that the temperature will run a little higher than the inlet? Will they know why? Students tend to talk about friction in the motor and similar factors, but for a first law analysis they should only be looking at energy crossing the system boundary. If the boundary is taken as the housing, then electric work is being converted to internal energy of the air.
- 2) The students will be seeing a significant difference in temperatures between different points in the outlet stream. The reasons for this are an interesting topic for discussion. Also, how would they handle this variation if they were trying to do calculations for the total energy leaving the outlet? Will a simple average be sufficient, or should they consider some other approach? One other approach might be to break the outlet into small areas and treat each one as a separate outlet, then sum the energy out over the number of areas to find the total energy out. This approach is described in more detail in reference 18. Weltner suggests a different method to account for the temperature difference at the outlet. He uses a cardboard tube attached to the end of the nozzle creating a mixing chamber, then getting a mean temperature for the air leaving the tube¹⁶.
- 3) If the students needed to do an energy balance for the hair dryer what other factors might be involved? Would they need to consider such things as kinetic energy, potential energy, heat transfer from the nozzle to the environment, or others? Would any of these be significant compared to the enthalpy changes between the inlet and the outlet? Again, reference 18 provides more insight into the significance of these factors.

At this point it might be interesting to use an unmodified hair dryer which does not yield the expected results. The students might be asked to devise some sort of test which would help them determine why this hair dryer reacts opposite to the one they had been working with. The best solution to determine this is to monitor the input wattage as the hair dryer is set to different operating conditions.

Conclusions:

Guided inquiry learning provides a rich environment for enhancing the learning experience. The exercise described in this paper is being developed as part a suite of exercises to be used in fluid and thermal sciences courses. Key features of these exercises include the use of devices that are familiar to the students and the use of low cost USB based data acquisition systems. The exercises are presented in a non-threatening environment with no grades attached to the outcomes. The three step approach engages the students over a period of time giving them more

exposure to the topics then they would otherwise get from a traditional lecture format. This exercise is designed to be used in conjunction with the normal lecture, not to replace it.

To date there is no formal assessment of the effectiveness of this exercise. It is just starting to be implemented and assessed. Preliminary feedback from students is positive. Assessment instruments are currently being created. There will be a survey administered prior to running any exercises. The purpose of the survey is to determine the attitudes of the students relating to the use of lab exercises as tool for learning concepts, not just having them demonstrated. A similar survey will be conducted later to see if any attitudes have changed. Keep in mind that this is just one of a suite of exercises. The students may be exposed to several of the exercises before the final survey is administered. Additionally, the worksheets will be reviewed to see if there is any change in the students understanding of the material between the first demonstration and the final exercise. Other plans are being made to compare the results of answers to exam problems targeting the concepts involved in the exercises between students who did the exercises and those who did not. Results of these assessments will be published at a later date.

There is one hurdle that needs to be further addressed. It is very difficult to get students to commit to outside the classroom work. For courses that have a lab component the exercise could be done during a regularly scheduled lab session, but if there is no lab component then scheduling the exercises is an issue. Various incentives are being considered to entice the students to participate outside of class, but nothing has been tried to date.

The author and Dr. Gerald Recktenwald from Portland State University are working jointly on the development of the suite of exercises and the assessment instruments. A website has been set up to provide more details (<http://pfeffer.cat.pdx.edu:81/>). Some information is available now, but much more will be available in the near future. We would like to acknowledge and thank the National Science Foundation for funding this research.

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