Using Laboratory Experiences to Facilitate the Teaching of Heat Transfer to Electrical Engineering Technology Students

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Abstract:

At Penn State Erie, Electrical Engineering Technology (EET) seniors are required to take a course in fluid and thermal sciences. The course consists of two hours of lecture and two hours of lab per week, and focuses primarily on heat transfer. With only two hours of lecture per week it is very difficult to teach a traditional heat transfer course to students with no significant background in the field. It is important to keep the focus on something that the students can find relevant to their major in order to maintain student interest throughout the semester. Thermal management of electronic systems has become an important issue over the last several years, and so the course focus is in that area. The students must gain some understanding of heat transfer principles in order to appreciate these issues, however it is not important that they receive the same in depth instruction that a mechanical student might receive.

It is a challenge to present heat transfer in just two hours a week to this audience. However there are two additional hours available each week during the lab session. By employing a constructivist type approach to the course these lab sessions can become an integral part of the overall learning experience for the students. Many of the lab exercises do not follow the typical gather data – write a report model. Lab exercises are intended to demonstrate concepts and to stir the curiosity of the students. Some of the labs are conducted before the theory is covered in a lecture. This way the students experience something they don't understand, wonder about it, and then learn about it in class. Other lab exercises try to tie together several methods or concepts that the students have learned throughout the semester.

This paper presents an overview of the course, a brief background to the constructivist approach to teaching, and examples of lab exercises intended to incorporate this approach.

Introduction:

As we move into the twenty-first century the power that is being dissipated by electronic components continues to rise exponentially. Computer chips have surpassed the 100 watts/sq cm threshold, and thermal management companies have already been looking ahead to 200 watts/sq cm and beyond for several years now. Removing this heat will be an increasingly difficult technological challenge for system designers.

Mechanical engineers are often called upon late in the design process to design thermal solutions for electronic applications. Electrical engineers usually have little background in thermal issues so thermal considerations usually wait until the mechanical engineers are given the problem. This can lead to costly redesigns late in the design cycle. As thermal issues become more of a concern in modern electronic systems they need to be considered much earlier in the process.

One approach to bringing thermal considerations into the early stages of a design is to educate the electronics engineers in basic thermal design principles. By doing this, the electronics engineers will be able to make design decisions which could help to minimize thermal problems. This doesn't eliminate the thermal expert from the process, but could make his/her job a little easier.

At Penn State Erie a course is currently being taught for Electrical Engineering Technology (EET) students which introduces them to the basics of thermal management of electronic systems. The course has two lecture hours and two laboratory hours per week. These students have little or no background in the thermal sciences. In an attempt to optimize the use of the available time the lab is used as an integral part of the learning experience. EET students are typically take classes in which lab exercises are used to reinforce the theory that is provided in the lectures. This course takes a little different approach. Laboratory exercises are conducted prior to the theory being presented. The goal is to stimulate the curiosity of the students to want to know more about the theory, thereby making the lectures a little more productive. This approach roughly follows the constructivist approach to learning.

This paper briefly describes the constructivist approach to learning and describes the experiments used in this course and how they relate to this approach.

Constructivist Approach to Learning:

The constructivist approach to learning exploits the learning that occurs when a person is able to make sense of a direct experience, or "construct" knowledge about the experience. In a very strict sense, this approach to learning relies on the student interacting with an environment created by the instructor to find his/her own solution to problems or to gain an understanding of a concept. A "quasi-constructivist" approach might be used to stimulate student interest in a subject and to help the student gain a better understanding of the concepts being presented. This type of approach involves providing opportunities for the student to experience phenomenon related to the concept, and to be able to construct his/her own ideas about those phenomenon. If the experiences are relatively common or familiar to the student then pre-conceived ideas about those experiences might affect the individuals perception of what is going on. Collaboration with other students with different pre-conceived ideas can help to lead all the students to a better overall understanding of the experiences.

In an environment where the students have little or no background training in the field there still needs to be some theory presented. However, the theory can be presented in a way that reinforces the experiments as opposed to the experiments reinforcing the theory. In a class such as the one this paper is addressing it is not necessary, nor is it even possible, to present all of the theory that would be presented in a traditional heat transfer class. By presenting the theory only when needed to help the students better understand the lab experiments they can better relate the theory to the lab exercises.

This approach can be awkward for the instructor at first. Usually an engineering instructor tends to build theory upon theory in lectures to develop the topic. Laboratory experiences can then be used to reinforce the theory developed in class. The approach taken in this class reverses that approach.

Students can also find this awkward at first. They are being asked to take a much more active role in their education. They are accustomed to going into a lab, following a very specific procedure for set-up and data collection, processing the data, and writing a report. This approach requires them to try different things and to collaborate with teammates to attempt to make sense out what is happening. They are also asked to formulate questions about things they do not understand. Ideally these questions will drive the discussion during lectures. It is important for the instructor to be flexible in order to be able to address questions from the students rather than follow a strict lecture plan.

Implementation:

The key to implementing this approach in a course such as this is a carefully thought out plan for laboratory experiments. The experiments need to lead the students toward the right kind of questions to assure that the material that must get covered during the semester is fully addressed. If the experiments involve common devices the students are familiar with it can enhance their understanding of the underlying principles. Added advantages of using common devices are that they are relatively inexpensive, easy to obtain, and easy for the students to relate to. The students end up getting lectures according to the general plan for the course without realizing that is happening. The course can appear to be somewhat disorganized in terms of the order of subject matter, but as they say "there is a method to the madness".

This particular course addresses the first law of thermodynamics, conduction, convection, and radiation as the main topics. Along the way students learn a little about the continuity equation, fans, general information about thermal management issues, and a basic introduction to commercial software used for predicting the thermal characteristics of electronics systems. Various experiments steer the students into those areas.

The Experiments:

- The first experiment is a first law of thermodynamics analysis of a hair dryer. A common misconception of the students is that all of the energy coming into the hair dryer is provided through the power cord and all of the outgoing energy is heat out the end of the nozzle. This experiment requires the students to take all of the measurements needed to conduct an energy balance for the device. Through this experiment the students find out that the energy going out the nozzle is not heat at all, but a combination of enthalpy and kinetic energy. The energy in is not just the electric work but also includes the enthalpy and kinetic energy of the incoming air. The flow of air in and out of the housing stimulates a discussion about the continuity equation. The misconception about heat going out the end leads to a discussion of what heat transfer is, and gives them their first introduction to natural convection occurring along the surface of the nozzle. Velocity is measured using a pitot tube and a differential pressure gauge which reads in inches of water. This leads to questions about how inches of water is a pressure unit, and how to read a manometer. This one experiment provides the opportunity to lecture in thermodynamics, heat transfer, and fluid mechanics. Figure 1 shows part of this experiment.

Figure 1

- An important part of most modern electronic systems is a fan or fan tray. A common misconception is that a fan will deliver a certain amount of air and can be selected based on that one data point. This experiment demonstrates to the students that fans have characteristic curves and have to be matched to a particular system impedance in order to assure enough air for the application. A common computer power supply is used to demonstrate this. Using a flow bench that was designed and built by Mechanical Engineering Technology (MET) students it is possible to create a fan characteristic curve for the power supply fan, and a flow impedance curve for the housing. By plotting the two curves on the same graph the intersection gives the predicted operating point for the fan when mounted in the system (see figure 2). The actual operating point can be measured and compared to the prediction. The flow bench can also be used to demonstrate the affect of running fans in series or in parallel. This experiment leads to a discussion of the use of fans in electronic applications. Students usually ask about how impedance curves can be created which brings up pressure drop calculations and is a good lead in to the use of commercial software to assist in sizing and selecting fans.

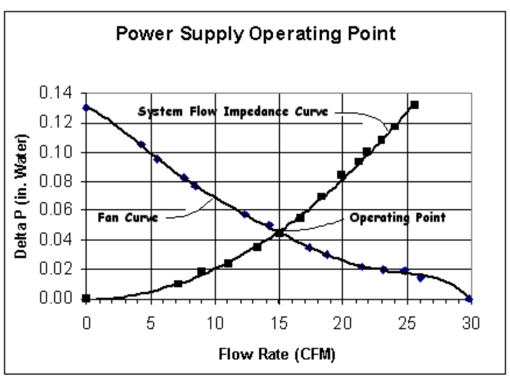

Figure 2

- Conduction is usually the first mode of heat transfer introduced as part of a traditional heat transfer course. In electronics applications convection is often more important than conduction, so it is the first mode introduced in this course. The students have already had some exposure to natural convection through the hair dryer experiment. The next experiment builds on that foundation. A variety of shapes are heated internally and placed in a small low speed wind tunnel which was also built as an MET senior design project. The students can experiment with different shapes, power inputs, and wind speeds to see the effects of each parameter. This leads to a

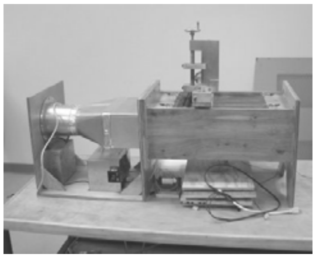

Figure 3

discussion of convection and convection coefficients. After the theory the students are asked to predict the surface temperature of one of the shapes for a given power input and air velocity. A final test is run to verify this prediction. Figure 3 shows the wind tunnel used for these tests.

- Conduction is the next topic introduced in the course. A conduction test device built by students is used to introduce the topic. This device gives the students a chance to look at the thermal conductivity of a variety of materials including aluminum, brass, and stainless steel. This leads to a discussion of conduction, material conductivity, and thermal resistance. Contact resistance can be measured for dry metal to metal contact and for a variety of thermal interface materials. The results from these tests provide a good base for talking about thermal resistance and the electrical ohm's law analogy for heat flow in the lecture. Since these are EET students they can relate well to the electrical analogy. Figure 4 shows the conduction device.

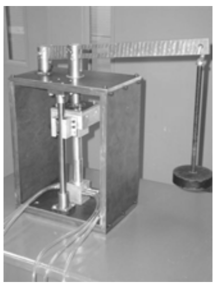

Figure 4

- Once the students learn about the ohm's law analogy they are ready to start looking at resistance networks to estimate temperature fields. The students are very familiar with P-Spice software for analyzing resistance networks which makes it very easy to move quickly to 2-dimensional problems. Several two dimensional thermal resistance networks are set up. Most of the networks are models of electronic chip packages. The students can then see how the heat from the chip is dissipated eventually into the surrounding air. They learn that the junction temperature will be higher than the case temperature, so they have to be careful when using the case temperature as a design parameter. They also learn a little about the junction to case and junction to ambient specifications often given on chip data sheets. Working on setting up the resistance networks and solving them using P-Spice software constitutes one of the lab exercises. The node temperatures can be entered into a graphing program and a 2 dimensional color plot of the temperature field can be produced. The exercise concludes with a three dimensional network to be modeled and analyzed. Since these students are already very familiar with resistance network concepts this lab provides a very nice basis for communicating heat transfer principles to the students using concepts they are already very familiar with.

- After working with two dimensional resistance networks the students are introduced to the finite difference method of solving for temperatures in a two dimensional field. In lab the students program several problems using an excel spreadsheet. The complexity of the model increases as they learn how to deal with more boundary conditions and other inputs. The final project is to program a spreadsheet to solve for the two dimensional temperature field for a printed circuit board with several components with different power levels. Excel can plot decent color plots of the temperature field, or data can be input into a separate graphing program for much better plots. Figure 5 shows an Excel plot for the circuit board the students analyze.

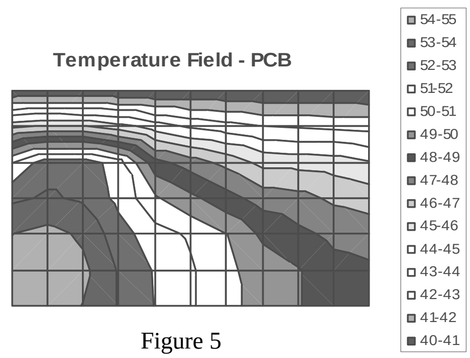

Figure 5

- The next lab is intended to pull together the things the students have learned about two dimensional heat transfer and the electrical analogy. A shallow tray is filled with a conductive liquid. Aluminum strips are placed in the liquid to simulate constant temperature surfaces. The low temperature is simulated by connecting it to ground and the high temperature surfaces are simulated by applying a DC voltage proportional to the temperature. Plastic strips are placed to simulate insulated surfaces. By probing the liquid with a voltmeter the temperature field can be plotted since voltages will be proportional to temperatures. The students begin with a one dimensional case and then move on to a variety of boundary configurations. The results can be entered into a graphing program and a colored two dimensional plot can be produced for the temperature field. For the final project in this lab the students create a color plot of the temperature field obtained from the experiment and compare it to a color plot produced through a finite difference analysis of the same boundary conditions. These two dimensional experiments help the students to better understand the complexities of heat flow in electronic devices.

- In parallel with the above experiments the students are learning to use commercial software to analyze heat transfer problems involving electronics equipment. The two dimensional analyses discussed above are also conducted using the commercial software to see how the results compare. The culmination of this work is a project involving an electronics enclosure with several circuit boards, one high power chip, a cooling fan, and vents. The students model the device and analyze it for component temperatures and air flow patterns. Figure 6 shows a temperature distribution and air flow plot for the final project.

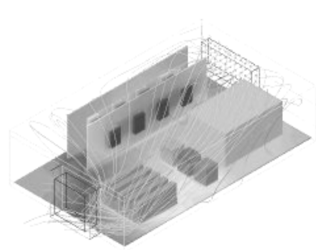
Figure 6

- Once the students are competent with the commercial software they are asked to run a simulation of a heat sink for a Pentium 4 processor to determine the maximum temperature to be expected on the base of the heat sink, and to estimate the temperature distribution throughout the heat sink. The heat sink is tested on a Pentium 4 thermal simulator in the low speed wind tunnel to see how the results compare. An infrared camera is used to look at the temperature distribution on the heat sink

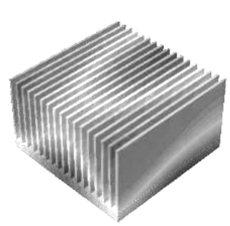
Figure 7

surface, and a thermocouple located at the center of the heat sink base is used to determine the temperature at that point. This leads to a discussion of the design and selection of heat sinks which is an important topic for EET's. Figure 7 shows a typical temperature distribution plot from the commercial software.

- Up to this point in the class there has been no discussion of radiation. A simple experiment using a toaster is used to demonstrate radiation heat transfer. Sheet metal "bread" is placed in the toaster. One side contains "bread" with a shiny surface and the other with a dull black surface. The toaster is pressed down to begin the heating process. Temperature data is collected every two seconds for two minutes as the sheet metal warms up. After two minutes the model toast is removed and allowed to cool. Temperature data continues to be taken every two seconds. The data for the two different sheet metal parts is plotted on one graph. The results show a significant difference between the heating rate for the two different surfaces. This leads quite nicely to a discussion of radiation and why the sheet metal parts had very different heating characteristics. Figure 8 shows some of the equipment used for this test.

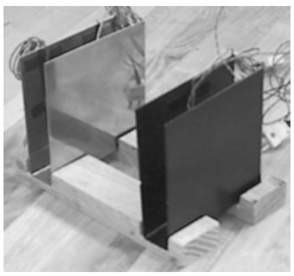

Figure 8

Conclusions:

Thermal management issues are taking on an increasingly important role in the design of electronic systems. Mechanical engineers with an expertise in the area will remain vital in the foreseeable future, and training at the undergraduate and graduate level will continue to be important. However, electrical engineers need to start gaining more of an appreciation for thermal issues than they currently gain from a typical curriculum. To accomplish this it is not necessary to try to make thermal experts out of the EET's. It is important to give them an appreciation of the importance and thermal management, and to give them enough background to understand the basic processes that are going on in the system. When electronic system designers have this appreciation they are more likely to think about thermal issues earlier in the design when it is economically feasible to do something about them. Laboratory experiments such as those described in this paper can provide good hands on experiences that the students will remember. Scheduling them before the theory is introduced helps to create interest among the students to learn more about what is going on. It puts more pressure on the students to think about what is going on rather than receive the information in a lecture, but if the lectures are designed to be flexible and built around the student questions they seem to respond better to the material.

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