ENGR 3030: Heat Transfer Project

December 8, 2006
Western Michigan University

Aaron Linenthal, Brian Naiman, and Andrew Waaso

Introduction

This memo is in regards to the final product of the Heat Transfer service learning design project. The initial purpose of the project was to measure and quantify the conduction, convection, and radiation of heat. These three types of heat were to be compared and contrasted. Our customer for this service design was Ms. Julie Jenkins, a sixth grade science teacher at Milwood Middle School. Ms. Jenkins wanted to show her students the general principles of heat transfer. By providing her students with a general understanding of heat transfer, she could then focus on the environmental aspect of heat transfer. In the past, she had trouble conveying the principles of heat transfer in the environment and she called upon us to design a hands on experiment involving heat transfer fundamentals. There were some initial ideas regarding the design process. Some proved to exceed the $500 budget and others were much too dangerous for young students. Heat transfer in general is a very difficult concept to grasp especially at a young age. The objective of the design process was to create a product which would not only be safe for students to work with, but also be understandable and interesting.

Background

The process began by reviewing the types of heat transfer, which are conduction, convection, and radiation. The most difficult part of the project was thinking of a way to teach heat transfer to a group of 24 6th grade audience with little math and science background. The three basic principles of heat transfer were broken down into concepts that were as understandable as possible.

Heat is energy caused by the motion of atoms inside of a material. According to the second law of thermodynamics, heat is energy and can never be created nor destroyed, only transferred. Atoms inside of a particular material constantly vibrate and collide with one another, causing friction which releases heat. There are three main types of heat transfer: conduction, convection, and radiation. Radiation is the transfer of heat energy through empty space. This energy is carried through wavelengths in the electromagnetic spectrum. When radiation strikes the surface of a material, it excites the atoms causing more vibration, and more heat. Heat energy radiated from the sun strikes the surface of the earth. Some of this energy is radiated back out to space, some is absorbed by the earth, and some is absorbed by the clouds. This energy radiated by the sun is a major driving source of the weather patterns and ocean currents which give the earth its unique climate. Convection is defined as heat traveling through a liquid or gas as it is circulated as a result of being heated. The driving force in convective heat transfer is the density differential due to temperature differential. Convection can occur naturally or can be forced. Natural convection is the transfer of heat due to density changes and buoyancy forces. Forced convection is the transfer of heat using a pump, fan or other means. An example of forced convection is blowing on food when it is hot in order to cool it. Conduction is the transfer of heat across matter. Although all materials can serve as conductors, more dense, as well as metallic materials tend to be the best conductors of heat. Materials which are good conductors of heat also tend to be good conductors of electric currents. Alternatively, materials which do not conduct heat or electricity very well are known as insulators. With these basic principles of heat and heat transfer in mind, the group began brainstorming possible design ideas.

Design Process

Within the first week the group began brainstorming design ideas to demonstrate heat transfer to sixth grade students, keeping in mind that it had to be done in a safe and interesting manner. There were also other constraints which had to be considered when choosing a design. The group was required to maintain a budget of $500 or less when shopping for materials. The group was also under a time constraint, which was the fall 2006 semester (September 5th- December 5th). The project, along with the presentation had to be planned out, completed, and delivered to our teacher contact by December 5th 2006. With these constraints in mind the group created three preliminary design concepts. Schematics of these deign ideas are included in **Appendix I**.

The group's first design concept involved constructing a furnace type apparatus. This furnace would be horizontally oriented and would use a high-wattage infrared heat lamp as its heat source. The basic idea of the furnace apparatus would be to show heat transfer through different materials using the principles of conductive heat transfer. The objective of the design was to have students measure the temperature on one side of the material. Then, using k-values and simple mathematical formula, the students would be expected to calculate the expected temperature on the other side of the materials. Although this design was promising because it would utilize a safely enclosed heat source, it was ultimately rejected. Reasons for this included difficulty of construction, high cost of the materials which would need to be used, and uncertainty about mathematical skills of the students to which it would be presented.

The second design concept created by the group involved created a classic "shell and tube" heat exchanger. The objective of this design would be to show heat transfer utilizing co-current and counter-current flow methods. In this design, students would be required to measure certain temperatures, and using given mathematical formula, calculate other temperatures which could be verified with measurement. The largest downfall of this design centered on its education value to the students. Co-current and counter-current flow are very difficult concepts to handle, and the group felt that this design would emphasize characteristics of heat transfer far too esoteric to be useful to the students. A further downfall of this design idea was the fact that it lacked any originality in the design process.

The third design concept brainstormed by the group involved constructing a furnace type apparatus. This design was intended to build off of and improve upon the original furnace design idea. In this design concept, the furnace apparatus would be vertically oriented and would use a standard Bunsen burner as a heat source. The Bunsen burner would be used to apply heat to a material, and a temperature difference could be measured across the material. The objective of this design was to demonstrate the concepts of conductive heat transfer as well as demonstrate the fact that certain materials transfer heat more effectively than others. The furnace apparatus would be constructed of high-temperature resistant polycarbonate with aluminum "L-channel" for increased structural integrity. Within the structure there would be two horizontal supports which would support the material being tested. The Bunsen burner would be placed underneath this material so that a temperature difference could be measured across the material.

The three design concepts were analyzed according to four different characteristics: safety, cost friendliness, ease of construction, and educational value. The design ideas were rated on equally weighted scales with points assigned to each design characteristic (1-10, 10 being the best score). According to the defender/challenger comparison, it is apparent that Design 3 is the best overall design concept. The defender/challenger comparison is shown in **Figure I**.

Design #	Safe?	Cost Friendly?	Ease of Construction	Educational Value	Total
1	8	1	3	8	20
2	10	5	9	2	26
3	**8**	**9**	**8**	**8**	**33**

Figure I: Defender/Challenger of Top 3 Design Ideas

After deciding on the construction of Design #3, a materials list needed to be assembled. In addition to the polycarbonate and "L-channel", the group decided to purchase four thermocouple, heat-resistant glue, 12"x 6" x ¼" sheet of copper, and a lava lamp. The lava lamp was chosen as an accessory to demonstrate natural convection. The group was also able to obtain 12"x 6" x ¼" sheets of steel and aluminum. A complete materials and price list is located in **Figure II**.

Object	Other Info.	Quantity	Product #	Price	Total Cost
Thermistor (A)	Up to 302F	4	9264T11	$28.15	112.6
Unpolished Copper	1/4"*12*6"	1	8964K422	64.21	64.21
Polycarbonate	1/4"*12"*12"	1	8574K28	$9.88	9.88
Polycarbonate	1/4"*24*12	3	8574K43	$18.36	55.08
Speed Bonder 325	50 mL(Up to 350F	1	7614A111	$15.09	15.09
Acitvator 7075	4.5 oz	1	7614A131	$23.72	23.72
Bunsen Burner	vwrlabshop.com	1	17928-027	$23.52	23.52
Lava Lamp (1)	52 oz (planetlava.com)	1		$19.79	19.79
L - Bar	Lowe's	2		$10.00	20
				Total	343.89

Figure II: Price List for Proposed Design

Interaction with Students

On Tuesday December 5, 2006 we presented our final design to the students. Overall, there were 23 students to which the group was presenting. We used a dual approach of a lecture session and a lab session. We felt that if we could explain heat transfer to the kids first, showing them in a lab setting would reinforce the principles that we tried to show them in a short PowerPoint lecture. The lecture portion contained many pictures and very simple explanations of a decently complex topic. Our goal was to show them the three different types of heat transfer that can occur, through simple explanatory pictures. Our job was made slightly harder because the students did not have very much background information on types of heat transfer. The other factor that we had working against us was time. We only had about 45 minutes to present our lecture and experiment portion. This meant that the lecture had to be cut even shorter, to less than 10 minutes in order for the children to fully get the experience of the experiment.

Overall we feel that our total interaction with the children was a success. They did not really take a lot of information out of the lecture portion of the experiment. The only question that we answered at the end of it was, “Can I go to the bathroom?” Because of this we have all decided that if we did a similar type of experiment again, we would try and incorporate the lecture into the actual lab. If we taught the presentation and showed the experiment side by side, we might be able to further reach out to the kids. While they did not take away as much material as we wanted them too in the presentation, they seemed to understand our experiment. They showed a knowledge of understanding in the experiment because they understood that when you heat a surface, the other side gets hot also. They also understood the concept that different surfaces heat differently. In the experiment that we showed the students, we only had time to experiment with two different types of metal, copper and aluminum.

There were basically two parts to the experiment; the first part of the experiment was showing heat transfer by conduction, the second part was to show heat transfer by convection using a lava lamp that was running throughout the entire experiment. The lava lamp shows this because the hotter wax rises, while the cooler wax falls to the bottom of the lamp to be heated again. They seemed to understand the concept of convection the best because they know that the second floor in a house is warmer than the basement. The entire procedure on how to run the experiment can be found in **Appendix II**.

The biggest problem that we did not plan for was the children's graphing ability. Their graphing ability was much lower than what we originally thought. Some of the children had absolutely no idea how to graph a simple X-Y graph, while others completely understood. Some students tried graphing temperature differences using a bar graph method, which is not correct. This is one of the major points that we did not plan for, so the final minutes of the lab were spent furiously running around the room trying to help them complete the graphs. A sample worksheet, identical to the ones that were given out in class, is attached in **Appendix III**.

Recommendations

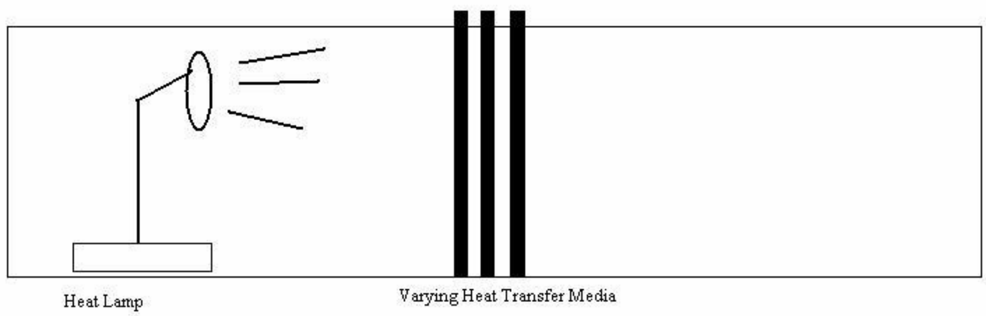
After working in the classroom and lab with the students of Milwood Middle School the group has a number of recommendations for any group which might continue this design project in future semesters. The largest improvement which could be made would be to expand the laboratory section of the presentation and do less of a lecture portion. The students were much more interested in the hands-on portion of the lab and paid much closer attention than during the lecture section. Future groups could capitalize on this by designing hands-on experiments to further expand on the concepts of convective and radiative heat transfer. Another improvement which could be made would be to first make sure that the students have a proper background in x-y graphing techniques. Given the time constraint that we had only 45 minutes to work with the students, we were not able to make sure that they had the proper background in making and understanding graphs. One possibility would be to request that Ms. Jenkins give her students a short lesson on graphing a few days before the group came to present.

Conclusion

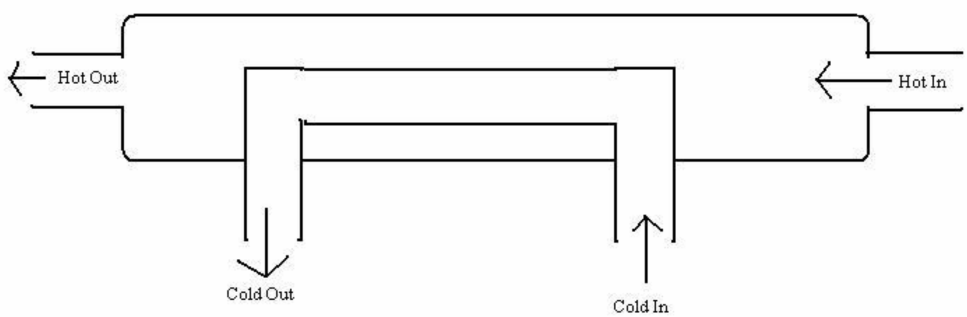
The group was presented the challenge of teaching middle school students about heat transfer. Several design ideas were presented regarding heat transfer, and all were analyzed under a defender/challenger scenario. The furnace type apparatus was the best way to present heat transfer to the students because it was safe and would be educational to the students. When presenting the apparatus to the students at Milwood Middle School, there were some difficulties for the students because of their lack of knowledge on heat transfer. After the experiment, many students appeared to take some information away from the classroom as they were able to communicate more clearly about the concepts of heat transfer. It was very rewarding for the group to take a difficult concept like heat transfer and present it in an interesting and educational manner. Overall, the design process and the trip to Milwood Middle School was a success.

Appendix I: Schematics of Proposed Designs

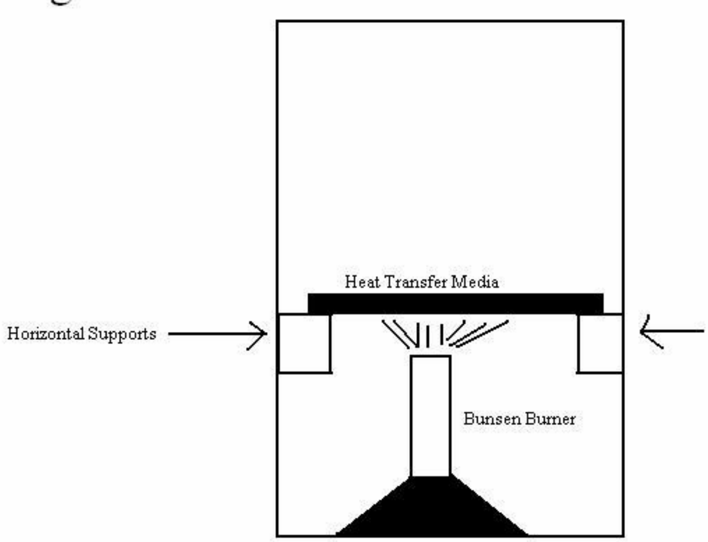
Design #1 - Horizontal Furnace



Design #2 - Shell & Tube Heat Exchanger



Design #3 - Vertical Furnace



Appendix II: Heat Transfer Lesson Plan for Furnace Apparatus

<u>Heat Transfer Lesson Plan for Furnace Apparatus</u>

I. Place furnace apparatus under fume hood, or well ventilated lab bench. As long as some ventilation system is present, everything can proceed.

II. Place Bunsen burner in the center of the furnace apparatus. There is a half sheet of plexiglass on one of the sides, which allows the Bunsen burner to easily slide under the apparatus.

III. Connect the gas hose and light the Bunsen burner, adjust the flame so the top of the flame is level with the two metal slider supports.

IV.

IV. Take the initial temperature with the thermocouple of the material being tested before it is heated up.

- A. The thermocouple works by:
  1. Turning the unit on.
  2. Deciding if the temperature measurement is wanted in °F or °C.
  3. Place the metal tip of the thermocouple on the surface of the material and take the reading that is presented by the digital display.
- B. The three materials being tested are aluminum, steel, and copper.

V. Use the heat resistant gloves to slide the material into the furnace utilizing the two metal slider supports.

VI. Center the metal over the flame, just making sure that the flame is centrally located on the metal.

VII. Have someone start the timer as soon as the flame touches the material.

VIII. Begin recording temperature readings each minute, for 5 minutes, with the thermocouple tip on the topside of the metal, opposite the flame.

- A. The thermocouple should be placed in a central location on the metal.
- B. To insure accuracy of the temperature readings the thermocouple sensor should be held on the material being tested for the duration of the experiment.

IX. After recording the temperature at the 5^{th} minute, the Bunsen burner can be turned off and the metal should be very carefully removed using heat resistant gloves.

- A. Allow at least 20 minutes for the metal to sufficiently cool before any other contact.

X. Repeat steps IV through IX for additional materials

Appendix II: Heat Transfer Lesson Plan for Furnace Apparatus (Cont.)

XI. After the experiment is sufficiently cleaned up, the temperature readings can be plotted on an X-Y plot, which is included in the student handout.

XII. The graphs should be plotted with the temperature on the Y (vertical) axis, and the time on the X (horizontal) axis

XIII. This plot can be used to compare conductive heat transfer.

Appendix III: Experimental Handout Given to Milwood Middle School Students

After recording all of the temperatures at one-minute intervals, plot the temperature versus time on the xy-graph.

Material: Steel	
Time (min)	Temp (C)
0	
1	
2	
3	
4	
5	

Material: Aluminum	
Time (min)	Temp (C)
0	
1	
2	
3	
4	
5	

Material: Copper	
Time (min)	Temp (C)
0	
1	
2	
3	
4	
5