2006-714: ENGINEERING STUDENTS' CONCEPTIONS OF HEAT AND TEMPERATURE PRE AND POST THERMODYNAMICS COURSE

Dennis Robbins, Borough of Manhattan Community College/CUNY

Dennis M. Robbins is Assistant Professor in the Science Department of the Borough of Manhattan Community College. A graduate of Teachers College Columbia University his research interests include topics in the learning and teaching of science. His publications appear in The Physics Teacher, The Journal of Chemical Education and The American Biology Teacher.

Mahmoud Ardebili, Borough of Manhattan Community College/CUNY

Mahmoud Ardebili, Ph.D., PE. is Associate Professor and Coordinator of Engineering Science Program at Borough of Manhattan Community College. He teaches Engineering Graphics, Thermodynamics, and Freshman Design classes. His research interests include computational fluid dynamics, alternatively fueled vehicles and engineering education.

Engineering Students' Conceptions of Heat and Temperature Pre and Post Thermodynamics Course

Introduction

During the last several decades research-based methods of teaching predicated on theories of student learning have risen to the forefront of undergraduate science and engineering education reform[1]. The term "scientific teaching" has been used to express the nature of these methods of instruction. "Scientific teaching," as supporters describe it "involves active learning strategies to engage students in the process of science and teaching methods that have been systematically tested and shown to reach diverse students[2]." An important feature of "scientific teaching" is research on students' understanding of various scientific concepts. Research suggests that students often have systematic "alternative" conceptions that might be particularly incorporated in curricular materials[3]. Physics Education Research (PER) has identified many of these conceptions and the research methods used to discover students' alternative understanding of topics in physics[4].

In this study we use PER inspired methods to evaluate physics instruction and assesses undergraduate engineering students' understanding of certain topics in thermal physics. PER documents students' difficulties with the conceptions of heat and temperature[5, 6, 7]. Much of this research suggests that many students hold an intuitive belief about the conceptual relationship of heat (Q) and temperature (T) which might be represented by this proportionality:

$$Q \propto T$$

As opposed to the established physics principle that heat transfer is proportional to the change in temperature:

$$Q \propto \Delta T$$

Many research-based conceptual diagnostic surveys are openly available for assessing learning in physics. The Heat and Temperature and Conceptual Evaluation (HTCE) by Thornton and Sokoloff[8, 9] was selected for the questions accessible language level and for its relative ease of use and analysis. The HTCE is a valid and reliable 28-item survey of temperature and heat transfer concepts using multiple choice questions containing distractors. Diagnostic surveys like the HTCE are generally used as a pre-instruction (before course) and post-instruction (after course) measurements of the state of students' knowledge and gain in conceptual understanding in introductory physics courses. In this study the preparedness (pretest) of students for an engineering course in thermodynamics is measured by using the results of the HCTE. Later the HCTE is used to assess the conceptual development course of temperature and heat transfer ideas after completing a course in engineering thermodynamics. The HCTE was administered to undergraduate engineering students entering their first course in engineering thermodynamics and all students had completed at least one term of university physics which had included topics in thermal physics.

Research Questions and Methods

This study focuses on two sets of related questions. The first assesses engineering students' understanding of fundamental topics in heat and temperature. The second set of questions links to the first by evaluating the effectiveness of traditional physics instruction on preparing students for learning thermal physics and preparing them to understand engineering thermodynamics. In this study traditional instruction or standard courses in physics refers to methods of teaching which do not rely on principles of "scientific teaching" and are characterized by their heavy dependence on lectures, textbook reading and laboratories that are often referred to as "cookbook" exercises[10].

- What understanding do engineering students have of heat and temperature? Do they have a functional understanding of the concepts of heat transfer and temperature? Does a course in engineering thermodynamics improve students' fundamental conceptions thermal physics?

- After traditional instruction in physics do engineering majors have more expert-like ($Q \propto \Delta T$) or more novice-like ($Q \propto T$) views? What should thermodynamics instructors know about engineering students understanding of thermal physics?

The HTCE was administered to undergraduate engineering majors in three thermodynamics courses at two different urban colleges with diverse and multicultural student populations. In one course students from a two-year college (2YC) were given the HTCE as a pre- and posttest. The study also acquired data from students in two other thermodynamics courses at a four-year college (4YC) where the HTCE was administered half way through the semester-long course. All three courses were equal in terms of syllabus coverage. Table 1 describes the sample size of each course and the timing of the HTCE administration.

Table 1. Courses and sample sizes.

Thermodynamics Course	Sample Size
2YC Pretest 2YC Posttest	N = 29 N = 22
4YC-1 Mid-course	N = 23
4YC-2 Mid-course	N = 27

Some attrition occurred in 2YC with fewer students taking the HTCE as a pretest. Students in the above courses, however, had all completed, at minimum, the first semester of introductory calculus-based university physics. While some variation existed in these courses, in general, they possessed the common feature of being traditional in makeup in the sense they do not use the principles of "scientific teaching".

Analysis of HTCE results used a cluster analysis. While not reported here pretest, posttest and mid-course scores on HTCE were compared between courses, but, the more important analysis in this study was students' responses to various collections of questions. We chose three sets of questions. The design of HTCE links questions to particular target concepts. For example (see Appendix 1) questions 1-4 assesses students' functional understanding of calorimetry and proportional reasoning of the relationships between heat transfer, mass, specific heat and temperature change. Table 2 summarizes the clusters of questions used from HTCE and their target concepts in heat and temperature.

Table 2. HTCE Clusters and Target Concepts.

HTCE Question Clusters	Thermal Physics Concepts
1-4	Calorimetry
12-15	Thermal Equilibrium
26-28	Heat Conduction

Students' who gave appropriate responses to every question in a specific cluster were regarded as having "functional" knowledge of the target concept. That is, the student understood that each question referred to the same principle and how to use the thermal principle in a coherent way to solve the problem. Also, these students had the more appropriate understanding that heat transfer was proportional to the change in temperature, the expert-like view. Students not responding to each question in cluster with the appropriate physics understanding were categorized as having "non-functional" understanding of the thermal topic.

Data and Results

These data are reported below. Students for each course possessing a functional understanding of the target concept is given as a percentage (see Table 3).

Table 3. Thermal Concepts and Percentage (%) Functional Responses.

Thermodynamics Course	Calorimetry	Thermal Equilibrium	Heat Conduction
2YC Pretest (N=29)	14%	31%	24%
2YC Posttest (N=22)	32%	45%	41%
4YC-1 Mid-course (N=22)	17%	44%	52%
4YC-2 Mid-course (N=27)	19%	26%	74%

Comparing the pretest scores of the two-year college students' to midterm scores of the four-year college courses finds little difference in two of the cluster categories. Under the calorimetry category scores of 2YC, 4YC-1 and 4YC-2 are 14%, 17% and 19%

respectively and among the given thermal concepts students' had the least success with these questions (see Appendix 1). The average of the four-year college courses was 35% for the thermal equilibrium questions cluster and was comparable to the pretest score for the two-year college.

The greatest difference between the two-year pretest scores and the four-year college mid-course scores existed in the heat conduction concept. The later courses had two to three times greater percentages of students giving functional responses to that particular cluster of questions. Same textbook (Cengel and Boles, Thermodynamics an Engineering Approach, 5^{th} edition) was used in all courses. It has a very brief introduction to heat conduction in second chapter of the book. Whether this introduction affected the mid-course scores of the four-year college courses cannot be ascertained without pre-test scores for the four-year college courses.

When comparing the pre- and posttest scores of students in the two-year college course for each category the posttest results finds that the percentage of students giving functional responses is higher at the end of the thermodynamics course. The number of students in this course decreased due to dropout.

Conclusions and Discussion

Conclusions about future courses and the instruction of engineering students in thermodynamics are made and discussed in this section. Our survey results suggests that after traditional physics instruction the majority of engineering students have not emerged with an effective understanding that would prepare them for a course in engineering thermodynamics since less then half will had a functional understanding of thermal concepts. Except for the four-year college courses in the heat conduction category the percentage students giving appropriate responses on the Heat and Temperature Conceptual Evaluation did not rise over 50%. Furthermore, based on our results for the two-year sample, a course in engineering thermodynamics does not necessarily improve students' fundamental understanding of heat and temperature. While the prettest scores are higher for this course this increase in percentage of functional responses can be accounted for by the reduction of the sample size of this course and the loss of students who possessed less understanding of thermal concepts.

In spite of taking introductory physics, then a course in thermodynamics, our survey found that about 10% still possess a strictly intuitive and deeply seated view of heat and temperature, identified by Physics Education Research that heat (Q) was proportional to temperature (T). In short, an object with higher temperature is an object with the higher heat.

The greatest difference between the studied courses was in the heat conduction category. We include these questions in Appendix 2. The differences in these scores might be accounted by the how the topic was addressed in the introductory physics but this study did not investigate that issue.

A thermodynamics course does not specifically improve students understanding of appropriate relationship that $Q \propto \Delta T$. We agree with reports that standard instruction, based on lectures, textbooks and "cookbook" laboratories are ineffective for most students. Our study supports the majority of studies on these issues. Engineering students need effective problem-solving abilities and these come by deep conceptual understanding of the fundamental physical understanding. The physics Nobel Laureate Carl Wieman has stated the problem thus, "typical students in traditionally taught course are learning by rote, memorizing facts and recipes for problem solving; they are not gaining a true understanding[11]."

The primary mode of instruction in the courses of our study was lecturing. In general education research in general, and in particular Physics Education Research, finds the lectures as a mode of instruction, while effective as any teaching methodology for transmitting information, it is the least effective methodology for promoting deep thought, creating conceptual understanding, cultivating problem-solving abilities, teaching the attitudes and beliefs associated with a subject and considerably diminishes students' motivation for learning that subject[12]. "On a majority of campuses the instructor as a didactic lecturer remains typical practice in STEM courses. As noted by Alison King (1994), 'Much of what transpires in today's college classrooms is based on the outdated transmission model of teaching and learning: the professor lectures and the students take notes, read the text, memorize the material, and regurgitate it later on an exam' (p. 15)." The findings in our study are in agreement with statement from the report "Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics" (2003).

Instructors of engineering thermodynamics courses might assess their own students' understanding of heat and temperature. Our study suggests that most students might not be prepared for the more advanced concepts as they may have undeveloped views of heat and temperature and their problem-solving abilities need more enhancement than traditional introductory physics courses have provided them. To overcome students' shortcomings, instructors should address these issues at the beginning of the term. One approach is to conduct a set of inquiry–based activities such as Real Time Physics[13], which focus on heat and temperature. The workshops allow students to gain a fundamental understanding of these concepts as they experiment with energy exchange. In one example, mechanical energy provided by students is transferred to heat via a hand-cranked generator. Specifically, exchange of mechanical energy to heat, heat to internal energy, which manifest in temperature rise, is investigated. This workshop and other workshops concentrating on temperature change of hot and cold objects as they are exposed to room temperature should improve students understanding of these concepts. The draw back for this approach is the time these workshops will take from class time. However as this research indicates, when students do not have a proper understanding of the fundamental concepts such as heat and temperature, all the learning in the class is purely memorization, which does not lead to problem solving ability required by an engineer.

References

[1] National Research Council, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Washington, D.C.: National Academies Press, 1999).

[2] Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., Wood, W.B., "Scientific teaching." *Science*, 304(5670): 521-522 (2004).

[3] Bransford, J. D., Brown, A. L., Eds. *How People Learn: Brain, Mind, Experience, and School*, (Washington, D.C.: National Academies Press, 1999).

[4] McDermott, L. C., Redish, E. F., "Resource Letter: PER-1: Physics Education Research." *American Journal of Physics*, 67(9): 755-67 (1999).

[5] Warren, J.W., "The teaching of the concept of heat." *Physics Education*, 7: 41-44 (1972).

[6] Erickson, L., "Children's conceptions of heat and temperature." *Science Education*, 63: 221-230 (1979).

[7] Arnold, M., Millar, R., "Children's and lay adults' views about thermal equilibrium." *International Journal of Science Education*, 16(4): 405-419 (1994).

[8] Redish, E.F., *Teaching Physics with the Physics Suite*, (Hoboken, NJ: John Wiley & Sons, Inc., 2003). HCTE found on included CD-ROM.

[9] Thornton, R.K., Sokoloff, D., "Heat and Temperature Conceptual Evaluation (HTCE)," (2001). Found at http://www.ncsu.edu/per/TestInfo.html.

[10] Hake, R. R., "Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics course." *American Journal of Physics* 66: 64-74 (1998).

[11] Wieman, C., Perkins, K., "Transforming physics education." *Physics Today* 58(11): 36-41 (2005).

[12] Bligh, D.A., *What's the Use of Lectures*, (San Francisco, CA: Jossey-Bass, 2002).

[13] Sokoloff, D. R., Thornthon, R. K., Laws, P. W., *Real Time Physics, Active Learning Laboratories, Module 2: Heat and Thermodynamics,* (New York, NY: John Wiley & Sons, Inc., 1998).

Appendix 1.

Questions 1 through 4 refer to two cups of water, A and B, which contain different amounts of water. The water in each cup is heated as described. In questions 1 through 3 cups are in a room where the temperature 25 °C. In question 4 the cups are in different environments. For each question choose one of the four answers **A** through **D**.

A) Cup A had more heat energy transferred

B) Cup B had more heat energy transferred

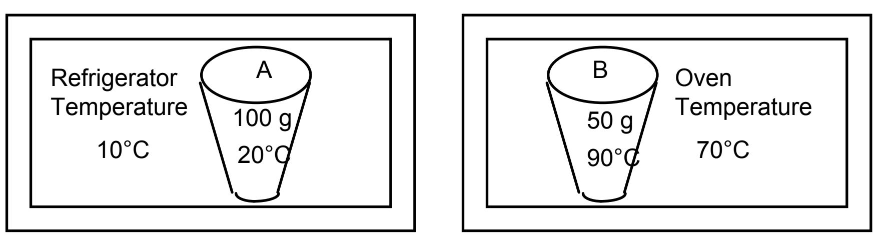
C) Both cups had the same amount of heat energy transferred

D) Not enough information is given to determine the answer

_______1. Cup A contains 100 grams of water and cup B contains twice as much water. The water in both cups was initially at room temperature. Cup A was heated to 75°C and cup B was heated to 50°C. Which cup had more heat energy transferred to it?

_______2. Cup A contains 100 grams of water and cup B contains 50 grams of water. The water in both cups was initially at room temperature. Cup A was then heated to 45°C and cup B was heated to 90°C. Which cup had more heat energy transferred to it?

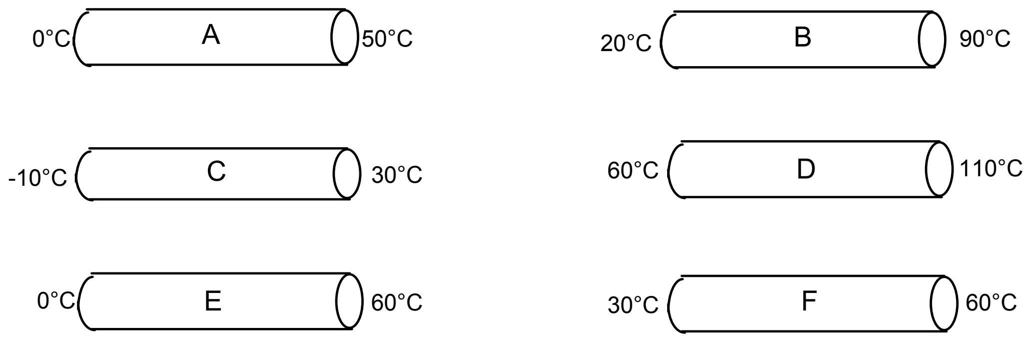
_______3. Cup A contains 100 grams of water and cup B contains 80 grams of water. The water in both cups was initially at room temperature. Cup A was then heated to 45°C and cup B was heated to 50°C. Which cup had more heat energy transferred to it?



_______4. Cup A contains 100 grams of water and is initially at 10°C in a refrigerator. Cup A is heated until its temperature is 20°C. Cup B contains 50 grams of water initially at 70°C in an oven. Cup B is heated until its temperature is 90°C. Which cup had more heat energy transferred to it?

Appendix 2.

Questions 26 to 28 refer to the six identical rods below (All are made of the same metal and the rods have the same shape). The temperatures at each end of the rods are indicated. The sides of the rods are insulated so that no heat can flow in or out .



____26. Along which rod does heat flow at the <u>slowest</u> rate? Answer **G** if you think that heat flows at the same rate along all of the rods.

____27. Along which rod does heat flow at the <u>fastest</u> rate? Answer **G** if you think that heat flows at the same rate along all of the rods.

____28. Along which rod is the rate of heat flow the same as along rod A? Answer **G** if you think that heat flows at the same rate along all of the rods. Answer **H** if you think that no rod has the same rate of heat flow as A.