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Undergraduate Engineering Students' Understanding of Heat, Temperature, and Radiation

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Heat and temperature concepts are found throughout science curricula, at both the pre-college and college levels (Jasien & Oberem, 2002) and previous research has found that students have difficulty discriminating between the two (Thomaz, Malaquas, Valente, & Antunes, 1995). It has also been found that learners hold a variety of misconceptions (Carlton, 2000; Self, Miller, Kean, Moore, Ogletree, & Schreiber, 2008; Thomaz et al., 1995). Thomaz et al. (1995) identified five misconceptions about heat and temperature, found recurrently in the literature, later labeled by Self et al. (2008) as "conceptual themes" (p. S2G-1). These themes included beliefs in the equivalency of heat and temperature, temperature being a measure of how hot or cold something feels, and the application of heat always resulting in making a body warmer. In addition, Streveler, Litzinger, Miller, and Steif (2008) found through a summary of educational literature that students at a variety of grade levels frequently think that temperature is a good measure of the energy in a system.

Difficulty understanding heat and temperature concepts has been documented in engineering education (Miller, Streveler, Olds, Chi, Nelson, & Geist, 2006; Prince & Vigeant, 2006; Self et al., 2008). Some recurrent areas where engineering students have had difficulty and misconceptions include rate versus amount of heat transfer, temperature versus perceptions of hot and cold, temperature versus energy, and the effects of surface properties on heat transfer by radiation (Miller, Streveler, Olds, Chi, Nelson, & Geist, 2006; Prince & Vigeant, 2006).

With *Rate versus Amount* of heat transfer, many students conflate factors impacting rate of heat transfer with amount of heat transferred (Prince, 2006; Miller et al., 2006). Students exhibiting this misconception have responded that any condition that made a glass of water cold *faster* would also cool it to a *lower* temperature. In the *Temperature versus Perceptions of Hot and Cold* concept area, it's been found that like other students, many engineering undergraduates view heat and temperature as equivalent entities (Prince & Vigeant, 2006). With *Temperature versus Energy*, students often believe that temperature is a good measure of the energy of an object or that objects at different energy levels have different temperatures (Streveler et al., 2008).

Radiation is a fundamentally different method of heat transfer in that it requires no intervening medium through which the energy transfers. Further, because in many industrial situations radiative heat transfer is small relative to convective and conductive heat transfer, relatively little instructional time is spent on this topic in a typical course. Therefore, it is not surprising that many students have been found to hold a number of misconceptions (Jacobi, Martin, Mitchell, & Newell, 2003). One aspect which students have found particularly confusing is the effect of color on radiation heat transfer rates. While most students are familiar with the phenomena in which black surfaces absorb radiation more effectively than white one (so that black clothing really does heat more on a sunny day), students often fail to predict that black surfaces also *emit* radiation more effectively such that black objects cool down more quickly as well. The general influence of surface properties on emission rates has proven to be one where students have a number of misconceptions.

Confusion in all four areas has been shown to persist, even when students successfully completed pertinent coursework (Miller et al., 2006; Self et al., 2008). This is not surprising given that traditional methods of instruction have been found to be ineffective at altering particularly resistant preconceptions (Laws, Sokoloff, & Thornton, 1999; Suping, 2003). As Self et al. (2008) noted, "It is very difficult to repair many of these robust misconceptions through simple lecturing…" (p. S2G-6).

The purpose of the current study was to determine whether undergraduate students' knowledge of four crucial heat transfer concepts significantly changed as a result of instruction and whether this varied by engineering major and self-reported grade point average (GPA). The conceptual areas assessed were: rate versus amount of heat transfer, temperature versus perceptions of hot and cold, energy versus temperature, and radiation. Assessment questions targeted previously documented misconceptions in those areas.

Methodology

Design

A one group, pre-test-post-test design was used. Descriptive statistics examined changes in knowledge, as measured by the mean scores of participants on the entire concept inventory as well as in each conceptual area sub-test. Paired sample t-tests were used to test the significance of changes in knowledge from pre- to post-test for the entire test and the sub-tests. One-way analysis of variance (ANOVA) was used to examine differences in performance by three engineering major groups and four grade point average (GPR) groups. Significant F statistics were followed by Tukey post hoc multiple comparison tests.

Participants

A sample of 228 undergraduate engineering students from six institutions was assessed in the first couple weeks of class, prior to instruction on the target concepts. The participants were then assessed in the last two weeks with the same instrument (n = 202). In the initial sample, 119 were mechanical engineering majors, 93 were chemical engineering majors and 16 were distributed among other engineering majors. Approximately 52% were juniors, 40% were seniors and the remainder was sophomores. The majority had a GPA of 3.00 or higher (73%) and 96% were enrolled in a heat transfer course at the time they were assessed.

Instrument

A Heat and Energy Concept Inventory (HECI) designed for undergraduate engineering students was used in the study. This instrument was patterned after concept inventories designed in other disciplines such as the Force Concept Inventory in physics (Hestenes, Wells, & Swackhamer, 1992) and was developed to document both conceptual change and the presence of previously identified misconceptions about heat and temperature (e.g., Nottis, Prince, & Vigeant, 2009; Prince, Vigeant, & Nottis, 2009). The instrument had 36 multiple choice questions constructed and reviewed by content experts. It included questions in all the targeted concept areas: rate versus amount (8 questions), temperature versus perceptions of hot and cold (9 questions), energy versus temperature

(9 questions), and radiation (12 questions). Questions in each of these areas were then examined as sub-tests of the entire instrument.

Two questions were used in two different conceptual categories. Question #24 was considered by content experts to be assessing both temperature versus perceptions of hot and cold and energy versus temperature. Question #29 was determined by content experts to be evaluating conceptual understanding in both temperature versus perceptions of hot and cold and radiation.

Internal reliability of the entire post-test and sub-tests was determined. As can be seen in Table 1, the Kuder-Richardson Formula 20 and Split-half reliabilities were high for the entire instrument. For the sub-tests, Kuder-Richardson Formula 20 ranged from .59 for temperature vs. perceptions of hot and cold to .77 for rate vs. amount of heat transfer.

Insert Table 1 about here

Results

Knowledge of Heat Transfer Concepts

The mean pre-test score for the total inventory was 17.90 (approximately 50%) and the mean post-test score was 20.21 (approximately 56%). A dependent t-test showed that participants significantly improved their overall scores, $t(202) = -6.067$, $p < .01$. However, the mean score on the total post-test demonstrated that students were still below what most instructors would consider content mastery.

Mean scores on sub-tests were then determined. As can be seen in Table 2, mean scores increased in all concept areas from pre- to post-test.

Insert Table 2 about here

Dependent t-tests showed that participants significantly improved in three of the four concept areas. There was no significant improvement in students' scores on the *Energy vs. Temperature* sub-test where mean pre-test scores were 4.86 (54%) while mean post-test scores were 5.04 (56%).

Questions #3, #27, and #28 were the most difficult for students. These questions can be found in Appendix A. Question #3 is a *Rate versus Amount* question while questions #27 and #28 are *Radiation* questions. Table 3 provides the percentage of students who selected the correct answer (difficulty levels), on both the pre- and the post-tests. Even after instruction, the percentage of students getting the questions correct was below 30%.

Insert Table 3 about here

Figures 1 and 2 graphically show the percentage of students selecting each of the distracters for Questions # 3 and #28. Even after instruction, approximately 50% of the students chose an incorrect distracter as the answer to Question #3. Although after instruction the correct response was selected the most for Question #28, a good percentage of the participants also chose each of the distracters.

Insert Figures 1 and 2 about here

Knowledge of Concepts and Major

A oneway ANOVA revealed a significant difference among the three engineering majors categories on the total pre-test scores, $F(2, 225) = 4.66$, $p < .05$. Tukey post hoc comparisons showed that pre-test scores of mechanical engineering majors were significantly higher than chemical engineering majors ($p < .01$). However, there was no significant difference among the major groups on the post-test.

When examining the conceptual area sub-tests, there was a significant difference based on engineering major on both the *Rate vs. Amount* pre-test, $F(2,225) = 3.92$, $p< .05$ and post-test, $F(2, 199) = 3.93$, $p< .05$. Tukey post hoc comparisons indicated that mechanical engineering majors had significantly higher scores than chemical engineering majors on both. There was also a significant difference on the *Temperature vs. Perceptions of Hot and Cold* pre-test, $F(2, 225) = 4.31$, $p<.05$. Mechanical engineering majors had significantly higher scores than chemical engineering majors.

Knowledge of Concept and Self-Reported GPA

Grade point average (GPA) was divided into four categories: 3.50-4.00, 3.00-3.49, 2.50-2.99, and 2.00-2.49. A oneway ANOVA revealed a significant difference among the four grade GPA groups on the total pre-test scores, $F(3, 223) = 5.11$, $p < .01$. Tukey post hoc comparisons showed that pre-test scores of the 3.50-4.00 group were significantly higher than the 2.50-2.99 group ($p < .01$). There was also a significant difference on the post-test, $F(3, 197) = 9.95$ ($p < .01$). Tukey post hoc comparisons revealed that the 2.50-2.99 group scored significantly lower on the post-test than all the other GPA groups ($p < .01$).

When examining the conceptual area sub-tests, oneway ANOVAs revealed significant differences based on GPA on the *Rate vs. Amount* and *Temperature vs. Perceptions of Hot and Cold* pre- and post-tests, and the *Radiation* Post-test. Tukey post hoc comparisons showed that on the *Rate vs. Amount* pre-test, the 3.50-4.00 GPA group scored significantly higher than the 2.50-2.99 GPA group, ($p< .05$). On the *Rate vs. Amount* post-test, Tukey post hoc comparisons revealed that both the 3.50-4.00 and the 3.00-3.49 GPA groups scored significantly higher than the 2.50-2.99 group, ($p<.01$).

On the *Temperature vs. Perceptions of Hot and Cold* pre-test, the Tukey post hoc comparisons showed that the 3.50-4.00 GPA group scored significantly higher than the 3.00-3.49 and the 2.50-2.99 GPA groups, ($p<.01$). Also, the 2.00-2.49 scored significantly higher than the 2.50-2.99 group, ($p<.01$). On the *Temperature vs. Perceptions of Hot and Cold* post-test, Tukey post hoc tests determined that three GPA groups (3.50-4.00, 3.00-3.49, 2.00-2.49) scored significantly higher than the 2.50-2.99 GPA group, ($p<.05$).

On the *Radiation* post-test, the Tukey post hoc comparisons revealed that both the 3.50-4.00 and the 2.00-2.49 GPA groups scored significantly higher than those in the 2.50-2.99 GPA group, ($p<.05$).

Conclusions and Educational Implications

Results indicated that students improved their understanding of target concept areas with conventional instruction however, mean scores were below what most instructors would consider mastery. The lack of significant change in the pre- to post-test scores on the *Energy vs. Temperature* sub-test may indicate that those misconceptions are particularly resistant to change. Students commonly believe that temperature is a direct measure of the energy in an object (Streveler et al., 2008), so something at a higher temperature always has more energy. This belief may be so pervasive that new instructional methods need to be found to change it.

Although students significantly improved from pre- to post-test in the three other concept areas there were individual questions that remained difficult. Even after instruction, less than 30% of the students had the correct response to questions #3 (*Rate vs. Amount*), and #27, and #28 (*Radiation*). In terms of question #3, the continued selection of an incorrect answer indicates that students were unable to predict heat transfer rates when multiple relevant variables changed. Distracter “c” was selected by about 50% of the students even after instruction. The selection of this response shows that participants failed to recognize that both surface area and temperature determine heat transfer rates rather than just one of these factors. Questions related to heat and temperature that required integration of multiple ideas have been found to be the most difficult for students in previous research (Jasien & Oberem, 2002). For questions #27 and #28, incorrect responses revealed a failure to recognize that radiation is a major factor in heat transfer or that participants do not understand the effect of surface properties such as color on heat transfer rates, supporting the previous findings of Jacobi et al. (2003). These recurrent issues may also indicate a need for different pedagogies. Preliminary work on some new instructional methods in engineering courses seems encouraging (Nottis, Prince, & Vigeant, 2008).

Significant differences on pre-test scores by major, specifically mechanical and chemical engineering majors) may be reflective of different prior knowledge as a result of varied academic coursework. However, the significant difference in scores after instruction that was found on the *Rate vs. Amount* sub-test may indicate that students with different engineering majors may need varied instructional pedagogies. Future research should continue to examine major as a variable to better determine whether the differences between mechanical and chemical engineering majors found in the current study are spurious or reflect a difference that should be addressed.

The significantly higher scores of the highest grade point average group (GPA) were not surprising. However, the higher scores of the lowest GPA group when compared with the next highest group were unexpected. This finding could reflect the effectiveness of instruction for this particular group or students or an error in GPA reporting. To better determine this, future research should use actual grade point averages rather than rely on students to indicate where their GPAs fall into pre-determined groupings.

Misconceptions resistant to change through traditional teaching methods are of particular interest to engineering educators, especially when the misconception concerns a critically important concept related to core engineering courses. The current research revealed that even after instruction, students from six institutions did not reach mastery in four heat transfer areas. New methodologies are needed to build conceptual understanding and alter misconceptions.

Acknowledgements

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References

Carlton, K. (2000). Teaching about heat and temperature. *Physics Education, 35*(2), 101-105.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141-158.

Jacobi, A., Martin, J., Mitchell, J., & Newell, T. (2003). A concept inventory for heat transfer. In *Frontiers in Education*. Boulder, CO.

Jasien, P. G., & Oberem, G. E. (2002). Understanding of elementary concepts in heat and temperature among college students and K-12 teachers. *Journal of Chemical Education, 79*(7), 889-895.

Laws, P., Sokoloff, D.,& Thornton, R. (1999). Promoting active learning using the results of physics education research*, UniServe Science News*, *13.*

Miller, R. L., Streveler, R. A., Olds, B. M., Chi, M. T. H., Nelson, M. A., & Geist, M. R. (2006). *Misconceptions about rate processes: Preliminary evidence for the importance of emergent conceptual schemas in thermal and transport sciences*. In Proceedings, American Society for Engineering Education Annual Conference, Chicago, IL.

Nottis, K. E. K., Prince, M., & Vigeant, M. (2008, October). *Addressing Misconceptions about Heat Transfer in Undergraduate Chemical Engineering Instruction*. Paper presented at the Northeastern Educational Research Association conference, Rocky Hill, CT.

Nottis, K., Prince, M., & Vigeant, M. (2009, January). *Development of an Instrument to Assess Crucial Concepts about Heat Transfer in Undergraduate Chemical*

Engineering Instruction. Paper presented at the 7th Annual Hawaii International Conference on Education, Honolulu, HI.

Prince, M., & Vigeant, M. (2006). *Using Inquiry-based Activities to Promote Understanding of Critical Engineering Concepts.* Paper presented at the ASEE National Conference, Chicago, IL.

Prince, M., Vigeant, M. & Nottis, K. (2009, June). *Development of Concept Inventory in Heat Transfer*, Paper presented at the ASEE National Meeting, Austin, TX.

Self, B. P., Miller, R. L., Kean, A., Moore, T. J., Ogletree, T. & Schreiber, F. (2008, October). *Important Student Misconceptions in Mechanics and Thermal Science: Identification using Model-eliciting Activities*, Paper presented at the ASEE/IEEE Frontiers in Education Conference, Saratoga Springs, NY.

Streveler, R., Litzinger, T., Miller, R., & Steif, P. (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions, *Journal of Engineering Education, 97*(3), 279-295.

Suping, S. (2003). Conceptual change among students in science. *Eric Digest*.

Thomaz, M. F., Malaquas, I. M., Valente, M. C., & Antunes, M. J.(1995). An attempt to overcome alternative conceptions related to heat and temperature. *Physics Education, 30*, 19-26.

Table 1

Internal Reliability of Entire Heat Transfer Concept Inventory and Sub-tests

Assessment	Split-Half	Kuder-Richardson #20
Entire Concept Inventory (Post-Test) 36 Questions	.84	.86
Rate *vs*. Amount Sub-test	.83	.77
Temperature *vs*. Perceptions of Hot and Cold Sub-test	.45	.59
Energy *vs*. Temperature Sub-test	.56	.66
Radiation Sub-test	.70	.71

Table 2

Pre-Post Scores of Sub-tests

Sub-test Area	Mean Pre-test Score n = 228	Mean Post-test Score
Rate versus Amount of Heat Transfer (8 questions)	2.99 (37.4%)	3.52 (44.0%), n = 204**
Temperature versus Perceptions of Hot and Cold (9 questions)	5.43 (60.3%)	6.36 (70.7%), n = 202**
Energy versus Temperature (9 questions)	4.86 (54.0%)	5.04 (56.0%), n = 202
Radiation (12 questions)	5.59 (46.6%)	6.33 (52.8%), n = 202**

** Significant difference, $p < .01$

Table 3

Percentage of Participants with Correct Answer on Most Difficult Questions

Question	Concept Area	Percentage Correct on Pre-test	Percentage Correct on Post-test
3	Rate versus Amount	12.7%	25.7%
27	Radiation	16.7%	29.7%
28	Radiation	12.3%	27.7%

Figure 1

Students' Responses to Question #3

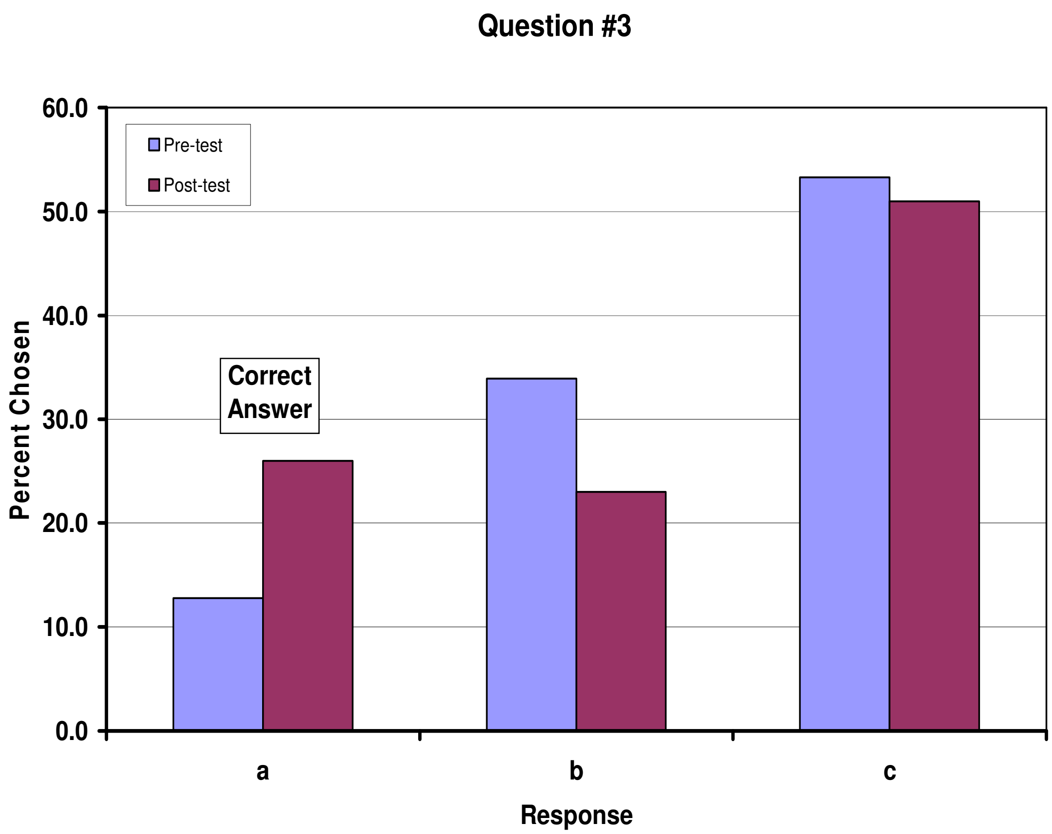
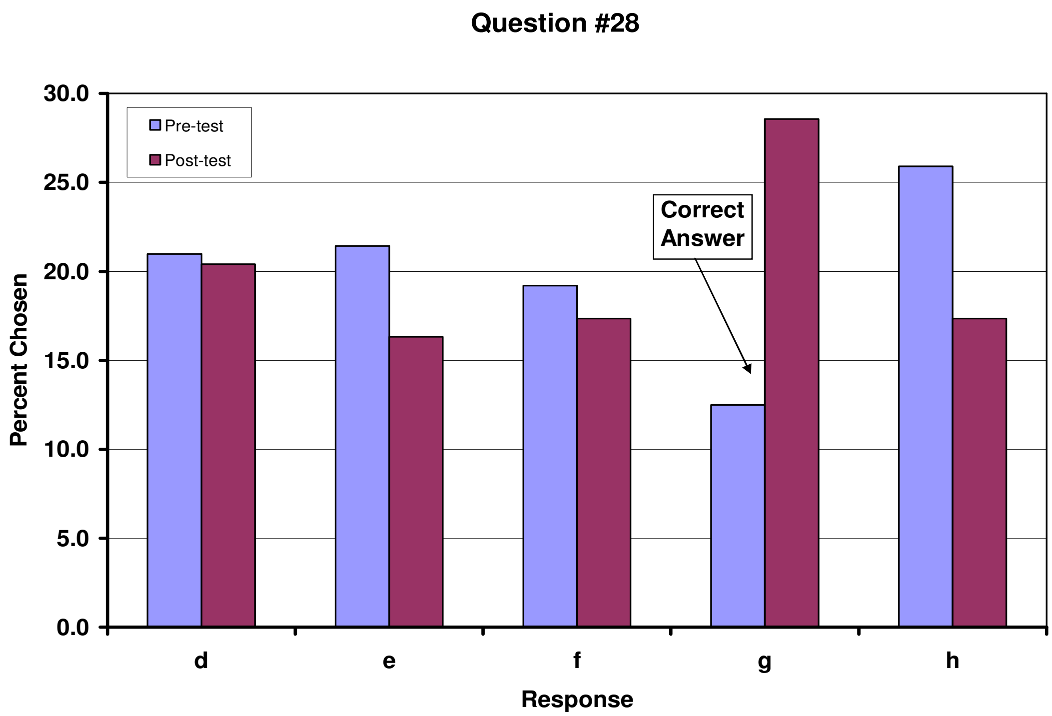


Figure 2

Students' Responses to Question #28



Appendix A

You would like to melt ice which is at $0^{O}C$ using hot blocks of metal as an energy source. One option is to use <u>one</u> metal block at a temperature of $200^{O}C$ and a second option is to use <u>two</u> metal blocks each at a temperature of $100^{O}C$. Each individual metal block is made from the same material and has the same mass and surface area. Assume that the heat capacity is not a function of temperature.

Question 3: Which option will melt ice more quickly?

- **a. Either option will melt ice at the same rate**
- b. The 100 ^{O}C blocks
- c. The 200 ^{O}C block

Question 27

Consider the cans of the previous problem filled with hot water at 100ºC and simply placed on a bench in a room at 20ºC. In which can will the water cool more quickly?

- a. The water in the shiny can will cool more quickly
- **b. The water in the black painted can will cool more quickly**
- c. The water in both cans will cool at the same rate

Question 28: Because…

- d. The paint acts as an insulator
- e. The black paint absorbs and holds in the heat better
- f. The shiny surface will reflect heat better
- **g. Black paint has a higher emissivity**
- h. In the absence of a heat source, the exterior color does not matter