Concept Inventories Meet Cognitive Psychology: Using Beta Testing as a Mechanism for Identifying Engineering Student Misconceptions

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Abstract

This paper summarizes our analysis of beta test results collected at four U.S. engineering schools using the Thermal and Transport Concept Inventory (TTCI) currently under development. The instrument consists of questions in heat transfer, fluid mechanics, and thermodynamics and is designed to elicit information about the nature of undergraduate engineering students' misconceptions in these disciplines. In addition to using conventional methods for determining TTCI reliability with correlation coefficients, we have applied cross-tabulation data analysis for six heat transfer questions to identify robust student misconceptions. The results of these analyses identified two categories of misconceptions which persist across heat transfer problems and contexts: 1) confusion about differences between energy and temperature, and 2) confusion about differences in steady-state and equilibrium processes.

Introduction

With funding from the National Science Foundation (DUE-0127806), a team of researchers at the Colorado School of Mines (CSM) is creating a concept inventory to measure engineering students' understanding of difficult concepts in thermal and transport science, the Thermal and Transport Concept Inventory (TTCI). [1] Our project began with a Delphi survey of experts to determine the concepts that were the most difficult and important for engineering students studying thermodynamics, heat transfer, and fluid mechanics. [2] Once the key concepts were identified, we created open-ended questions related to each concept and asked students to think aloud as they answered the questions. Multiple-choice questions were then developed using students' misunderstandings as documented in the think-alouds as the basis for writing distractors (incorrect but plausible answers). The resulting inventory was alpha tested at CSM [3], expanded, and beta tested at four other engineering institutions.

Standard psychometric procedures include testing to establish various forms of reliability (how repeatable are the results?) and validity (are we really testing the concepts that we intend to test?) for an instrument under development. We are currently analyzing beta test data from the TTCI to establish these parameters, and more detailed findings will be reported elsewhere. However, we are also using the beta test data to develop methods for identifying the kinds of misunderstandings or misconceptions students hold about concepts included in the TTCI. In particular, we are interested in seeing if the results of beta testing support Chi's theory that specific classes of conceptual misunderstandings arise when students incorrectly think of emergent processes as having the attributes of the direct processes they see in everyday life. [4]

In Chi's theory, direct processes involve distinct, sequential, goal-oriented events that have an observable beginning and end (e.g. bulk fluid flow in a pipe, forced convection heat transfer from a surface) while emergent processes involve uniform, parallel, independent events with no beginning or end but in which observable macroscopic patterns eventually emerge. Viscous momentum transfer, conductive heat transfer, and thermal equilibrium are but a few of the many examples of emergent processes that our students tend to misclassify as direct. Thus, Chi's theory explains why some students persist in their belief that molecules move with intent, that heat and temperature are substances which flow and can be stored, and that the dynamics of processes at equilibrium have stopped. [5]

This paper will focus on the way we have used the test data collected with the TTCI to learn more about the misunderstandings/ misconceptions that students hold about difficult concepts in the thermal and transport sciences.

Participants and Methods

For ease of beta testing, the original 32-question Thermal and Transport Concept Inventory (TTCI) was divided into subsets for heat transfer (6 questions), fluid mechanics (12 questions), and thermodynamics (13 questions). Faculty members at four engineering schools across the country agreed to coordinate their institution's participation in beta testing. This paper reports preliminary results on the heat transfer subset of questions; these questions were chosen for initial analysis because they are the subset most likely to elicit response data showing that students are incorrectly applying direct mental models to heat transfer processes with emergent characteristics. Approximately one hundred undergraduate engineering students' answers were included in our initial analyses. Students were asked to provide demographic information as well as to report on the engineering courses they had completed or were currently taking.

Determining instrument reliability. As the TTCI was created, we wrote three questions for each concept for which beta test data would be collected and used to establish: 1) instrument reliability and, 2) that students are taking the assessment seriously. Pearson's correlation coefficients were calculated for all paired combinations of heat transfer questions and pairs which gave statistically significant correlations exceeding 0.4 at the 0.99 level of significance were used to search for persistent student misconception. Calculations were based upon the number of students who answered each question correctly in a pair of questions plus the number of students who selected distractors in each question which were related conceptually.

The TTCI contains two question formats. Some of the questions asked students to select a single answer from a list of 4-5 choices, while others consisted of a two-part question in which students were first asked to answer a "what will happen?" question followed by a "why will it happen?" question. The two-part question format provides additional reliability data by allowing us to determine how many students answered the two questions consistently (that is, both correct answers or pairs of incorrect answers that are logically related). All heat transfer questions from the TTCI discussed in this paper are provided in Appendix A (for convenience, each question has been coded with a keyword reference that will be used throughout the paper).

For example, the *MeltIce* questions constituted a paired set of questions (labeled *MeltIce1* and *MeltIce2*). If students were not simply guessing, answers to the first part should correlate very strongly to specific responses in the second part. Students who answered the *MeltIce1* question by indicating that two 100°C metal blocks would melt more ice than one 200°C metal block, would logically choose "two blocks have twice as much surface area as one block so the energy transfer rate will be higher when more blocks are used" as their response to the *why* question, *MeltIce2*. As indicated in Table I, we found that the correlation was very strong (over 80%) which suggests that students were not simply guessing, but seem to have answered the questions seriously and consistently. This provides further evidence beta test reliability.

Table I – Correlation[1] between Related Parts of the *MeltIce* Question

		MeltIce1	*MeltIce2*
MeltIce1	Pearson correlation coefficient N = 102	1	.807
MeltIce2	Pearson correlation coefficient N = 102	.807	1

[1] Correlation is significant at the 0.01 level (2-tailed)

Determining the presence of robust misconceptions. In addition to a statistical check on reliability, the beta test data can also be used to search for the presence of underlying misconceptions students revealed in their answers. The first step of this analysis was to create cross-tabulation tables on student response data to pairs of heat transfer questions. As shown in Table II, a cross-tabulation table is a convenient way to display data that allows two variables to be compared with each other. In cross-tabulation tables, we can see frequency counts of how many students selected each answer for the two questions. By observing the individual entries in each row and column, we can determine how many students answered both questions correctly. More importantly, when students answer both questions incorrectly using wrong answers that are related conceptually, we have obtained evidence of a misconception which carries across the context of both questions. For example, the results in Table II indicate a strong correlation for the correct answer pair (c,f) as well as two sets of incorrect responses (a,e) and (b,g); the incorrect response pairs can then be analyzed to determine if a consistent misconception can be identified from these incorrect responses.

Table II – Cross Tabulation Results Comparing Correlated Answer Pairs for the *MeltIce1* and *MeltIce2* Questions

		MeltIce2					Total
		e	f (correct)	g	h	i	
MeltIce1	a	39	3	0	2	1	45
	b	0	0	16	0	0	16
	c (correct)	2	19	2	0	2	25
	d	0	2	0	0	8	10
Total		41	24	18	2	11	96

Results and Analysis

In this section, we will discuss results from beta testing of the TTCI that illustrate how these data can be used to identify persistent engineering student misconceptions about heat transfer topics. As discussed earlier, we are focusing on analyzing the responses to pairs of questions, both of which were designed to assess student understanding of a specific concept. In addition to tabulating how many students answered both questions in a pair correctly (information which is used to establish question reliability), we are also interested in how many students selected paired wrong answers (distractors) to both questions. In this way, we are able to begin identifying those misconceptions that students hold tightly across multiple heat transfer contexts and problem types.

To conduct this analysis, we first cross-tabulated beta test student responses from all possible pairs of heat transfer questions included in the TTCI, version 2.2. A typical cross-tabulation comparing results for the *MeltIce* vs. *Carpet* questions is shown in Table III. Results show that only 19% of the students answered both the *MeltIce1* and *Carpet* questions correctly and only 20% answered both the *Meltice2* and *Carpet* questions correctly. Overall, 28% of the students correctly answered the *MeltIce1* question, 25% identified the correct reason (*Meltice2*), and ~64% correctly answered the *Carpet* question. Of interest is the significant number of students (approximately 13%) who incorrectly answered all three questions by selecting distractors (“a” for *MeltIce1*, “e” for *MeltIce2*, and “d” for *Carpet*) that indicate the same misconception. Rather than simply being confused about a question or the distractors, these students appear to be consistently applying their robust but incorrect mental models to each of the questions compared in Table III. Those students who selected consistent but incorrect distractor pairs for the heat transfer portion of the TTCI are the focus of this paper and ultimately are of interest when identifying and repairing incorrect thermal science misconceptions.

Table III – Cross-Tabulation of Student Responses to *MeltIce1*, *MeltIce2* and *Carpet* Questions[1]

	Carpet responses				Total
	a	b	c (correct)	d	
MeltIce 1 responses					
a	5	1	27	13	46
b	3	0	10	3	16
c (correct)	4	0	19	5	28
d	1	0	8	1	10
Total	13	1	64	22	100
MeltIce2 responses					
e	4	1	24	12	41
f (correct)	2	0	19	3	24
g	3	0	11	4	18
h	1	0	1	0	2
i	2	0	8	1	11
Total	12	1	63	20	96

[1] yellow cells are located in rows and columns of the correct response to each question; blue cells represent distractor pairs which indicate persistent misconceptions in significant numbers of student respondents. For example, 13 students chose distractor ‘a’ on the *MeltIce1* question and distractor ‘d’ on the *Carpet* question. By comparing these two distractors, incorrect ideas (or misconceptions) about the concepts can be recognized.

All questions listed in Appendix A were cross-tabulated in pairs using the format shown in Table III. Significant misconceptions were identified and grouped into two overall categories:

- energy vs. temperature
- steady-state vs. equilibrium processes

The following subsections present beta test data for each of these categories, describe in more detail the nature of each identified misconception and, in selected cases, we speculate about why the misconceptions exist.

Misconceptions about energy vs. temperature. Misconceptions about energy and temperature are well known in the science and engineering education literature with approximately 500 reference citations listed by Duit in 2004 (from a larger list of over 6000 misconception papers in physics chemistry, and biology). [6] Most studies have focused on the presence of misconceptions formed by common sense observations of the world by elementary and secondary school children. However, work we have reported previously based on interviews with engineering students indicates that these misconceptions are carried forward into college and that some of our best students (as measured by grade point average) still possess significant heat transfer misconceptions when they graduate. [3]

Results from cross-tabulation of student responses to the *Carpet*, *Hotplate, Swim* and *MeltIce1* questions were used to identify persistent student misconceptions about the relationship between the thermal energy stored in a system (termed internal energy) and the temperature of the system. Table IV summarizes the key distractors selected by students for these question pairs, the percentage of students selecting both of these distractors and the persistent misconception these selections indicate. For comparison purposes, the percentage of students correctly answering both questions in the pair is also tabulated. It is likely that a larger percentage of student respondents possess one or more of the misconceptions listed, but these students are not included in the tabulated percentages because they answered only one of the questions in each question pair incorrectly. The results shown in Table IV indicate the percentage of engineering students who exhibited the same misconception in both questions listed. As explained earlier, results from cross-tabulation of the *MeltIce1* and *Meltice2* answers suggest that the majority of students did not simply guess on the TTCI.

Table IV – Summary of Question Pairs Which Identify Robust Misconceptions about
Energy vs. Temperature

Question pair	% students answering correctly	Incorrect distractor pair		Misconception
		answers	% responding	
Carpet/Hotplate (n=100)	34	d/e	9	don't understand how heat capacity relates temperature change to energy chance
Hotplate/Swim (n=99)	30	e/a+b	10	don't understand mechanism of energy storage in a system
MeltIce1/Hotplate (n=100)	13	a/c	13	incorrectly equates change in energy to change in temperature without regard to heat capacity
MeltIce1/Hotplate (n=100)	13	a/e	10	don't understand how temperature is related to energy content

Taken together, these data suggest that at least ~10 percent (and likely quite a few more) of engineering students participating in the beta test conceptually do not understand how internal energy and temperature are related, even though all of the participants were junior and senior engineering students. Some believe that a change in temperature equates to an equal change in internal energy while others don't understand how the heat capacity (perhaps a poor choice of term but the one that's used historically) and temperature together can be used to estimate changes in a system's stored internal energy (in the absence of complications such as a change in phase).

How can we explain the presence of this misconception in the mental models of well-educated, upper-level engineering students who nearly all have completed courses in thermodynamics and/or heat transfer? Reiner, Slotta, Chi and Resnick [5] have reported that some students incorrectly view processes such as transfer of energy and movement of electricity, etc. as flows of material substances. Such a view probably arises from incorrectly applying the attributes of a direct macroscopic process to molecular-level processes in which patterns emerge from random molecular motion. In the case of energy transfer, energy does not "flow" in the conventional sense, but occurs as a result of random diffusion and collision of a collection of molecules with varying individual energies.

We can hypothesize that students who view energy transfer as a substance-based process and who also think about temperature as a substance to be used up or stored may tend to equate energy transfer and temperature change. In this view, transfer of one "substance" like energy is equivalent to transfer of the other "substance" like temperature and thus a process involving changing the temperature of different substances should equate to the same amount of energy being added to each substance. To these students, the concept of heat capacity is not needed. For example, during alpha testing, one engineering student interviewed about the *Hotplate* question (see Appendix A) in which water and ethanol are heated on identical hotplates said:

> "[The process is] transferring the same amount of heat no matter how long each liquid is heated since the temperature change is the same."

When questioned again about the different length of time each liquid was heated (and therefore the different amounts of energy being added to each), the student responded:

> "You're transferring the same amount of heat because you have the same heat source [for each fluid]."

Another student realized that heat capacity might be useful to analyzing the hotplate process but claimed that he needed to be given values for the heat capacities of water and ethanol, even though the relative values could be obtained by knowing which fluid was heated longer for the same change in temperature. When asked if there was any way to estimate whether the water or ethanol heat capacity was larger from the information given, his response was a categorical "No."

The same incorrect mental model is apparently also being applied to the *Carpet* problem in which differences in the heat capacity of carpet and floor tile play a major role in the observation that tile feels colder to a bare human foot than carpet does. Some students believe that temperature <u>equates</u> to energy storage in the tile, carpet, or human foot without regard to physical property differences. These students will not have a reasonable explanation for the observation that tile feels colder and thus, in interviews with students answering the *Carpet* question, we heard explanations like the following:

> "Tile doesn't release the heat as quickly as the carpet so the tile feels cooler."

> "The carpet is absorbing more radiation and the tile has a higher reflectance, so the carpet feels warmer."

> "The heat transfer coefficient is larger for the tile."

As part of our future work we will ask students possessing the energy/temperature equivalence mental model to predict what will happen during processes like boiling and freezing of water where energy transfer occurs with no change in temperature. Assuming they correctly predict no temperature change (based on common everyday experience), follow-up questions asking why phase changes behave as they do will provide more valuable information about flaws in these students' mental models.

Misconceptions about steady-state processes vs. thermal equilibrium processes. Significant numbers of engineering and science students interchangeably use the terms "steady-state" and "equilibrium" to describe processes where one or more system conditions are not changing with respect to spatial position or time. [7,8] In heat transfer processes, these terms are conceptually quite different (as they are in other important scientific and engineering applications) with "steady-state" referring to conditions not changing with time at a fixed spatial position in the system and "thermal equilibrium" referring to a thermodynamically balanced state in which the system is at the same temperature as its surroundings and therefore net heat transfer ceases. Similar misconceptions occur with other forms of equilibrium (e.g. mechanical, chemical).

Results from cross-tabulation of student responses to the *MeltIce2*, *Heatpipe1*, *Heatpipe2*, and *Tongue* questions identified persistent misconceptions about the differences between a steady-state thermal process and a thermal process operating at equilibrium. Table V summarizes the key distractors chosen by students for these question pairs, the percentage of students selecting both of these distractors, and the persistent misconception these selections indicate. The percentage of students answering both questions correctly is included for comparison. Once again, the percentages shown in Table V represent our estimates of the minimum number of students possessing each misconception because it tabulates only those students who have chosen *both* incorrect answers in the pair.

Table V – Summary of Question Pairs Which Identify Robust Misconceptions about Steady-State vs. Thermal Equilibrium Processes

Question pair	% students answering correctly	Incorrect distractor pair		Misconception
		answers	% responding	
MeltIce2/Heatpipe1 (n=96)	17	e/d	15	confusing steady-state rate of energy transfer with total amount of energy transferred and ability for system to come to thermal equilibrium
MeltIce2/Heatpipe2 (n=94)	15	e/h	14	incorrectly believes that if heat transfer is occurring, system can never be at steady-state
Tongue/Heatpipe2 (n=97)	35	a/f+h	8	believes that different materials (water, air, metal) in contact with each other will not necessarily come to thermal equilibrium

The data shown in Table V indicate that at least ~8-14 percent (and likely quite a few more) of the engineering students participating in the beta study do not have a clear conceptual understanding of steady-state and thermal equilibrium processes and how they differ. Some believe that processes in which energy transfer is taking place can never be operating at steady-state nor eventually reach equilibrium, while others believe that different materials in contact with a constant-temperature medium such as air will not necessarily equilibrate given enough time.

Once again, we seek to explain the presence of these misconceptions in the mental models of well-educated, upper-level engineering students who have completed courses in thermodynamics and/or heat transfer. Chi's theory of robust misconceptions involving the misapplication of attributes associated with direct, macroscopic processes to molecular systems dominated by random molecular action may give us some relevant clues. [4] The theory suggests that students who view equilibrium in a macroscopic sense will predict that all thermal transfer will cease when thermal equilibrium (i.e. constant temperature) is achieved rather than understanding that energy transfer still occurs at the molecular level but will be balanced between bodies of equal temperature so that no net transfer will be observed. Similarly, a steady-state process (one in which no apparent change occurs with respect to time at a specified location in the process) will involve a <u>net transfer</u> of energy that is the result of complex and random interactions involving local transfer of energy at the molecular level.

Thus, in student interviews discussing the *Heatpipe*, *Meltice*, and *Tongue* questions, we heard comments like the following:

> "Equilibrium means that nothing's happening, basically."
>
> "[The system is at] steady-state because nothing's changing."
>
> "I'm not sure you can have steady-state without equilibrium – either you have both of them or you have neither of them."
>
> "Equilibrium is a balance of ratios, and steady-state refers to how fast those balances are changing."

Students without the correct emergent mental model are not able to differentiate between the overall macroscopic pattern of thermal transfer (e.g. equilibrium systems are static) from molecular activity (e.g. equilibrium systems involve random molecular activity which results in a pattern of no net change). We hypothesize that this type of mental model also explains why steady-state systems seem equivalent to the concept of thermal equilibrium for some students.

Interestingly, we found in other concept inventory work that students exhibited the same confusion between steady-state and equilibrium for a process involving dissolution of salt in a beaker of water but not for diffusion of a drop of blue dye in a beaker of water. This suggests that the conceptual flaws we have identified are complex and that further work involving extensive student interviews will be required to refine our analysis and conclusions.

Conclusions/Implications

Beta test data from the Thermal and Transport Concept Inventory (TTCI) collected at four engineering schools of varying size, demographics, and geographical location have been used to demonstrate statistically significant reliability among six heat transfer TTCI questions. We have also shown that cross-tabulation analysis can be used to identify robust student misconceptions by pairing related distractors in different heat transfer problem contexts. For the data set analyzed in this study, we identified two categories of fundamental heat transfer misconceptions: 1) energy vs. temperature, and 2) steady-state vs. equilibrium processes.

For example, approximately 13% of junior and senior engineering students in the beta test apparently don't understand how heat capacity is related to temperature change or that different substances have different heat capacities. Nearly as many don't understand how temperature is related to energy content. Although these numbers seem low in absolute terms, when compared with the number of students who were able to correctly answer both questions in conceptually-related pairs (~13-30% depending upon specific question combinations), it is clear that a significant number of highly-educated engineering students still possess strongly-help fundamental misconceptions about basic heat and heat transfer fundamentals.

We saw similar results with the questions designed to probe understanding of the differences between steady-state and equilibrated processes. Approximately 10-15% of the students apparently believe that processes in which heat transfer is occurring can never come to steady-state, while a similar number confused the rate of heat transfer with the total amount of energy transferred.

These same types of heat and temperature misconceptions have previously been identified and studied with K-12 students but our data suggest that the same misconceptions persist in some college-level engineering students, even after formal study of thermodynamics and/or heat transfer. Our findings suggest the need for new, theoretically-based instruction specifically designed to repair faulty heat transfer mental models of our students. The direct/emergent theories of Chi and her colleagues give us important clues about why these misconceptions are robust and also provide guidance about how effective instructional materials can be developed to repair them.

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Biosketches

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Appendix A

List of Heat Transfer Questions from the TTCI Analyzed in This Paper

Note: Reliability and validity not fully determined. The TTCI is not yet available for general use.

MeltIce Questions

You are in the business of melting ice at $0^{O}C$ using hot blocks of metal as an energy source. One option is to use one metal block at a temperature of $200^{O}C$ and a second option is to use two metal blocks each at a temperature of $100^{O}C$.

All the metal blocks are made from the same material and have the same weight and surface area.

(*MeltIce1*) Which option will melt more ice?

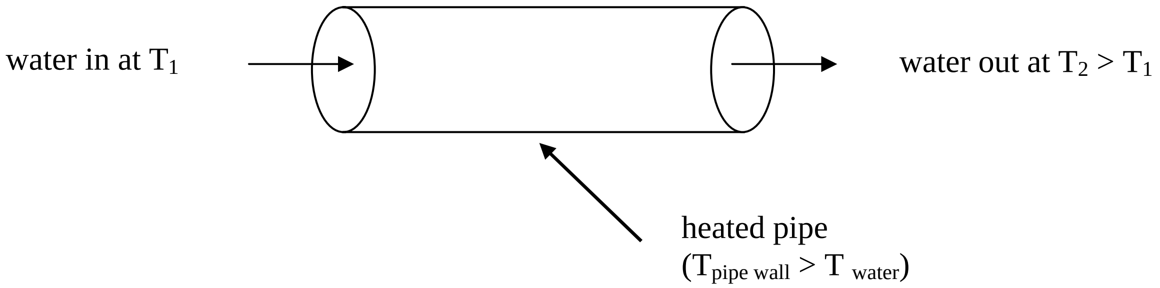
a. the 100 ^{O}C blocks
b. the 200 ^{O}C block
c. either option will melt the same amount of ice
d. can't tell from the information given

(*MeltIce2*) because:

e. 2 blocks have twice as much surface area as 1 block so the energy transfer rate will be higher when more blocks are used
f. energy transferred is proportional to the mass of blocks used and the change in block temperature during the process
g. using a higher temperature block will melt the ice faster because the larger temperature difference will increase the rate of energy transfer
h. the temperature of the hotter block will decrease faster as energy is transferred to the ice
i. the heat capacity of the metal is a function of temperature

Heatpipe Questions

Water flows through the pipe system shown below. The pipe wall is heated so that the temperature of flowing water increases from T_1 at the pipe inlet to T_2 at the outlet.



(*Heatpipe1*) If the pipe wall temperature and water velocity are constant, what can be said about the water flowing through the pipe:

a. Water is at steady-state and is in thermal equilibrium with the pipe wall
b. Water is not at steady-state but is in thermal equilibrium with the pipe wall
c. Water is at steady-state but is not in thermal equilibrium with the pipe wall
d. Water is not at steady-state and is not in thermal equilibrium with the pipe wall

(*Heatpipe2*) because:

e. system can never be at steady-state until T_2 equals the pipe wall temperature
f. steady-state and equilibrium occur together – you can’t have one without the other
g. water temperature is not changing with time and is not equal to pipe wall temperature
h. heat transfer is occurring at the water/pipe wall interface so the system can never come to steady-state

Tongue Question

On a very cold day in winter, a group of engineering students notices that quickly licking the metal end of an ice scraper left outside overnight causes their tongues to freeze to the metal surface. However, a quick lick of the wooden or plastic handle of the scraper doesn't cause any freezing to occur.

How can you explain this observation?

a. metal is colder than wood or plastic because it conducts energy to the atmosphere faster

b. metal conducts and stores energy better than wood or plastic, so energy is drawn from the tongue faster

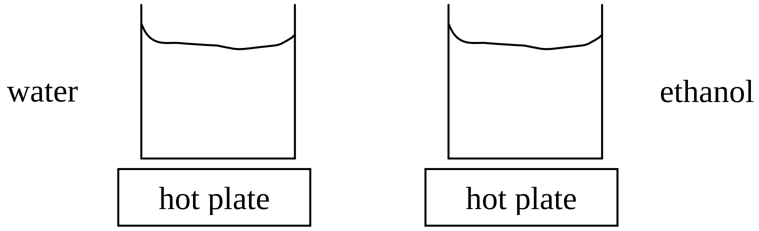
c. wood and plastic have different porosities than metal so water on the tongue has a place to move before it freezes

d. a metallic surface is more susceptible to the onset of freezing than wood or plastic because metal has more sites for ice crystals to form and grow

***Hotplate* Question**

Two identical beakers contain equal masses of liquid at a temperature of 20 ^{O}C as shown below. One beaker is filled with water and the other beaker is filled with ethanol (ethyl alcohol). The temperature of each liquid is increased from 20 ^{O}C to 40 ^{O}C using identical hot plates.

It takes 2 minutes for the ethanol temperature to reach 40 ^{O}C and 3 minutes for the water to reach 40 ^{O}C. Once a liquid had reached 40 ^{O}C, its hot plate is turned off.



To which liquid was more energy transferred during the heating process?

a. Water because more energy is transferred to the liquid that is heated longer.

b. Alcohol because more energy is transferred to the liquid that heats up faster (temperature rises faster).

c. Both liquids received the same amount of energy because they started at the same initial temperature and ended at the same final temperature.

d. Can’t determine from the information given because heat transfer coefficients for water and ethanol are needed.

e. Can’t determine from the information given because heat capacities of water and ethanol are needed.

Carpet Question

An engineering student walking barefoot (without shoes or socks) from a tile floor onto a carpeted floor notices that the tile feels cooler than the carpet.

Which of the following explanations seems like the most plausible way to explain this observation?

a. The carpet has a slightly higher temperature because it retains energy from the room better since the carpet contains air between the fibers and air is a good insulator.

b. The carpet has more surface area in contact with the student's foot than the tile does, so the carpet is heated faster and feels hotter.

c. The tile conducts and stores energy better than the carpet, so energy moves away from the student's foot faster on tile than carpet.

d. The rate of heat transfer by convection (air movement) is different for tile and carpet.

Swim Question

If 20 ^{O}C (68 ^{O}F) air feels warm on our skin, why does 20 ^{O}C water feel cool when we swim in it?

a. When water contacts human skin, it vaporizes at the surface which causes the water to feel cooler than air.

b. Water holds energy better than air does, so air feels warmer since it is transferring energy faster.

c. The heat transfer rate in water is faster than the rate in air because of differences in fluid physical properties.

d. Water opens pores in human skin better than air does, so the heat transfer area is larger with water.