Fundamental Research in Engineering Education

IDENTIFYING AND REPAIRING STUDENT MISCONCEPTIONS IN THERMAL AND TRANSPORT SCIENCE:

Concept Inventories and Schema Training Studies

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Engineers need to possess a deep understanding of the fundamental concepts of their field. Even advanced engineering students, however, may hold misconceptions that are "robust" or resistant to instruction.[1] This paper describes an integration of two ongoing research lines combining *identification of* students' misconceptions of difficult engineering concepts with efforts to *repair* some particularly robust misconceptions. Previous studies reported that misconceptions related to heat transfer, fluid mechanics, thermodynamics, and other engineering and science concepts persist among engineering students even after they completed college-level courses in the subjects.[2] Therefore, the first line of our research is focused on two research questions:

- *"What important concepts in thermal and transport science are difficult for engineering students to learn?"*
- *"How can a valid and reliable instrument be developed to identify engineering student misconceptions of these difficult and important concepts?"*

The first research question was investigated by conducting a Delphi study with experienced engineering faculty to identify important and difficult concepts in thermal and transport science.[3] The second research question was investigated by developing the Thermal and Transport Concept Inventory (TTCI). The TTCI is an instrument that measures the conceptual understanding of key ideas in thermodynamics, fluid mechanics, and heat transfer for undergraduate engineering students. Thus, TTCI is also a tool for identifying students' misconceptions in thermal and transport science. Details of misconception identification and TTCI development are provided in the following section.

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The second line of our research is focused on how to repair students' misconceptions of difficult engineering concepts once the misconceptions are identified. As indicated in the misconception literature, some of these misconceptions are particularly robust and therefore are particularly difficult to repair using traditional pedagogical strategies. Thus, for this line of the research, we are testing schema training strategies for helping engineering students develop more fundamentally accurate mental models of selected engineering and science concepts. Specific research questions in this research line include the following:

- *Can schema training materials be developed to help students develop appropriate schema for understanding difficult engineering concepts?*
- *How effective is schema training in making measurable change in students' conceptual understanding of heat transfer, mass diffusion, and microfluidics?*

The schema training strategies were based on the assumption that students learn new concepts by assimilating or encoding new information into an existing schema or framework. Assimilation helps students make inferences about and assign attributes to a new concept or phenomenon. When students begin learning some particularly challenging engineering concept that is fundamentally different from their common-sense conception, however, they can make the wrong inference or assign incorrect attributes to the new concept based on their existing incomplete or incorrect schema. For example, a significant number of students think that the hot or cold sensation we sense when touching an object indicates its temperature when actually it is a measure of how fast energy is transferred into or out of our finger.

To repair such robust misconceptions, Chi and her colleagues proposed an innovative instructional approach involving schema training methods that focuses on helping students develop appropriate schemas or conceptual frameworks for learning difficult and challenging engineering and science concepts.[4] Such methods were effective in helping middle school students and undergraduate psychology students learn difficult science concepts. We are testing Chi's theoretical framework by developing effective schema training protocols and materials that help engineering students create appropriate mental models of fundamentally important dynamic processes and concepts, especially those operating at small length scales.

There is ample evidence in the literature to suggest that students of all ages (including science and engineering students) do not easily understand fundamental small-scale phenomena such as heat transfer, diffusion, fluid mechanics, and electricity.[2] Given the current interest in advances at small length scales (*e.g.*, microfluidics, biotechnology, genetic engineering, nanoscale machines), new engineering graduates must have a firm grasp of fundamental processes that are characterized by small-scale dynamic systems. Therefore, schema training methods hold promise not only for thermal and transport science but also for other disciplines in engineering.

METHODS

In this section, we discuss the methodology used to identify important and difficult thermal and transport science concepts that are included in the TTCI instrument. We also discuss the methodology and procedures used to generate TTCI items and the results of validity and reliability analyses from TTCI pilot testing with engineering students. Development of schema training methodologies and materials is discussed followed by a brief summary of schema training results obtained so far.

Identifying Important But Difficult Concepts in Thermal Science

After considering several methods of identifying important but difficult concepts in thermal and transport science, we choose the Delphi method, which focuses on developing consensus expert opinion. We considered "experts" to be experienced engineering professors who paid close attention to student learning. Over their professional careers, these faculty members have informally collected data about student misconceptions directly from student interactions. Collecting misconception data from students themselves would be problematic, however, since students with strongly held misconceptions would not be able to determine if misconceptions are <u>difficult</u> and/or <u>important</u>—the task posed to the Delphi study experts. Our experts consisted of 31 engineering professors ranging from assistant to full professors. Five of the experts were also textbook authors. They were asked to complete a generative round to develop candidate concepts and then three rating rounds in which each concept was rated on two scales: importance and difficulty. The non-parametric median and interquartile range were used (rather than mean and standard deviation) because an ordinal scale was used to rate the concepts. The rankings for most concepts stabilized by round two (the median for 19 of the 28 concepts changed by a value of 0.5 or less) as suggested by other Delphi studies reported in the literature.[5]

The goal of this part of the study was to identify concepts that were very important (those that were given a high ranking in the "importance" scale) and were also conceptually difficult (those that were given a low ranking on the "conceptual understanding" scale). As shown in Table 1, a total of 12 concepts (from an original list of 28 concepts from the generative round) were identified as meeting the criteria of <u>high importance</u> but <u>low conceptual understanding</u>. These items included key topics in thermal science and transport disciplines such as the second law of thermodynamics including reversible vs. irreversible processes, conservation of fluid momentum, viscous momentum transfer, the Bernoulli principle, several energy-related topics (heat, temperature, enthalpy, internal energy), and steady-state vs. equilibrium processes. At the request of several Delphi participants, we included the ideal gas law and conservation of mass concepts in the TTCI since both are fundamental concepts in fluid mechanics and thermodynamics. With the exception of thermal radiation, all concepts listed in Table 1 are included in TTCI items. Students' specific conceptual difficulties with thermal radiation have yet to be identified, but the plan is to include this concept in future versions of the instrument. It is important to emphasize once again that the concepts in Table 1 only represent a small sub-domain of all relevant concepts in thermal and transport science—the sub-domain of difficult but important concepts as identified by the Delphi study experts.

TTCI Development and Results

Based on results of the Delphi study, items were developed for the TTCI assessment instrument.[6] Each item was developed using a seven-step process recommended by Downing and Haladyna[7] including:

- *drafting open-ended questions about the concept*
- *collecting student response data orally (think-aloud problem-solving sessions) and in written form*
- *using the responses to convert the open-ended questions to multiple-choice items with distractors describing plausible but incorrect answers*
- *beta testing the drafted items on groups of engineering students*
- *collecting expert reviews on each item to establish content validity*
- *revising the items based on statistical performance and expert feedback*
- *collecting additional beta test data.*

Updated versions of the TTCI have been created by deleting or adding items based on difficulty and discrimination indices. Statistics for each succeeding version of the instrument have indicated improved reliability. The present version of the instrument (version 3.04) has consistently demonstrated reliabilities of 0.7 and higher for each of the following inventories:

- *heat transfer – 12 items containing 18 questions (0.77)*
- *fluid flow – 19 items containing 26 questions (0.70)*
- *thermodynamics – 17 items containing 24 questions (0.70)*

The number of questions exceeds the number of items in each inventory because some items consist of two questions—usually of the form "what will happen?" in a posed situation followed by a question of the form "why did it happen?" or "why did you answer the first question the way you did?" Other items consist of one question in which the answers (correct answer and distractors) contain information about both "what?" and "why?" An example of each item construct is provided in Appendix A. The first sample item assesses students' understanding of the difference between the amount of energy required to melt ice vs. the rate at which the energy is delivered to the ice. The second item focuses on students' understanding of the difference between the actual temperature of an object and the perceived temperature when the object is walked on with bare feet. More details about TTCI development have been published[6] and version 3.04 is now available online (<www.thermalinventory.com>). Nearly 1,200 students at more than 20 engineering schools have used at least one of the three TTCI instruments. To protect the integrity of the instrument, items in the TTCI are password protected. Faculty interested in reviewing the TTCI or using any of the TTCI inventories in their classes are encouraged to contact Dr. Miller at rlmiller@mines.edu for a password.

Schema Training Development

Chi has argued that students possess robust misconceptions because they have no existing schema or mental framework for understanding some complicated science and engineering processes.[4] A particular ontological class of difficult concepts identified by Chi is termed "emergent processes," which are fundamentally different from "sequential processes." Emergent processes occur in systems of constituent elements (*e.g.*, molecules) interacting over time in a random and simultaneous pattern. In contrast, sequential processes occur in systems of interacting agents in a causal and dependent pattern. For example, the schooling of fish is the result of an emergent process. Even though the fish seem to move as one, there is no "leader" fish directing their movements. All members of the school simply want to stay as close to their neighbors as possible. This is a survival strategy that helps an individual fish from being singled out by a predator. So the pattern we see is a result of all the individual fish *simultaneously* moving together. In contrast, the construction of a skyscraper is an example of a sequential process. All actions by different actors (*i.e.*, different construction trades) need to occur step-by-step in a particular sequence to reach the overall goal.

Many of the concepts with which engineering students struggle can be identified as emergent processes including heat transfer and diffusion.[4,8,9] Emergent process misconceptions are particularly resistant to traditional instruction because they occur at the ontological level where students ascribe a

TABLE 1
Difficult and Important Concepts in Thermal and Transport Science Identified in the Delphi Study

• Bernoulli principle	• Enthalpy vs. internal energy (flow work)
• Linear fluid momentum	• Viscous momentum transfer
• Second law of thermodynamics	• Ideal gas law
• Reversible vs. irreversible processes	• Mass conservation in fluid systems
• Heat vs. energy	• Steady-state vs. equilibrium
• Heat vs. temperature	• Thermal radiation

fundamental characteristic to the concept that is at odds with the scientifically normative view.[4] What does it mean to hold a misconception at an ontological level? A simple example may help clarify. Some people may misclassify a whale as kind of fish instead of kind of mammal. This misclassification would probably lead people to think that whales had the same attributes as fishes. So one might think that whales get their oxygen from the water and lay eggs to reproduce, because that's what fish do. In the same way if students think that diffusion is the result of a sequential process, they may think that diffusion terminates when equilibrium is reached—because sequential processes have an endpoint.

To help students learn concepts of the emergent process ontology, instruction should help students develop a "schema" or mental framework for emergence that would make subsequent related concepts easier to understand.[9,10] The schema training we describe in this article provides students with an explicit explanation of the attributes of emergent processes and provides a step-by-step comparison with the attributes of sequential processes. Examples of each process are illustrated and embedded computer simulations allow students to manipulate system parameters to see the effects on emergent patterns.

Since prior work has demonstrated that even advanced engineering students still hold misconceptions about fundamental concepts in thermal sciences and other scientific subjects,[11] this study is intended to test whether the schema training framework is effective in helping repair engineering students' misconceptions in heat transfer, diffusion, and microfluidics.

Following the work of Chi and her colleagues, the schema training experiment collected both quantitative and qualitative data. Quantitative data were collected from multiple-choice questions (in pre- and post tests). Qualitative data were collected from students' verbal explanations of their answer choices to multiple-choice questions. The qualitative data were coded to explore the amount of "emergent" vs. "sequential" language used in the explanations.

The *a priori* codes were developed using common attributes of emergent and sequential processes as described by Chi. Specific examples of what constituted emergent or sequential language are shown in Table 2. Prior to coding the entire dataset, three researchers coded the same set of data selected from three verbal explanation questions on diffusion for 10 participants and the inter-coder agreement was over 90%. Then two researchers independently coded the datasets collected from diffusion and microfluidics assessments. The coding scheme developed for this analysis is summarized in Table 2.

If emergent process language was used (*e.g.*, the participant's explanation included one or more attributes of emergent processes or a detailed description about the independent behavior of a single molecular entity) that participant's response was coded as 1, otherwise it was coded as 0. For instance, when asked to explain in their own words what diffusion is, Peter responded, *"Diffusion is spreading and mixing of gases or liquids from the random motion of molecules"* an example of using emergent process language. On the contrary, Bill responded, *"Diffusion is the process of molecules, atoms, etc., moving from an area of higher concentration to an area of lower concentration,"* exemplifying the use of sequential process language.

After the coding, we summed all the "1"s and "0"s for both experimental and control participant groups and conducted a nonparametric "two-independent samples" test between the experimental and control group results because a nonparametric test makes minimal assumptions about the underlying distribution of the data.[12]

As shown in Figure 1, both experimental and control groups were matched for equivalent levels of engineering education (the gray portion of Figure 1 indicates where instruction differs between experimental and control groups). A pre-test in heat transfer concepts was used as a further measure of the "equivalence" of the two groups prior to schema training, by establishing that prior knowledge of the students was similar. The experimental group completed an online training module describing the characteristics of sequential and emergent processes and described why diffusion is an emergent process. The purpose of the training module was to help experimental group participants develop a "schema" for thinking about diffusion in emergent terms. Students' emergent schema were further developed using two computer simulations—one showed the macroscopic behavior of blue dye in water while the second showed molecular behavior of the same diffusion process. The effect of changing dye concentration was observed in each simulation.

The control group completed an online training module of approximately equivalent length and complexity (words and figures) that described the nature of science. Diffusion was

TABLE 2
Summary of Coding Scheme

Language	Coding Rubric	
Emergent Process	0	If subject does not respond, or provides an inaccurate or irrelevant response.
	1	If the subject refers to emergent themes such as "indirect," "continuous," "independent," "simultaneous," "equilibrium," or "balanced ratio of molecules."
Sequential Process	0	If subject does not respond, or provides an inaccurate or irrelevant response.
	1	If subject refers to sequential themes such as "direct," "distinguishable," "restricted," "sequenced," "dependent," or "end/terminate."

Procedure	Experimental Group	Control Group
Demographic Survey	Participants' Demographic Information	
Pre-Test	Heat Transfer concept questions	
Training Module	Sequential and emergent processes; diffusion as an example of an emergent process	The nature of science; diffusion example with <u>no</u> mention of emergent processes
Test for Understanding	Diffusion concept questions with verbal explanations	
Target Instruction	Heat Transfer instruction	
Post Test	Heat Transfer concept questions (repeated measure)	
Far Transfer Instruction	Diffusion in Microfluidics	
Test for Far Transfer	Microfluidics concept questions with verbal explanations	

Figure 1. *Schema Training Experimental Design (gray portion indicates where instruction differs between experimental and control groups).*

TABLE 3
Demographic Data for Schema Training Participants

Demographic Information	Category	Number of Participants	Total
Gender	Female	23	60
	Male	37	
Year of College	Junior	21	60
	Senior	39	
Ethnicity	Caucasian	45	60
	Other	15	
Major	Mechanical engineering	20	60
	Chemical engineering	24	
	Other	16	

TABLE 4
Descriptive Statistics of Heat Transfer Pre-test Multiple-Choice Assessment Questions (18 total questions) for Control and Experimental Cohorts

Group	N	Mean number of correct answers	Standard Deviation
Experimental	30	10.17	3.23
Control	30	9.67	3.38

described but *no mention was made of emergent processes* in the online training module for the control group. Control group students also read about the macroscopic and molecular behavior of blue dye diffusing in water. After completing the training module, both cohorts completed a test for understanding of the emergent nature of diffusion. Multiple-choice and open-ended questions were included in this assessment.

Both cohorts then completed the same target instruction module on heat transfer principles focused particularly on the nature of molecular motion and heat conduction but without explicit reference to emergent processes. Two online heat conduction simulations (one at the macro scale, one showing molecular motion) were used as part of the target instruction and students could simulate the effect of changing material properties on heat conduction rates (both simulations) and molecular behavior (molecular-level simulation). The heat transfer concept questions used in the pre-test were re-administered to each cohort as a post-test. Finally, each cohort completed a "far transfer" module describing ultra-laminar fluid flow in a microfluidics apparatus. The diffusion behavior of dye molecules and particles such as viruses and bacteria in these flows represented an ideal application of emergent process principles in a context for which undergraduate engineering students were unfamiliar prior to their participation in the schema training study. Then, the module described microfluidic flow behavior and diffusion using text and graphics and also included a short video clip of a microfluidic mixing chamber involving blue dye and water. Far transfer occurs when students can apply knowledge from one context to another. The module ended with a series of multiple-choice and open-ended questions about the emergent nature of diffusion in microfluidic systems.

RESULTS AND DISCUSSION

The first group of students participating in our schema training experiment consisted of 60 juniors and seniors at a large Midwestern research university. Table 3 summarizes the demographic data for these students. Each student completed schema training protocols over a two-day period (2 hours per day—day 1 through the assessment for diffusion understanding; day 2 starting with the target heat transfer instruction).

Both groups of participants (experimental and control) completed the pre-test for heat transfer at the beginning of the study on the first day and the post test for heat transfer on the second day. The pre- and post tests consisted of 18 multiple-choice questions that were chosen from the Thermal and Transport Concept Inventory (TTCI) for identifying students' misconceptions.[13] Table 4 compares heat transfer pre-test data showing that the two cohorts were the same (p=.560) in terms of their knowledge of heat transfer prior to the study.

The overall mean gain (the average of post test scores minus pre-test scores) for the experimental group (1.10) was larger than that of the control group (0.97) as shown in Table 5. There was no statistically significant difference (p=0.82) between the two groups, however. These results can be explained in one of two ways: 1) the schema training approach did not help students in the experimental group repair misconceptions about the emergent nature of heat conduction, or 2) the pre-/post test heat transfer questions did not adequately assess the presence or absence of an emergent schema in the study cohorts. To help clarify this result, future schema training experiments will include additional heat transfer questions designed specifically to probe for the presence or absence of emergent thinking in student participants. Students without prior coursework in heat transfer will also be included in the study.

Table 6 summarizes the results of diffusion and microfluidics assessment questions. Based on the data from 19 multiple-choice diffusion concept questions, the overall mean for the experimental group (15.40) was larger than that of the control group (13.87). In addition, there was a significant difference (p=0.037) between the two groups and effect size was 0.56, a moderately large effect size. This result showed that the schema training approach did help those engineering students in the experimental group develop a better "emergent focused" understanding of some diffusion concepts.

Based on the data from five multiple-choice questions on microfluidics, the overall mean for the experimental group (3.60) was larger than that of the control group (2.77). In addition, there was a significant difference (p=0.027) between the two groups and the effect size was 0.60, a moderately large effect size. This result is particularly encouraging because it shows a statistically significant improvement in development of students' emergent schema as applied to a far transfer topic—that is, a topic they had never seen before and one that is far different than traditional diffusion applications in their classes and textbooks. Since the ability to transfer knowledge from one context to another indicates development of a coherent understanding of underlying concepts,[14] evidence of far transfer reinforces the conclusion that students in the experimental group have developed their emergent schema for thinking about diffusion processes.

To gain a better understanding of how students' emergent schema (or lack thereof) influenced their answers to the multiple-choice assessment questions, we used the coding scheme shown in Table 2 to analyze qualitative data collected from open-ended questions that ask students to explain their choices to diffusion and microfluidics multiple-choice questions. Table 7 summarizes the results for 22 diffusion explanation questions; the overall mean for the experimental group (17.03) was much larger than that (2.97) of the control group, a statistically significant difference (p<0.0005). This result indicates that the schema training approach did facilitate students' conceptual change in terms of the kind of emergent process language they displayed when explaining their answers to the diffusion multiple-choice questions.

Based on results from six microfluidics explanation questions, the overall mean for the experimental group (4.10) was much larger than that of the control group (0.63) as shown in Table 7. In addition, there was a statistically significant difference between the two groups (p<0.0005). This result also suggests that the schema training approach facilitated students' conceptual change in terms of the kind of emergent process language they displayed when explaining their answers to the microfluidics multiple-choice questions.

Although preliminary, these data suggest that schema training methods can be designed to help engineering students repair strongly held misconceptions of concepts in which a well-developed emergent schema is required for correct understanding. The absence of a measurable improvement in heat transfer scores for the experimental group is still under investigation but perhaps may be attributed to students taking multiple heat transfer courses that may solidify (sometimes incorrect) cognitive structures of heat transfer processes. For example, a statistically significant improvement in heat transfer scores was found for students taking two or fewer heat transfer courses while no improvement was noted for students who completed three or more courses. More investigation is needed but these results do support the notion that additional heat transfer instruction did not improve pre- and post test gains.

TABLE 5
Descriptive Statistics for Mean Gain in Heat Transfer Multiple-Choice Assessment Questions (18 total questions)

Group	N	Mean Gain*	Standard Deviation
Experimental	30	1.10	1.97
Control	30	0.97	2.59

*gain = (# correct answers on post test) – (# correct answers on pre-test)

TABLE 6
Descriptive Statistics for Performance on Diffusion and Microfluidics Multiple-Choice Assessment Questions

Assessment	Group	N	Mean Number of correct answers	Standard Deviation	Effect size
Diffusion (19 questions)	Experimental	30	15.40	2.67	0.56
	Control	30	13.87	2.89	
Microfluidics (5 questions)	Experimental	30	3.60	1.38	0.60
	Control	30	2.77	1.45	

TABLE 7
Descriptive Statistics for Students' Open-Ended Explanations: Diffusion and Microfluidics Assessment Items

Assessment	Group	N	Mean	Standard Deviation
Diffusion (22 questions)	Experimental	30	17.03	2.12
	Control	30	2.97	1.85
Microfluidics (6 questions)	Experimental	30	4.10	1.77
	Control	30	0.63	0.89

CONCLUSIONS

This paper has described two related lines of research involving development and testing of an assessment instrument to identify strongly held student misconceptions in thermal and transport science and development of a method for helping students develop accurate schema for describing and understanding emergent processes that are common in heat transfer, molecular diffusion, and molecular momentum transfer. Results show that the assessment instrument, the Thermal and Transport Concept Inventory (TTCI), can reliably identify misconceptions related to 12 important but poorly understood concepts in heat transfer, thermodynamics, and fluid flow.

The TTCI instrument is now available online and can be used for course and/or program-level assessment. Used only as a pre-test, instructors can use the TTCI to gauge students' conceptual understanding as they begin a course. This will allow the instructor to focus on areas where misconceptions are most prevalent. Used with repeated administrations, the TTCI can be used to calculate gain scores that are an indicator of concept repair and depth of learning. For example, comparison of gain scores on the Force Concept Inventory have been used in physics education to compare the effectiveness of different modes of instruction[15] and such a comparison of TTCI gain scores could be used in chemical engineering education for the same purpose.

Preliminary schema training results show that materials informed by relevant psychological theory can be used to help students develop correct mental schema for understanding robust misconceptions involving emergent processes important to thermal and transport science. We believe that understanding emergent processes will become more important as greater emphasis is put on learning about physical phenomena at the micro-, nano-, and molecular scales. Thus we predict that understanding emergent processes and the phenomena that result from emergent systems will become an important outcome of educating future chemical engineers.

This line of research is based on the assumption that students have little experience with emergent processes and therefore their mental framework (or schema) for understanding these kinds of phenomena may be weak or missing altogether.

The training we are developing attempts to strengthen frameworks for thinking about emergent phenomena or provide a framework if none exists. This kind of training may be of greatest use at the beginning of instruction in a new conceptual area. Our results suggest that, not surprisingly, changing frameworks about topics for which students have had a great deal of instruction is much more difficult to accomplish.

Additional data collected in this project will provide more detailed guidance about how to transform schema training to classroom contexts. Because the current training materials are modular and web-based, it will be possible to develop stand-alone modules that can be used for instruction at different times. The format of the modules also lends itself to adaptation as an electronic supplement to appropriate engineering textbooks. What implications does this research have for the chemical engineering educator? Our data suggest that helping students learn about the emergent processes of systems can increase students' deep understanding of important concepts in the thermal and transport sciences. Ideally, instruction will help students develop systems thinking at appropriate length scales and highlight where and when simultaneous interactions occur.

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APPENDIX A – SAMPLE TTCI ITEMS

Sample Two-Question Item

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

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

If the blocks are placed in insulated cups filled with ice water at 0 ˚C, which option will melt more ice?

a. *the 100 ˚C blocks*

b. *the 200 ˚C block*

c. *Either option will melt the same amount of ice.*

d. *Can't tell from the information given.*

I answered the question the way I did because:

e. *Two blocks have twice as much surface area as one 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. *Higher temperature blocks contain more energy per mass of block than lower temperature blocks.*

i. *The heat capacity of the metal is a function of temperature.*

j. *Multiple blocks have more mass and therefore more energy than a single block.*

k. *The temperature of the hotter block will decrease faster as energy is transferred to the ice water.*

Sample One-Question Item

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 air trapped in the carpet retains energy from the room better.*

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 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 into the room by convection (air movement) is different for tile and carpet surfaces.*

e. *The carpet has a slightly higher temperature because air trapped in the carpet slows down the rate of energy transfer through the carpet into the floor.* ❐