AC 2009-2039: INQUIRY-BASED ACTIVITIES TO REPAIR MISCONCEPTIONS IN THERMODYNAMICS AND HEAT TRANSFER

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Abstract

This NSF funded (DUE 0442234) study examines the use of inquiry-based teaching to promote understanding of critical engineering concepts. Significant research shows that students often enter the classroom with tightly held misconceptions about the physical world that are not effectively addressed through traditional teaching. As a result, students are frequently able to solve problems that have been explicitly taught, but are unable to apply course concepts to solve real problems not seen in class. Failure to grasp prerequisite concepts also leaves students poorly prepared for more advanced study.

Students' conceptual understanding can be dramatically enhanced, however, through a paradigm shift in teaching that incorporates inquiry-based methods. This is an inductive and collaborative teaching method where students are placed in carefully designed situations where reality, rather than the professor, can dispute their preconceptions. The effectiveness of this approach has been extensively documented using thousands of undergraduate physics students. As of yet, however, inquiry-based activities have not been systematically developed for engineering education.

This work seeks to fill that gap. Nine conceptual areas in Heat Transfer and Thermodynamics have been targeted. Inquiry-based educational materials have been developed and tested for four of the nine areas, and modules are under development to address the remaining five areas. The poster will discuss the operation and preliminary measurements of effectiveness for the newest inquiry-based materials. In order to assess the effectiveness of these modules, concept inventories addressing relevant areas in thermodynamics and heat transfer have also been developed and assessed for validity and reliability.

Introduction

A solid grounding in conceptual understanding is required for students to shift from novice to expert problem-solvers in chemical engineering (Bransford, 2000). However, traditional instruction based upon "telling" and heavily reliant on theory and computation is not highly effective at developing accurate conceptual knowledge (Bransford, 2000). In Physics, the "Workshop Physics" model and other similar inquiry-based pedagogies have been demonstrated to be more effective at increasing students' conceptual understanding (Laws et al 1999). In this work, we seek to adapt that model in order to repair student misconceptions about the fields of heat transfer and thermodynamics within chemical engineering.

The following concepts were targeted within the two areas:

- Heat Transfer
  - H1) Temperature vs. Energy
  - H2) Temperature vs. "Feeling Hot"
  - H3) Rate of Heat Transfer vs. Amount of Energy Transferred
  - H4) Radiation
- Thermodynamics
  - T1) Entropy

T2) Reversibility
T3) Internal Energy vs. Enthalpy
T4) Steady State vs. Equilibrium
T5) Reaction Rate vs. Reaction Equilibrium

Concepts H1, H2, H4, T1, T2, T3, and T4 were selected based upon those that were identified as both difficult and important in a Delphi study (Streveler et al, 2003). Concepts H3 and T5 were added based upon the authors' observations in class and laboratories.
This work consists of two main parts. First, in order to assess the level of conceptual understanding of chemical engineering students before and after instruction, an instrument is needed. To do this, we have constructed concept inventories in these areas, as described below. Second, to repair misconceptions, we have developed inquiry-based activities following the model of Laws et al (Laws, 1999). In the final stage of the work, these two will be brought together to assess student understanding and hopefully demonstrate improved conceptual knowledge as a result of the activities.

Instrument Development

Having valid and reliable instruments to measure student conceptual understanding in Heat Transfer and Thermodynamics is key to this work, because without them, it is impossible to demonstrate changes in student understanding as a result of instruction. The instruments were created in two steps. First, a target of five questions per concept area was set. These questions were used (with permission) from the Thermal and Transport Sciences Concept Inventory (Olds et al, 2004) and the Thermodynamics Concept Inventory (Midkiff et al, 2001).

New questions were also created to address areas where there were not sufficient questions or no pre-existing questions. This was done in stages; in the first version of the instrument, a combination of multiple choice and open-ended questions were used. Instruments were piloted with about 100 students each, at diverse universities. Results were compiled, and initial assessments of reliability and validity were made. Meanwhile, student answers to open-ended questions were categorized and used to generate multiple-choice options for new versions of the instrument.

In the second test of the instruments, again students at diverse institutions were asked to take the concept inventory. The refined heat transfer instrument was 36 multiple choice questions, while thermodynamics instrument had 34 multiple choice questions and retained four open-ended questions. Again, these instruments were assessed for overall reliability and validity. Analysis of these results indicated that the Heat Transfer Instrument has sufficient validity and reliability that it can be used to assess changes in student conceptual understanding in this area (Split-Half Correlation 0.80; KR20 0.83). The Thermodynamics Instrument fell short in the reliability (Split-Half Correlation 0.65; KR20 0.66), so questions were refined again based upon feedback from students and faculty and once more tested with ~100 students at diverse institutions.

Activity Development

Activities are inspired by questions from the concept inventories. In particular, we seek to recreate the situation described in questions students consistently get wrong either as a physical experiment or simulation. Previous work has documented three simulations and two activities (Prince, 2007). This work describes current progress on six more activities and three further simulations. These activities are still in the refinement stage, where they are tested only on one or two students and feedback on their clarity and feasibility is sought. Each should be ready for implementation in a class by the Fall 2009 semester.

Each activity is accompanied by a pre-activity worksheet, priming student learning through leading questions that ask them to explain their ideas before conducting the experiment. There are also worksheets that guide students through the experiment and ask them to assess how their thinking changed when they were done.

Thermodynamics Activities

Internal Energy vs. Enthalpy

<u>Evacuated Tank Experiment & Simulation</u>: By far the most difficult question on this concept describes a situation where pressurized air flows into a initially evacuated well-insulated tank until the pressure inside the vessel and inside the feed are equal and asks “what is the final temperature in the tank?” While this question is challenging, it is straightforward to implement experimentally or through simulation. A physical version of the experiment exists at a partner institution, and will be used by students. An analogous simulation is underdevelopment for parallel testing as well.

<u>Fan Experiment:</u> A question similar to that described above asks about the impact of a common room fan on the temperature of the air that passes through it. This is a “scaffolding” step to the preceding situation, where enthalpy may be considered independently of internal energy. In the experiment, a high-velocity fan of the type used to help dry large water spills is used with electronic thermocouples to measure the temperature both up and immediately down-stream of the fan.

Equilibrium vs. Steady State

<u>Hot Pot Experiment:</u> This question asks students to consider a metal pot with a metal handle sitting on a heated stove. Frequently, students assume that the pot must come to equilibrium with the stove-top and reach an un-touchable temperature, rather than recognizing that a touchable steady-state temperature is possible due to convection to the air. The experiment directly recreates this situation by boiling water in a metal saucepan and first asking students to probe the temperatures along the outer surface of the pot and pot handle and then asking them to confirm their measurements by (safely) lifting the pot by its handle.

Entropy

<u>Piston-Cylinder Simulation</u>: This simulation accompanies a group of questions rather than a specific question. One of the difficulties students display with entropy is a refusal to accept that an engine cannot be 100% efficient if we just make it work better. One common suggestion is to eliminate the “waste heat” step in a heat-engine cycle and use that energy to make more work instead. This simulation invites students to try just that; students control a piston / cylinder system and may put it through a cycle of their

own design, using adiabatic, isobaric, isothermal, or isochoric steps in any combination that creates a complete cycle. Movement of the piston is shown visually, as is a plot of the cycle on a PV diagram. The program also tracks the amount of work that has gone into or come out of the system. By working with this simulation, students will be able to experience that they cannot close the cycle without some amount of “waste-heat”.

Heat Transfer Activities

Temperature vs. Energy

Touching Foil: This experiment is similar to a question that asks students why a person is not burned by a sparkler spark that may be 1000ºC but would be burned by a metal poker at 100ºC. That situation is not physically realizable in a safe manner, but it is possible to ask students to make measurements on and touch a piece of thin aluminum foil that has been in a hot oven. Because of the low mass and low energy content of the foil, it may be touched safely. This experiment relies upon prior knowledge of the students that they cannot touch the interior surface of the oven safely, even though it is at the same temperature as the foil.

Radiation

Color and Radiation: While students correctly answer that a black surface will absorb energy more rapidly than from a sun-lamp than will a shiny surface, they often miss-predict the relative cooling rates of the two surfaces. In this experiment, thermocouples are wrapped in material of various absorptivity, and allowed to heat in identical conditions under a sun lamp and then cool once the lamp is turned off. Students can observe the temperature changes in real-time on a computer. This experiment is still under development because the cool-down time tends to be longer than our target experiment time of 15 minutes.

Steam Pipe Simulation and Experiment: One of the concept inventory questions asks if more steam will condense in a pipe that is painted white or in one painted black, given that radiation is a significant factor in the rate of energy transfer for this system. This experiment can be done both physically and through simulation. The physical experiment consists of three parallel steam pipes, plumbed to receive steam, one at a time, from the same source at the same flow rate. Students can measure condensation by assessing the quantity of liquid that is caught in a trap at the exit. In the simulation, students can watch a cut-away image of the same pipes to visually assess the liquid accumulation in real-time. While the physical experiment has the benefit of being “real”, the simulation is significantly faster which may be important for implementing this activity in classes.

Conclusions and Future Work

At this point, there exists a reliable and valid instrument for assessing student conceptual understanding in key areas for Heat Transfer. We anticipate that the most recent round of editing and testing for the Thermodynamics concept inventory will result in a valid and reliable instrument as well. In parallel with the instrument development, further inquiry-based activities were created. In the final step of this work, the concept inventories will be used in a pre-test / post-test fashion to assess the effectiveness of the inquiry-based activities for repairing student misconceptions.

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