AC 2011-2273: INQUIRY-BASED ACTIVITIES TO ADDRESS CRITICAL CONCEPTS IN CHEMICAL ENGINEERING

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Abstract
It is widely agreed that a conceptual understanding of engineering concepts is a required compliment to a technical understanding of the equations and how to solve them. However, students often enter our classrooms with misconceptions about fundamental phenomena, presenting a significant obstacle to conceptual learning. The first part of our work consisted of establishing reliability of instruments to assess conceptual understanding. In the present study, we share results from multi-institution concept inventory assessments in heat transfer and thermodynamics. Our results indicate that instruction typically improves students' conceptual understanding in these areas, but not typically to "proficient" levels (concept inventory scores over 70%). However, after implementation of inquiry-based activities, scores improve significantly, both with respect to the pre-course concept inventory scores and with respect to post-course scores for students who do not perform these activities.

Background
The overall goal of this project is to improve undergraduate student conceptual understanding in heat transfer and thermodynamics through the use of inquiry-based activities. As shown in Tables 1 and 2, four concepts from thermodynamics and four from heat transfer were identified as difficult yet important to understand by Streveler et al [1], and an additional concept was added to this group for Thermodynamics based upon instructor observation.

Table 1: Thermodynamics Concept Areas

Concept Area	Misconception
Entropy	Students often misconstrue the impact of entropy on the efficiency of real systems, believing if a system is reversible, frictionless, and appropriately adiabatic, it can have a thermal efficiency of 100%. That is, they often assume the thermal efficiency of a Carnot engine is 100%, regardless of heat source and sink temperatures.
Reversibility	Students often assume reversible behavior for real systems where such an assumption is inappropriate. That is, students fail to grasp what reversibility would mean for the behavior of a real system.
Steady State vs. Equilibrium	Students confound steady state and equilibrium, believing they are synonyms or that one necessarily implies the other for a given system.
Internal Energy vs. Enthalpy	Students confound internal energy and enthalpy, assuming they are interchangeable. Students often conflate "flow work" (that which distinguishes enthalpy from internal energy) with kinetic energy.
Reaction Equilibrium vs. Reaction Rate	Students often believe that a reaction that favors products strongly will react rapidly. That is, they confound factors that impact reaction rate with the factors that impact how much product is produced.

Table 2: Heat Transfer Concept Areas

Concept Area	Misconception
Rate vs. Amount	Many students seem to believe that factors which increase the rate of heat transfer always increase the amount of heat transferred. These misconceptions carry over to related fields such as mass transfer.
Temperature vs. Heat	Many students think that temperature is a measure of how hot or cold things feel. Many students do not understand that other factors, such as the rate of heat transfer, frequently affect how hot or cold something feels.
Energy vs. Temperature	Many students believe that temperature is a direct measure of the energy of an object, so something at higher temperature always has more energy than something at a lower temperature.
Radiation	Students are often confused about the effect of surface properties on the rate of radiative heat transfer.

As a first step in this project, multiple-choice concept inventories for both Heat Transfer and Thermodynamics were piloted with students and established as instruments with sufficient reliability for research use. These inventories use both new questions and questions drawn from existing sources, but are distinct from the originals because of the focus on only the concepts identified in Tables 1 and 2 [2-5]. Further, these inventories were used to establish the baseline change in conceptual understanding after "typical" instruction. In summary, students' conceptual understanding in these areas improves by about 10% as a result of typical instruction [6-15]. However, performance still falls short of mastery-level performance.

The second step in our proposed work was the development of inquiry-based activities designed to repair the misconceptions documented by the concept inventories. The activities follow the description established by Laws et al [16], and have the following general outline:

1) Are presented with a misconception-eliciting situation, and asked to make a prediction.
2) Groups of students are allowed to work with either a physical experiment or computer simulation that replicates the situation described in the question. Students are asked to write observations of what *actually* occurs. It is key in this step that the students can observe that there is not a "trick" involved. Appropriate guidance from a faculty or teaching assistant during this experiment is beneficial.
3) Students must complete a post-lab homework in which they reflect on the discrepancies between the experiment/simulation and their prediction, describing how the two were different and revising their answer to reflect what actually occurred. In the process of written reflection, students have the opportunity to revise their conceptual understanding of the activity.

Two activities with associated homework questions were developed for each target concept and were piloted in the 2009-2010 academic year at a variety of engineering institutions.

Methodology

Testing and refinement of activities is ongoing, however results from the first set of test institutions is able to be shared. A sample of convenience was used for this study, composed of undergraduate engineering students studying either Heat Transfer of Thermodynamics whose instructors volunteered their courses for testing of the inquiry-based activities. The appropriate concept inventory was given within two weeks of the start and end of the semester. During the semester, students were given the activities and associated homework in a manner and order determined by the faculty to best fit their course. Some students performed the activities in groups as described above, while some watched the experimental portion of the activity as a class demonstration.

The Heat Transfer test group was composed of students from four diverse institutions, public and private. The Thermodynamics group was similarly composed of students from three institutions, both public and private. All data shown are from institutions that completed all inquiry-based activities. Further analysis of schools where only some of the activities were performed is ongoing, but is clearly different from the performance of those that completed the full set of activities.

Results and Discussion

Table 1 summarizes the preliminary results from the implementation of inquiry-based activities. In the pre-tests, both the “control” and “test” groups are statistically similar. In post-tests, scores are significantly higher for all conditions, demonstrating that both typical teaching and teaching with inquiry-based activities is capable of creating conceptual change. However, the change is dramatically higher in the case of activities for Heat Transfer. In Thermodynamics, the change is also significant although smaller than for Heat Transfer. This is understandable, as this data represents an implementation of activities for only four of the five concept areas.

Table 3: Comparison of Concept Inventory Scores with and without activities

Content Area	Mean Score, Control (no activities)		Mean Score, Test (w/ activities)	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Thermodynamics, Overall	51.4% N=176	65.7%** N=176	51.3% N=239	73.1%** N=64
Heat Transfer, Overall	49.2% N=373	54.5%** N=344	46.6% N=116	70.1%** N=103

* Statistically significant at the $p < 0.05$ level.
** Statistically significant at the $p < 0.01$ level.

The results are dramatic and promising. Ongoing work seeks to expand the test group to even more schools in order to verify the results. Also, the thermodynamics results do not include activities for one of the concept areas. Further result collection will include this additional area for analysis.

Acknowledgements
This work was generously supported by the National Science Foundation (DUE-0717536) and would not have been possible without the collaboration of colleagues who teach heat transfer and thermodynamics at a number of other universities.

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