Work In Progress: A Concept Inventory for Heat Transfer

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Abstract - **A concept inventory has been developed for heat transfer, which is typically taken in the junior or senior year in mechanical engineering. The subject builds on material previously introduced in thermodynamics and fluid mechanics, and the concepts in these subjects are intertwined. The course has been given as a pretest in one course. An item analysis of the inventory has been made to assess the validity of the inventory, showing that further work needs to be done. The inventory will be given as a posttest and then modifications to the inventory will be made. The current draft inventory is available for testing and evaluating.**

Index Terms - assessment, concept inventory, heat transfer

INTRODUCTION

A Concept Inventory is an assessment tool designed to determine the degree to which students understand the concepts of a subject. Among the first concept inventories were those developed to assess understanding of Newtonian physics, which is typically the subject of a first-year physics course. The basic concepts have been well defined (Hestenes) and are unique to Newtonian physics. The resulting concept inventory allows each concept to be evaluated separately.

In contrast to a first-year physics course, most applied engineering courses are taken at the junior and senior year. The core courses in the Thermal Sciences stem of Mechanical Engineering, usually taken in sequence starting with the junior year, are thermodynamics, fluid mechanics, and heat transfer. The courses are designed so that the material progresses to become more realistic of practice. Each course includes concepts from a number of different areas. The advanced nature of the courses and specialized topics in design and analysis that are introduced complicate the development of concept inventories. Fundamental ideas are often hidden by the complexity of the material and the applications to actual systems.

A cooperative effort between faculty at the Universities of Wisconsin and Illinois has been directed toward developing a concept inventory for heat transfer. A number of steps were involved to generate the final draft inventory. The current status of the Heat Transfer Concept Inventory and proposed plans are reported in this Work in Progress.

METHODOLOGY

The first phase was discussion with focus groups of students who had taken a course in heat transfer. The experiences with students have been reported previously (Jacobi et.al., FIE, 2003). The important conclusion of this phase was that students were far less grounded and confident than faculty would be predicted.

The second phase was the identification by faculty of the concepts that they believed students needed to master. A long list of important concepts was generated, and then these were divided into topical areas:

- Fundamental Ideas (properties, control volumes and surfaces, modes of energy transfer, steady state, transient)
- Conduction (Biot-Fourier law, gradients, heat diffusion equation, steady and transient applications)
- Convection (conduction and advection, mechanism and conservation equations, boundary layers, internal and external flow, flow conditions, correlations)
- Radiation (electromagnetic properties, surface properties, radiative processes, radiative exchange)

During this phase it was decided that the final inventory should include about 30 questions, and that there should be some redundancy in the questions to help establish validity. It was realized that the current taxonomy based on topical areas was not appropriate to these goals. The number of questions to cover each concept once would be on the order of 50, and there would be little opportunity to include multiple questions on a given topic.

In the third phase, the concepts were recast into a different matrix (Table 1) that incorporated the common important features of heat transfer. For each of the three important modes (conduction, convection, and radiation), there are three levels of understanding. Physical “Intuition” is whether a student can recognize the mode and some of its basic characteristics. Mechanistic and Physical Description covers ideas such as, for example, the relation between temperature gradient and heat flow. Mathematical Models covers the basic laws as, for example, the relation between radiation heat transfer and the fourth power of temperature. Control Volumes and Energy Balances are ideas that come from previous courses, but mastery is essential to understanding heat transfer. The lines between these

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categories are blurry, with questions not clearly in one category only.

The recasting of concepts into the form of Table 1 yielded only 12 basic concepts that needed to be evaluated. The four faculty then prepared a large number of questions covering these concepts, and then pared the number down to about 30. The final number of questions in the draft inventory in each of the categories is giving in Table I.

TABLE I
CONCEPT MATRIX FOR HT INVENTORY

	"Physical Intuition"	Mechanistic and Physical Description	Mathematical Models
Conduction		10	1
Convection		8	2
Radiation		5	2
Control volumes, energy balances	3	1	

RESULTS

The draft concept inventory has been given as a pretest to a heat transfer class of 42 students at the University of Illinois in spring, 2004. The mean score was 45 %, with a range from 20% to 88%. The relatively high score indicates that students have a fairly solid mastery of the expected concepts upon entering the course. This is consistent with the observation by faculty that heat transfer is mainly a "skills" course that focuses on methods of calculation, and that not many new concepts are introduced.

The measure of test reliability for the inventory, Chronbach's alpha, was 0.6. This value is lower than a desired value of about 0.8. An item analysis was performed, which indicated that some of the questions had satisfactory validity, while for others the validity was questionable. Two questions are described to illustrate the results. The students were divided up by total score into quintiles, with 1st the lowest 20 % and 5th the highest. The score of each quintile is plotted against the score on the question. The item analysis for question 1 is in Figure 1, and question 13 in Figure 2.

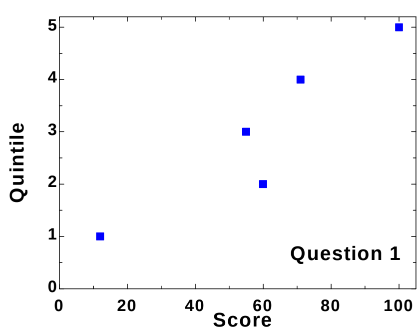

FIGURE 1
ITEM ANALYSIS FOR QUESTION 1

For question 1, the average score was 52 %. The correlation coefficient for the correct answer was 0.54, indicating that the highest scoring students were more likely to get this question correct. The correlation coefficients for the wrong answers were all negative and relatively large, indicating that the highest scoring students were not likely to select the wrong answer. Each of the answers was selected by several students, which indicates that the distracters are appropriate. These are the characteristics of a question with satisfactory validity.

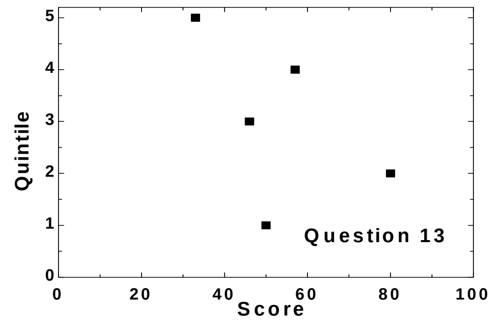

FIGURE 2
ITEM ANALYSIS FOR QUESTION 13

Question 13 had an average score of 50 % correct, which is about the same as for Question 1. However, the correlation coefficient for the correct answer was essentially zero and some of the correlation coefficients for the incorrect answer were positive. Although the validity of this question does not appear to be satisfactory, it may be because the inventory was given as a pretest. This particular question requires concepts developed in the course. The item analysis at the end of the semester may be a more valid assessment.

CONCLUSIONS AND FUTURE WORK

The material covered in heat transfer integrates concepts from a number of areas, and is typically divided into topics. A matrix was generated to divide concepts into three levels: physical intuition, mechanisms, and mathematical models. This taxonomy allowed a concept inventory to be generated with questions that adequately covered the subject.

The inventory was given as a pretest to a class of 42 students, and will be given again at the end of the semester to the same group of students. The gains in understanding will be assessed and an item analysis will be conducted. Over summer, the inventory questions will be examined in light of the item analysis and modified, as necessary, to improve reliability. The following fall semester the concept inventory will be given to students in heat transfer classes both as a pretest and as a posttest.

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