DEVELOPMENT OF A CONCEPT INVENTORY FOR STRENGTH OF MATERIALS

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Abstract *With the success of David Hestenes's Force Concept Inventory, many educators are now working on developing concept inventories for other subjects such as math, biology and engineering science. Development of a useful concept inventory is not easy, however. This paper describes development of two concept inventories for strength of materials, the first of which was a failure. Psychometric testing of this concept inventory indicated serious deficiencies. A new and larger project team was assembled (including the second author) to develop a better inventory. The results of the psychometric analysis of the first inventory, which showed its shortcomings, are first presented, followed by the improved development procedure for the second inventory. Finally, the lessons learned developing first a failed inventory and then a promising inventory are discussed.*

Index Terms – concept inventory, strength of materials, student misconceptions

INTRODUCTION

Every engineering subject has a body of knowledge that must be understood for students to master the subject matter and apply the material to engineering problem solving. These key concepts describe the topics, or ideas, that the whole of the subject is based upon. Key concepts are not simple lists of topics covered in a syllabus. Key concepts are the fundamental ideas of a subject which underlie the equations and problem solving techniques. Students who do not understand the key concepts are doomed to memorize equations and problem solving procedures.

The Force Concept Inventory (FCI) developed by David Hestenes and others [1,2] has motivated many physics teachers to change their teaching methods. Upon administering the FCI at the end of the semester and reviewing the results, a teacher is frequently brought face-to-face with the ugly truth—his or her students do not understand some of the most basic key concepts. The realization can prompt the teacher to try different teaching methods, sometimes one involving more student participation.

Engineering teachers have begun to develop concept inventories for engineering science courses—typically courses taken in the sophomore year of an engineering curriculum which form the foundation for the subsequent discipline-specific courses. Concept inventories have been or are being developed for electromagnetic waves [4,5], thermodynamics [6] and signals and systems [8].

The first and third author constructed an initial Strength of Materials Concept Inventory (SOMCI) in 2001 [7]. The concept inventory was tested on approximately 200 students at both University of Alabama and Texas A&M University. This inventory, as well as other products of our project, can be viewed at the web site: "somci.eng.ua.edu". Psychometric analysis of the test results was disappointing. The analysis basically indicated that the inventory had no internal consistency. Also, a look at the inventory itself reveals that although the questions would be suitable for a quiz or an exam in a strength of materials course, they are not suitable for use in a concept inventory.

The second SOMCI is showing much more promise. A larger project team, following a more thoughtful design procedure, and benefiting from the earlier experience with the failed inventory is making slow but steady progress. The steps the new team has taken and plans to take are outlined in the last section of this paper.

FIRST SOMCI

The first SOMCI was developed by the first and third authors by simply generating "interesting" questions on SOM topics. Psychometric analysis of this inventory indicated a weak instrument, prompting development of the second SOMCI. Work on this second SOMCI has revealed several shortcomings in the first SOMCI.

Results of the psychometric analysis are presented in this section for item difficulty, item discrimination, and correlation with course grade. The results indicate that the first SOMCI had too many questions that were either too easy or too difficult (item difficulty). Also, student performance on many of the questions did not match their overall performance (item discrimination). And finally, performance on the first SOMCI was only weakly correlated with students' course grades in the strength of materials course (correlation to SOM grade). Each analysis result is described in more detail below.

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- **Item difficulty** for the first SOMCI is shown in Figure 1. The purpose of analyzing item difficulty is to determine if a disproportionate number of the items are either too easy or too hard. Ideally, the items should be in the 0.4 to 0.6 range. Only six of the 24 items fell within this range. Questions 1, 3, 4, 5, 9 and 10 were too easy—over 80% of the students answered these questions correctly. And Question #7 was too difficult—only 5% of the students answered this question correctly.
- **Item discrimination** for the first SOMCI is shown in Figure 2. For a particular question, the discrimination index is an indicator of how well the question discriminates between high scorers and low scorers. The discrimination index can be interpreted as the percent more high scorers than low scorers who got the question correct. We hope that the final version of the inventory has questions with a discrimination index above 0.40
- **Correlation with course grade** is shown in Figure 3. Students' score on the inventory is plotted against their course grade from their strength of materials course. The R-square value means that the SOM course grade accounts for 11.8% of the variability in the students' score on the inventory. Ideally, we would like higher slope, a higher R-square and a significance at the 0.05 level (alpha value = 0.05).

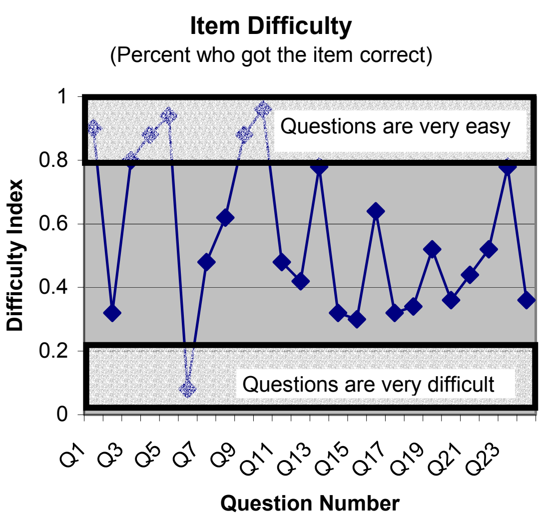

FIGURE 1
ITEM DIFFICULTY FOR FIRST SOMCI.

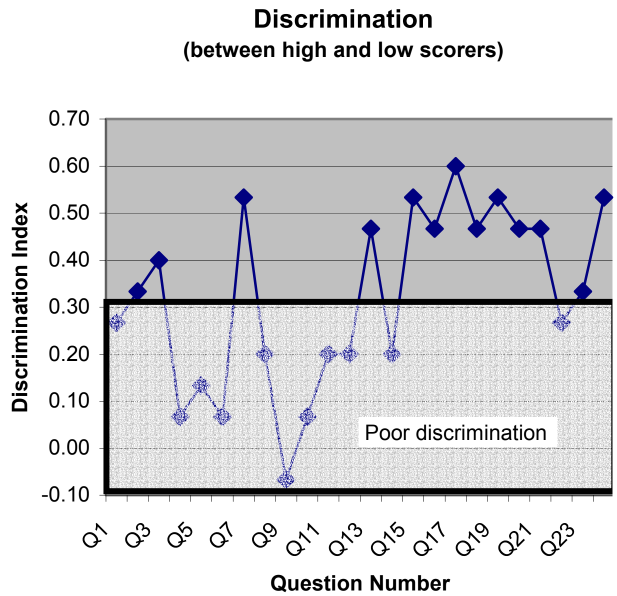

FIGURE 2
ITEM DISCRIMINATION FOR FIRST SOMCI.

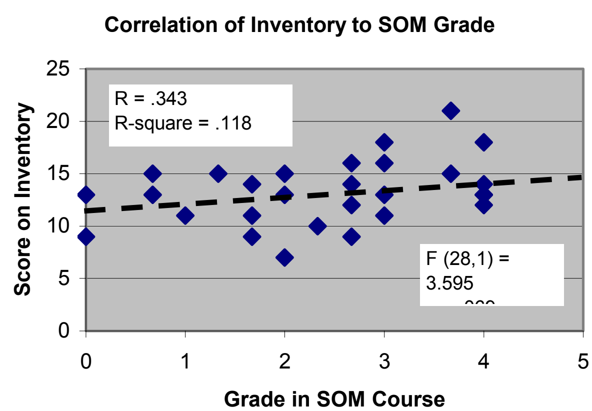

FIGURE 3
CORRELATION OF FIRST SOMCI TO COURSE GRADE

LESSONS LEARNED FROM FIRST SOMCI

Readers can benefit from the authors' experience building first a poorly performing and then a promising concept inventory. Several differences between the two are pointed out. First, the questions on the first SOMCI usually involved more than one concept, making it impossible to determine which concept was misunderstood by students answering the question incorrectly.

An example of a concept question involving more than one concept is shown in Figure 4. This question was intended to examine students' understanding of stress transformation, specifically, the relationship between normal and shear stresses. To answer the question, however, a student would need to know that ductile materials fail in shear, and then that the plane oriented at 45^o to the horizontal has the maximum shear stress. The concept question in Figure 5, on the other hand, only requires the student to be able to visualize the stress on the inclined plane that is required to satisfy equilibrium.

Second, few questions in the first inventory examined the same concept. Multiple questions examining the same concept will increase the validity of the inventory for each concept. For example, a student may not know a concept but could guess the correct answer, or the student may know the concept but could misread the question. The new multiple-question-per-concept inventory will be more valid on a per-concept basis, especially when administered to small class sizes.

Third, the wrong answers in the first SOMCI were not good "distractors"—answers based on common student misconceptions. This is probably the most challenging aspect of concept inventory development but is probably the most important--the quality of our distractors will determine the usefulness of the entire concept inventory.

SECOND SOMCI

Our first task was to develop a list of concept descriptions to which we could map our concept questions. We then began developing concept questions. An important part of developing a good concept question is generating good "distractors" for the multiple-choice answers. Next, we plan to assemble approximately 30 questions covering roughly 10 concepts (giving three questions for each concept, on average) into a draft concept inventory. The inventory will be given to a large and diverse group of students to generate reliable statistics for evaluating the validity and reliability of the inventory. Each step of the development process is described in more detail below.

Step 1: Develop a List of Concept Descriptions

This task has proven to be much more difficult then we anticipated. Our goal is to be able to map each question in our inventory to a unique concept. We are proceeding on this task with several sub-steps.

- **Solicit input from colleagues.** We asked our colleagues to send us lists of important concepts that students frequently misunderstand. This step is important for establishing the validity of the inventory (i.e. for establishing that the inventory measures what we say it does: student understanding of fundamental SOM concepts.)
- **Synthesize into comprehensive list.** We then synthesized these lists into one big master list in a face-to-face meeting. We have subsequently revised our list of concepts many times to make it more readable, more precise, and more complete. We also revised the list after developing initial concept questions to improve the question-to-concept mapping.
- **Ask colleagues to rate each concept.** We will ask our colleagues to rate each concept with regard to (1) importance and (2) persistence as a source of student errors. We will take these ratings into consideration when selecting the approximately ten concepts for our inventory.

Step 2: Develop Concept Questions

The project team's earlier work developing a set of precise concept descriptions is paying off during the concept question development phase. Team members have a clear idea of the "boundaries" of a particular concept for which they are developing a question. And, more importantly, team members now have a shared vocabulary for describing SOM concepts.

Question development will be a multi-step process. For each question, we will:

- **Generate a draft question.** 55 questions were recently developed by team members, working independently. The team critiqued each of this first batch of questions at a face-to-face meeting. The first task was to identify the concept or concepts needed by a student to answer the question. Most of the questions touched on more than one concept, and were therefore unsuitable for use in the concept inventory without some modification. Team members then noted other confusing or misleading aspects of the questions and offered suggestions for improvement.
- **Identify common student misconceptions.** One of the strong points of the Force Concept Inventory is the wrong answers for a question are based on common student misconceptions. Unfortunately this is a daunting task because most professors, authors included, have limited knowledge of what goes on in students' minds when working engineering problems. Our approach for identifying common student misconceptions is to have students work concept questions with no multiple-choice answers. Some team members will also work with student individually and ask them to think out load as they work the problems.
- **Develop "distractors" for multiple-choice answers.** Distractors are wrong answers to a multiple-choice question based on common student misconceptions. The misconceptions identified in the previous step will be used to formulate as many distractors as possible for each question. Students will then be given the concept questions with the full list of distractors as possible answers. The distractors most frequently selected by the students will be used as the wrong multiple-choice answers in the inventory.

Step 3: Build Concept Inventory and Test

Based on the input from colleagues regarding importance and persistence as a source for student errors and other criteria, the project team will assemble the concept inventory. We currently envision about 30 questions covering 10 concepts. This will provide three questions per concept, on average, and produce a test short enough to be worked in 20 to 30 minutes.

The new inventory will be given to as many students as possible, on as many different campuses as possible. Students will be asked to indicate their gender and ethnicity on the instrument. A psychometric analysis will be performed on the test results to evaluate validity and reliability of the inventory, and to check for bias with respect to any one demographic group of students.

ACKNOWLEDGMENT

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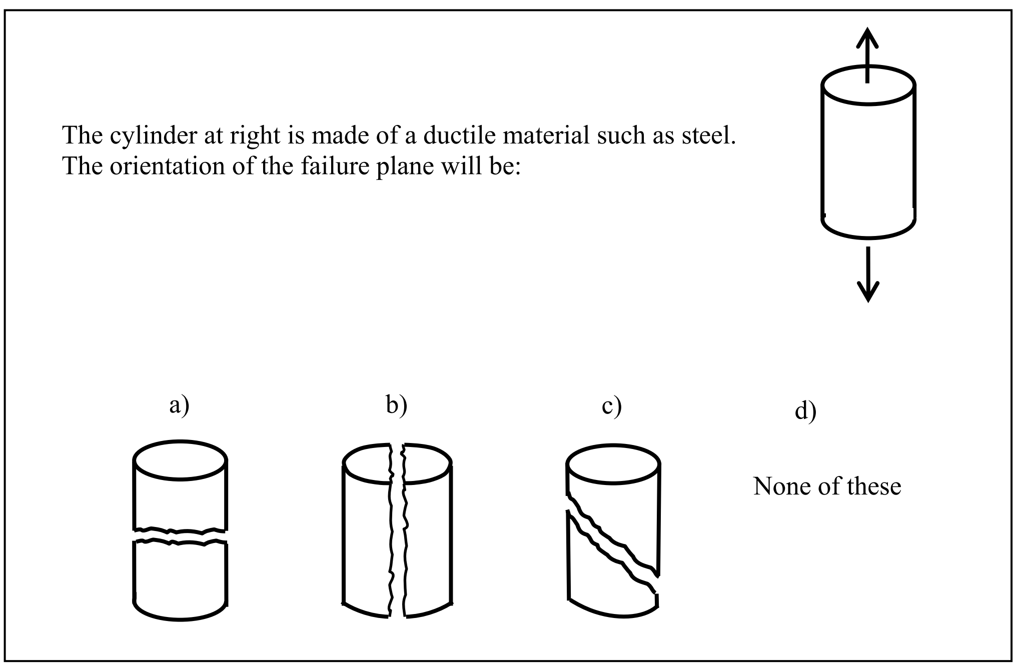
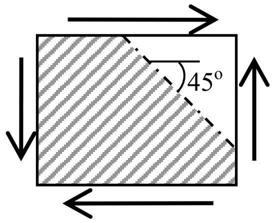
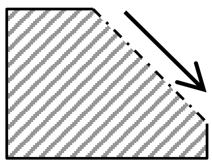


FIGURE 4
Example of Poor Concept Inventory Question

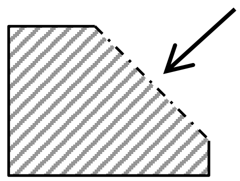
Shear stresses are applied to the outside of a block as shown.



Which figure below describes the internal force acting on the inclined surface inside the block while the shear stresses on the outside of the block are acting?



(a)



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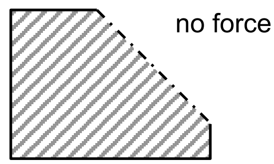

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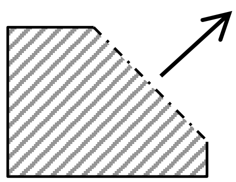

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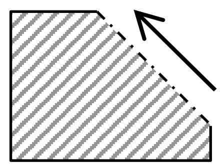

(e)

FIGURE 5
Example of Good Concept Inventory Question