Concept Inventories for Shape Memory Alloys and Piezoelectric Materials

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Abstract

New materials with attractive properties for design, so-called smart materials such as shape memory alloys and piezoelectric materials, are being introduced rapidly and incorporated into diverse applications. Since these materials change engineering practice, these materials are being introduced into undergraduate engineering curricula. However, the degree to which students understand concepts associated with these materials is difficult to assess. As the work by Hestenes and Halloun on the Force Concept Inventory has shown, students may pass science and engineering courses but still retain alternate conceptions about the topics presented in the courses. Therefore, substantial interest in concept inventory assessment instruments for many engineering subjects, e.g., materials, signals and systems, fluid mechanics, has been generated and numerous projects are underway. Since smart materials are being introduced into undergraduate engineering curricula, assessing students' understanding of these smart materials would be reasonable. Therefore, two new concept inventories, one on shape memory alloys and one on piezoelectric materials, are being developed as part of a Combined Research and Curriculum Development (CRCD) project at Texas A&M University. The paper will describe the background for concept inventories. Then, concept inventories for both types of materials will be described in parallel presentations. First, concepts associated with the material will be described and then sample questions designed to assess understanding of these concepts will be presented. Results from students who have taken preliminary versions of each concept inventory will be presented.

Introduction

Curriculum innovation projects that introduce new topics into undergraduate engineering curricula have two curricular challenges. First, they must determine how well students have grasped the new material. Second, they must prepare a transferrable instructional plan to facilitate learning of the new material, based upon the successful teaching and learning experiences in the pilot. The second challenge is regularly confronted and many curricular pilot projects have produced and shared instructional materials for the new material that the project teams have introduced into their curricula. However, fewer resources have been generated for the first challenge. This paper describes a curriculum innovation project that intended to incorporate so-called smart materials and intelligent systems into undergraduate engineering curricula at Texas A&M University (TAMU). In addition to describing the curricular innovations, the goal of the paper is to present two concept inventory assessment instruments that have been constructed to ascertain the degree to which students have acquired a conceptual understanding of the innovative topics that have been introduced into the curriculum.

Interest in conceptual understanding, commonly held misconceptions, and how misconceptions might be repaired has generated extensive research in several areas [1-3]. In science and engineering, an important step in moving research into college classrooms was taken with development and eventual widespread use of the Force Concept Inventory (FCI) [4-6]. Motivated by the success of the FCI in promoting deeper inquiry and innovation in physics education [5], engineering faculty members have begun developing concept inventories for many areas in engineering science. Some of these efforts are describe in the next section. Since the Integrated Multidisciplinary Curriculum for Intelligent Systems Combined Research and Curriculum Development (CRCD) project aimed to incorporate subject matter on shape memory alloys (SMAs) and piezoelectric materials into the engineering curricula, development of concept inventories for these two areas seemed to be a natural step to take.

To date, initial versions of two concept inventories: a Shape Memory Alloy Concept Inventory (SMACI) and a Piezoelectric Material Concept Inventory (PMCI), have been developed. Each has been tested on small groups of students with encouraging results. The purpose of the paper is to describe the state of development of the two instruments within the context of a larger project on curricular development. The next section of the paper will describe the general state of development with respect to concept inventories. Then, the project that motivated development of the SMACI and PMCI will be described. Specifics about each instrument will be provided followed by results that have been obtained from initial testing. The conclusion section will provide information on availability of the instruments and possible future directions.

Concept Inventory Assessment Instruments

Student understanding of material in a course is typically assessed on final examinations at the end of the course. On final examinations, students typically solve problems similar to homework and in-class problems. Although these types of final examinations are in widespread use to assess student mastery of course material, doubts or concerns often linger about students understanding of the concepts introduced in the course. Similar concerns motivated Hestenes and Halloun to construct the Force Concept Inventory (FCI) [4]. Questions on the FCI do not require computation. Instead, students are presented with verbal or pictorial depictions of a situation and asked to choose which of the offered alternatives best describes the result which will occur. Questions on the FCI are not arbitrarily generated. Instead, as Hestenes describes "The …FCI is not comparable to the off-the-cuff multiple choice tests that teachers construct on their own. The carefully constructed distracters for each item are not typical multiple-choice throwaways, but common sense alternatives to Newtonian concepts that amplify the significance of student responses" [5]. Results from the FCI showed that students who completed first-year physics courses still retained conceptual misunderstandings, often referred to as misconceptions or alternative conceptions, even students who had received high grades. As Hestenes describes their understanding of Newton's Third Law, "...we have found that nearly 80% of the students could state Newton's Third Law at the beginning of the course, while FCI data showed that less than 15% of them fully understood it at the end" [5]. Gains from pre- and post-tests indicate that gains in conceptual understanding as measured by the FCI depend on the pedagogical approach adopted for the course [6]. Results from the FCI and other studies of students' conceptual understanding of physics topics have driven substantial research in physics education.

Concept inventory assessment instruments in other disciplines are under development in other projects as well:

- Materials Concept Inventory [7, 8]
- Signals and System concept inventories [9-11]
- Fluid Mechanics [12]
- Thermal and Transport Sciences [13]
- Strength of Materials [14]
- Electromagnetics [15]
- Electronics [16]

Reports from each of these projects indicate that gains in student conceptual understanding in courses taught using traditional lectures are less than might be expected.

Curriculum Innovations

Development of an Integrated Multidisciplinary Curriculum for Intelligent Systems is a project that is supported by the Combined Research and Curriculum Development (CRCD) program at the National Science Foundation (NSF). It is being implemented by a multi-disciplinary project team to incorporate subject matter on smart materials and intelligent systems throughout four-year engineering curricula.

- In the first-year engineering course sequence at TAMU, two short introductory lectures were prepared and offered. One lecture was on SMAs and the second on piezoelectric materials. The SMA introduction is available [17]. After the SMA introduction, student teams worked on a SMA project in which they started with the Stiquito [18] kit and then built their own vehicle in which the energy and momentum were provided through SMA wires. Vehicle performance was measured by the distance traveled in three minutes. More details about the introduction of smart materials into the first-year curriculum can be found in [19].
- The project prepared modules on SMA and piezoelectric materials into a sophomore introduction to materials course, ENGR 213 Principals of Materials Engineering.
- A project on synthetic jet actuators (SJA) was introduced into a junior aerospace engineering laboratory course, AERO 302 Aerospace Engineering Laboratory I.
- The project introduced material on analyzing SMA components into a structural analysis course, AERO 306 - Structural Analysis II. Specifically, students studied how finite element analysis can be performed on structures that contain SMA components. More information about the specific changes can be found at http://crcd.tamu.edu/curriculum/aero306/aero306.html.
- Finite element analysis of aerospace structures, including structures with SMA components, was continued in AERO 405 Aerospace Structural Design. In this course, students analyzed more complex structures including analysis of spars and ribs in a wing that contained SMA components.
- One student team in AERO 401/402 Aerospace Vehicle Design I and II worked on the design of a vehicle that incorporated smart materials.
- The project created a new course, AERO 489: Special Topics in Aerospace Intelligent Systems, to describe integration of shape memory alloys, piezoelectric materials, other smart materials, and SJA into design of aerospace subsystems and systems.

If students participated in one or more of the above learning activities it was essential to know how much students' conceptual understanding of smart materials has changed. To address this question data on the conceptual understanding of students could be obtained by more than one method.

Concept Inventory Assessment Instruments for Shape Memory Alloys and Piezoelectric Materials

Motivated by development of concept inventory assessment instruments for other engineering science disciplines, the project team attempted to develop similar instruments for shape memory alloys and piezoelectric materials. Unlike physics and some engineering science disciplines, development of concept inventory assessment instruments for these two areas of material science did not have research in student misconceptions upon which to draw. To develop the instruments, four types of questioning would be pursued:

- Basic Questions: To determine if the student was able to recall basic facts about shape memory alloys
- Application Questions: 1) To determine if a student could recognize real world applications for SMAs; 2) To determine if a student could recognize which shape memory characteristic was used in the given example
- Basic Problems: 1) To determine if the student was able to apply this knowledge to a problem involving an SMA material, 2) To determine if the student was able to combine sophomore level engineering knowledge with their basic knowledge of SMAs to complete simple problems
- Advanced Questions: 1) To determine if the student was able to recall more detailed information about SMAs provided from either an upper level undergraduate course or a graduate course, 2) To determine if the student was able to apply this knowledge to a problem involving an SMA material, 3) To determine if the student was able to integrate their knowledge about SMAs with knowledge recalled from other courses

Here is an example of a basic question from the SMA Concept Inventory:

1. What is the basic mechanism of the shape memory effect (SME)?
    a. Deformation due to the motion of mixed dislocations
    b. Interstitial diffusions within the crystal lattice structure
    c. Phase transition in a crystal lattice structure (correct)
    d. Grain boundary growth after recrystalization
    e. None of the above

Here is an example of a basic question from the Piezoelectric Material Concept Inventory:

1. Which are steps required in making a piezoelectric material?
    a. Heating the material above the Curie Temperature and cooling it with no electric field present
    b. Heating the material above the Curie Temperature and cooling it with an electric field present (correct)

c. Cooling the material to the Curie Temperature while an electric field is maintained and then reheating it to room temperature
d. Cooling the material to the Curie Temperature with no electric field present and then reheating it to room temperature

Results from the SMA Concept Inventory

A draft version of the SMA Concept Inventory was given to ten students at the upper division and graduate level. Eight students had taken courses that included topics on SMA and two students had not. One criterion for initial validation of the questions about this preliminary version of the concept inventory would be that students who had taken courses with SMA topics would outperform students who had not. That result would indicate whether the current draft of the instrument tested understanding about SMA. Figure 1 shows the results. Results are encouraging since students with experience (those who had taken courses that included SMA topics) answered many of the questions correctly while students without experience failed to answer questions correctly. In some cases, for example, Question 15, no one answered the question correctly; therefore, Question 15 must be revised. Subsequently, a group of students who had participated in learning activities which included SMA topics, including some of those who had taken the draft version of the test, were asked to critique the questions and multiple choice answers on the draft version of the concept inventory. This feedback was utilized in revising the questions. The next step in the development of the instrument is to distribute the instrument to faculty with SMA expertise for additional feedback on revisions, and to make it

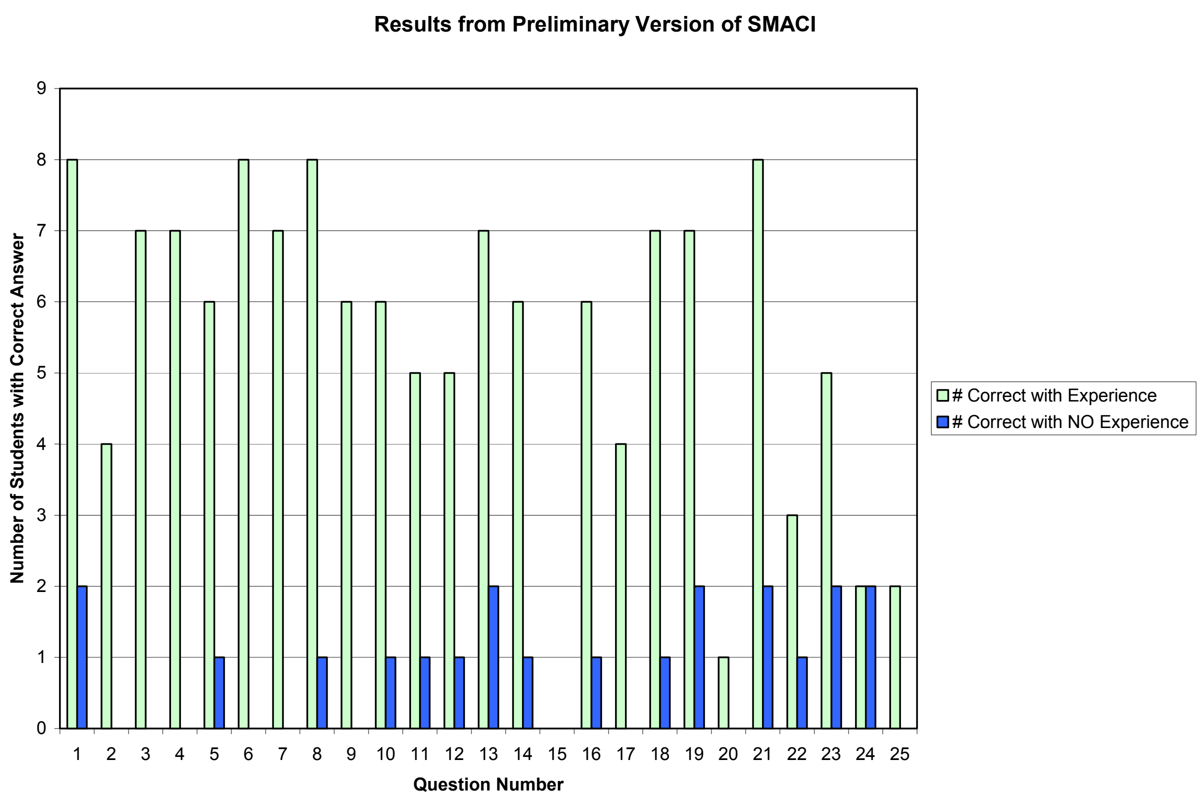

Figure 1. Student Performance on Preliminary Version of SMA Concept Inventory

available for tentative field testing.

Results from the Piezoelectric Material Concept Inventory

The draft of the Piezoelectric Material Concept Inventory was given to eight students at the senior and graduate level. Three students had taken courses that included topics on piezoelectric materials and five students had not. Results are shown in Figure 2. On questions 12, 13, and 14 the only students with correct answers had no previous formal experience with piezoelectric materials. At least these questions will require revision. The validity of the questions on this test also requires exploration similar to what has been discussed in relation to the SMA Concept Inventory. Critiques, revision, and continued development testing are also planned for this instrument.

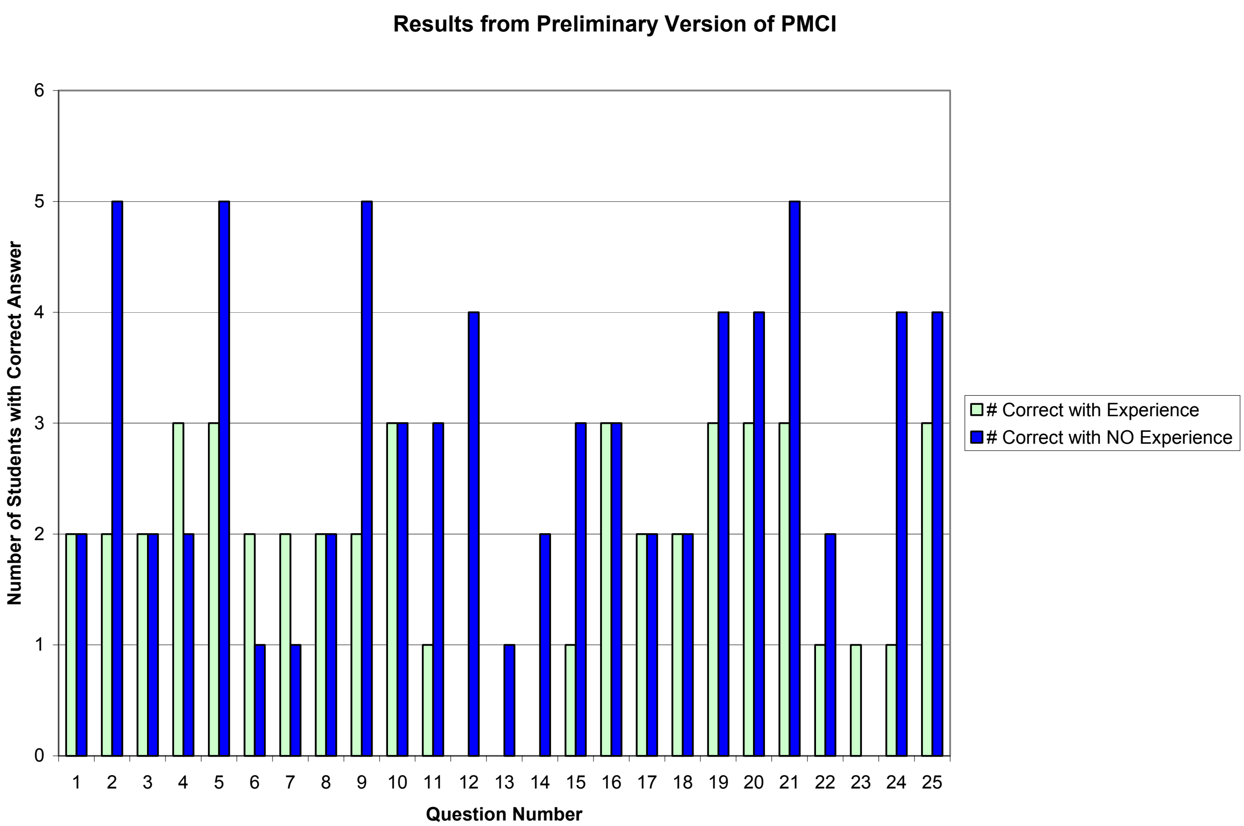

Figure 2. Student Performance on the Draft Piezoelectric Concept Inventory

Conclusion

The challenge of generating instructional materials and implementing instructional plans for innovative pilot programs may come rather naturally and easily to faculty who undertake curriculum innovation; however, determining how effective these materials and instructional plans may be at facilitating the desired learning requires efforts which are less intuitive. The project we have described has pursued the challenges of pointedly assessing student learning from curriculum innovation and doing so at a level more penetrating than what is normally measured by final class examinations. The "SMART MATERIALS" CRCD project at Texas A&M University project has undertaken the development of one concept inventory on shape memory alloys and another on piezoelectric materials, and has completed several of the preliminary steps of assessment instrument development. These inventories have reached a point at which they may be shared for critiquing and "beta" field testing for further refinement and improvement of their power to measure the level and the nature of student understanding and student misunderstanding of the subject matter in those two fields.

Copies of both concept inventory instruments may be obtained by contacting the first author. The inventories will not be posted openly on the web to limit access to students who might download copies. As a result, the validity of the instrument would be threatened. However, faculty members are encouraged to obtain a copy of either or both instruments, provide feedback, and use the instruments in their classes. Participation by a broad range of faculty members and data from large number of students are needed to improve the instruments to measure conceptual gains in understanding these two new classes of materials.

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