AC 2009-751: DETERMINING THE FACTOR STRUCTURE OF THE MATERIALS-CONCEPT INVENTORY

James Corkins, Arizona State University

James Corkins, Arizona State University James Corkins is a Ph.D. student in Science Education, Department of Curriculum and Instruction at ASU. He earned his MA degree in Science Education at Arizona State University. His BS degree is in Physics. His principle research areas are inquiry-based learning and characterization and measurement of conceptual change in thermodynamics and introductory materials science.

Jacquelyn Kelly, Arizona State University

Jacquelyn Kelly, Arizona State University Jacquelyn Kelley is a M.S. student in the School of Materials in the Fulton School of Engineering at Arizona State University. Her BS degree is in Physics and Chemistry Education. Her principle research areas are inquiry-based learning and development and assessment of inquiry-based modules in materials science and engineering. She teaches physics, chemistry and mathematics in a local arts high school.

Dale Baker, Arizona State University

Dale Baker, Arizona State University Dale R. Baker is a Professor of Science Education in the Department of Curriculum and Instruction at ASU and is the Co-Editor of The Journal of Research in Science Teaching. She teaches courses in science curricula, teaching and learning, and assessment courses with an emphasis on constructivist theory and issues of equity. Her research focuses on issues of gender, science, and science teaching. She has won two awards for her research in these areas.

Sharon Robinson Kurpius,

Sharon Robinson Kurpius, Arizona State University Sharon E. Robinson Kurpius is a professor of Counseling Psychology. She has received numerous national grants examining undergraduates' academic persistence and the academic success of talented adolescent girls. She was recently named a "Multicultural Scholar" by the NACAC for her work on the retention of racial/ethnic minority students in higher education.

Amaneh Tasooji, Arizona State University

Amaneh Tasooji, Arizona State University Amaneh Tasooji is an Associate Research Professor in the School of Materials at ASU and has been teaching and developing new content for materials science and engineering classes and laboratories. She has developed new content and contextual teaching methods from her experience as a researcher and General Manager at Honeywell Inc. She is currently working to develop new assessments to reveal and address student misconceptions in introductory materials engineering classes.

Stephen Krause, Arizona State University

Stephen Krause, Arizona State University Stephen J. Krause is Professor in the School of Materials in the Fulton School of Engineering at Arizona State University. He teaches in the areas of bridging engineering and education, design and selection of materials, general materials engineering, polymer science, and characterization of materials. His research interests are in innovative education in engineering and K-12 engineering outreach. He has been working on Project Pathways, an NSF supported Math Science Partnership, in developing modules for Physics and Chemistry and also a course on Engineering Capstone Design. He has also co-developed a Materials Concept Inventory for assessing fundamental knowledge of students in introductory materials engineering classes.

Determining the Factor Structure of the Materials Concept Inventory

Abstract

A 30-item Materials Concept Inventory (MCI) was created six years ago in order to help measure conceptual change and identify misconceptions in introductory materials science and engineering classes. Since that time it has proven useful as a tool to examine student conceptual knowledge and the effect of pedagogy on conceptual change. However, the current effort and prior work by others indicate that an MCI with a reduced number of topical areas and more multiple representations of important concepts could improve its validity and reliability. In particular, we are reporting in this research the analysis of the factor structure of the MCI using a principle component factor analysis. 318 students completed pre-post course testing of the MCI while enrolled in sections of an introductory materials engineering course in six different semesters. There was a good degree of internal consistency, and the principal components analysis supported the notion of a seven-factor solution. The reliability coefficients for the MCI was determined to be alpha = .73. Factor analysis is being used to test the effect of substitution of new or modified items to improve the construct validity of the MCI. Ultimately, a more accurate measurement tool has the potential to improve student learning through better assessment of the effect of pedagogy on student conceptual change.

Introduction

Engineering faculty sometimes comment that even students who correctly solve problems in phase diagrams may mistakenly believe that, the atom size in a substance increases as it changes from liquid state to gaseous state or when heated[1]. These observations are supported by evidence in the literature that suggests that engineering students taking an introductory materials science course often have similar misconceptions about how molecular-scale processes fundamentally differ from observable, macroscopic causal behavior we experience in our daily lives[2].

The Accreditation Board for Engineering and Technology (ABET) commissioned a team of researchers at the Penn State Center for the Study of Higher Education to assess the impact of the accreditation criteria on student learning outcomes[3]. The first learning outcome of the ABET, Criterion 3 (a), states that, "Engineering programs must demonstrate that their graduates have an ability to apply knowledge of mathematics, science and engineering appropriate to the discipline"[3]. Simply stated, this requires that students need to be able to transfer previously acquired knowledge and skills to new engineering learning situations and applications.

One important subject area taught in a fundamental way in chemistry and in an applied way in engineering is the domain of materials. It is an area of fundamental conceptual knowledge that is applied to a broad set of disciplines in chemical, mechanical, aerospace, physics and materials engineering[4]. It is usually assumed that prerequisite science classes provide students with a foundation of content that is strong enough to be challenged by this application to new domains, but students' incorrect prior conceptions may be a barrier which handicaps this transfer.

Incorrect prior conceptions, often referred to as misconceptions, need to be repaired, modified, or discarded in order to achieve scientifically valid conceptual knowledge. These scientifically invalid concepts can be carried over into introductory materials engineering classes as misconceptions. As such, they can inhibit students' ability to understand the content domains necessary for effectively understanding materials engineering.

To help faculty identify the concepts that their students do not understand and decide which misconceptions are most prevalent, a number of instruments, called concept inventories, or CI's, have been developed in selected fields, most notably the Force Concept Inventory in physics. With National Science Foundation (NSF) support, Krause, Decker, Niska, Alford & Griffin[5] in 2002 developed the materials concept inventory (MCI) for materials engineering and materials sciences encompassing introductory subject field such as: solubility, phases, atomic bonding, crystal structure, defects, and macroscopic properties.

Framing Statement - In this paper we will describe the research, development and testing of the beta version of the MCI. We will present our preliminary analysis of the results from the beta test, and discuss the plans for extending the beta version concept inventory into a more fully developed valid and reliable assessment.

Review of the Literature

The Need for the MCI - For the last three decades concept inventories have been in use, but it was only recently that the application of various concept inventory assessment tools began to be applied to engineering subjects. As part of a continuous improvement process implemented by the ABET, this process must demonstrate the "achievement of… objectives and uses the results to improve the effectiveness of the program"[3].

As part of this process, an initial concept inventory test for the subject "materials science and engineering" was developed called the Materials Concepts Inventory (MCI). We will discuss here the development of a MCI, validation, reliability and future revision. The concepts covered by this test emphasized principles that govern concepts on relationships between structure, processing and properties of engineering materials[6]. A secondary emphasis was on understanding how effectively background educational concepts were developed in earlier papers.

The Creation of the MCI - The general principles utilized by Hestenes et al. in 1992[5] in the development of the FCI were applied in the development of the MCI. A team of undergraduates, a graduate student, and faculty utilized a variety of resources in the MCI development. Broad general categories of materials concepts and their course linkages were delineated from the content contained in class syllabi and in introductory materials science and engineering textbooks[7]. Multiple choice questions on the categories defined were: phase diagrams, atomic bonding, electronic structure, atomic arrangement & crystal structure, defects & microstructure, solubility, and macroscopic properties[7].

The creation of the test was to establish the levels of students' prior conceptual knowledge of the subject matter, determine the fundamental concepts to be taught and measure the gains in conceptual change[6]. The average student taking the introduction to materials course is a college sophomore with two to three semesters of experience[7]. These students typically have taken one semester of college level chemistry, one to two semesters of physics, one to three engineering-oriented math courses, and a number of high school level math and science courses[7]. From these courses it was determined that some of the concepts covered by the introductory materials course were covered in some of the students' previous courses, but usually only in passing and not in depth[6]. Thus, it was determined that on the concept inventory that a fraction of the questions would not only be created to cover key concepts, but be presented in a manner that students would have been exposed to them in previous courses[7].

The Methods of the Creation of the Beta Version of the MCI. - A literature survey was initiated to help determine the difficulty level of the questions, how other researchers had created their questions and distractors, and the guidelines used in creating such concept inventories. To establish a set of questions and realistic distractors, the researchers began a series of weekly short answer, open-ended questions, or multiple choice quizzes with students from an introductory materials course[7]. Interviews with volunteer students were conducted weekly to discuss what they were learning that week, and any feedback they had on how the class was going. Then the students were asked some brief questions on the future class content to see what, if anything, the students knew about that subject already[7]. The results of these interviews, along with the quizzes and short answers, and the project teams' own experiences in the field helped to create a multitude of possible concept test questions, and realistic distractor answers[7].

Once 30 to 35 items were created, the researchers established two criteria before selecting what questions were to be placed on the test. The first was that roughly 1/3 of all the questions were in a form that students would have had previous exposure to them in preceding courses, and the second was that two to six questions that would be based on each of the seven primary concepts covered in the course[6]. To meet the first criteria it was determined that a majority of students would have been exposed to several of the primary concepts in their previous chemistry courses, and to a lesser, and surprising, extent, their geometry courses[6]. The test was then administered, as an alpha version, allowing the students 30 minutes to finish the 30-problem multiple-choice test. In the analysis of the results of the alpha version, they removed or re-wrote poorly worded or ambiguous items. This revision eventually became the beta version of the MCI.

Assessment of student learning is an important and timely issue across all areas of science education, but within the area of materials science, a valid and reliable assessment is critical since it is a fundamental learning outcome in the engineering education community. Due to the rise in new literature in recent years surrounding misconceptions in materials science, a fresh review of the research was needed for improving the beta version of the MCI.

Misconceptions Literature Review Relevant to the MCI. - To capitalize on the research that has been done on misconceptions in general chemistry, a literature review was conducted. This section will focus on six topics from general chemistry relevant to this study. They are phase change, solubility, atomic bonding, macroscopic properties & defects, electronic structure, and atomic arrangement & crystal structure[7]. There is a relatively large amount of research regarding phase change, solubility, and atomic bonding, but only one author investigated the topical areas of electronic structure, and atomic arrangement & crystal structure. From a review of this literature, distractors were developed from the misconceptions reported, then will be applied to the revision of the MCI. The following is a brief introduction to misconceptions based on content areas relative to the MCI.

Phase Change - A substantial body of research literature has reported students' misconceptions concerning the particle nature of phase changes, but only some studies were relevant to this paper. Understanding the particle nature of matter plays an important role in learning chemistry shown by the fact that students' chemistry achievement could be improved through emphasis on the particle nature of matter. First, students probably lack the ability to explain the state change of a substance through a microscopic perspective. One study indicated that none of the high school students held scientifically correct views in explaining the differences of solids, liquids, and gases by using a sound particle model. Another found that no 7th graders utilized a particle model as its definition and only 25% of the 8th graders did so. One aspect of this misconception is transferred to the introductory materials science course. Although all of the students had taken chemistry in the past, MCI results showed that the students did not distinguish the nature of the difference between atoms and molecules. The students had transferred a misconception that was not effectively addressed in the materials course in teaching by lecturing (10% gain), in teaching with team based discussions (15% loss) with only minor improvement with team based discussions and concept sketching (31% gain). Effective interventions need to be designed to address this type of persistent misconception.

Solutions. - The studies that are most pertinent to understanding of solution concepts related to phase diagrams are those that are related to solubility, including the meaning of the terms unsaturated, saturated, and supersaturated[7]. One study researched students' understanding about how solution concentration changed when water evaporated from a beaker of water with salt sitting at the bottom. This was done with a two-tiered multiple choice set of questions, where in the first tier question only 32% (34% post) specified that the solution concentration stays the same as the water evaporates while 64% (61% post) believed concentration increased and 3% (4% post) thought it decreased. In the second tier question, 30% (48% post) stated that there was the same amount of salt in less water while 30% (18% post) said the salt didn't evaporate and remained in solution while only 25% (26% post) stated that more saturated salt forms at the bottom of the beaker[7]. Krause[7] postulated that there might be a misconception as to the meaning of supersaturation in that there is excess solid present as a separate phase in the beaker. Students bring these types of misconceptions about solutions and solubility to the introductory materials course. An MCI question about this is the following. Given a beaker with a solution of water and solid salt at the bottom, what would happen to the concentration if a small percentage of salt is slowly added to the glass while stirring the solution[8]. The average percentage of *entering students* from three different classes using different pedagogies that chose the correct answer, "stays the same", was 43% while the most frequent incorrect answer was "increase". This misconception shows that entering students did not understand the concepts of solubility and solubility limit from earlier chemistry classes, where students evidently did not develop a working knowledge of equilibrium phenomena[8]. The effectiveness of the learning from three different pedagogies is as follows. When solution and solubility concepts were taught by lecturing there was a 42% gain, while teaching with team based discussions gave a 64% gain, and there was a major improvement with team based discussions and concept sketching of 96%. As described previously, effective interventions need to be designed to address the type of misconception like those related to solutions and solubility that were transferred from chemistry.

Atomic Bonding. - In 1989 Peterson, Treagust and Garnett[10] published a paper detailing their development of a test for identifying misconceptions in bonding and molecular structure. It was called the Covalent Bonding and Structure test. They found that students' ideas developed during an advanced chemistry course, but their progress was often accompanied by misconceptions about these associated areas. For example, they found that 23% of 17 year olds thought that electrons were equally shared in all covalent bonds, while about one-quarter attributed the shape of molecules to repulsion between the bonding pairs of electrons, or to bond polarity. Only about 60% of students knew the correct position of the electron pair in a bond between hydrogen and fluorine. The same question asked of first year university students studying chemistry yielded a 55% correct response, implying that many students who learn about bond polarity retain their knowledge. When students' ideas about the energetics involved in bond formation were probed by asking why a methane molecule has the formula CH4, Very few responded in energetics terms, but about 6% at the start and 16% at the end said, "C and H are more stable as CH4." A very popular response, given by 56% of 16 year olds and 61% of 18 year olds was "C needs four bonds". This answer ignores the hydrogen in the molecule and attributes anthropomorphic behavior to the carbon atom.

Macroscopic Properties and Defects - There are many types of macroscale property misconceptions that exist where one is misattribution of macroscopic properties to atomic scale features[7]. One example was that copper metal is not malleable because "individual copper atoms are malleable". Another related to thermal processing is in explaining why taking a hard, strong copper wire from a hardware store and holding at 600^{o}C for 15 makes the copper a softer, weaker material. Although the formal answer is reduction of dislocation density and recrystallization, a few of the misconceptions proposed by sophomore engineering students included; "atomic bonds are weakened" or "atomic bonds are stretched"[3]. It has been shown that using different pedagogies can impact conceptual change for this type of concept. For the years 2002, 2003, and 2007, gains for this so-called MCI annealing question were 11%, 51%, and 48%. For fall 2002 with lecture-based teaching, the gain was in the low range of 16% which is similar to the FCI traditional teaching value of 20%. When teaching with team-discussions in fall 2003 and fall 2007 the gains increased to 51% and 48%, both values of which are in the middle range and in agreement with FCI gains of 30%-60%. However, an additional change in pedagogy, such as using concept sketching, might be more effective than team discussions alone.

Electronic Properties. - Some topical areas may receive emphasis in the introductory materials course at different schools depending on the needs of their students. Such differences may be revealed by MCI questions that query sophomore engineering student conceptual knowledge of electrical versus mechanical properties of materials as shown in a question: why is aluminum a better electrical conductor than glass[3]. Twenty percent of entering students chose the correct answer, "has more conducting electrons per volume". The most frequent incorrect answer was "has more conducting electrons per volume that move faster than those in glass", where other misconceptions were "has more total electrons per volume", "has electrons which move faster", and "has which move slower"[8]. The misconception here is that electrons move faster in aluminum than glass. A possible explanation for scores may be the fact that there is more emphasis on electrical properties of materials in materials courses.

Atomic Arrangement & Crystal Structure. - An area relevant to materials science is in the geometry area, which students often find difficult is the characterization of points, lines and planes (Miller indices) in crystal structures[8]. A solid understanding of this topic is required to understand a variety of other topics in the course, which include deformation behavior and mechanical properties of metallic systems. When considering the features of a simple cube, such as number of faces and number of edges, the percentage of entering students that chose the correct answer, "6 and 12", was 61%. The most frequent incorrect answer was "6 and 8". Other misconceptions were "4 and 6", "4 and 8" and "8 and 12". These misconceptions are probably due to the fact that students forget to count the four edges, which connect opposite faces of the cube[8]. The underlying origin of the misconception is probably a limited ability to visualize 3-dimensional solid objects. A possible explanation for the low scores may be the fact that there are no introductory design class visualization building activities such as 3-D related technical drawing or computer aided design (CAD).

Method

Students - The MCI was administered to a convenience sample of 318 sophomore engineering students at Arizona State University from 2006–2008. A response was considered a returned test from a single student. The instructors who administered the MCI to their students had no knowledge about the construction of the MCI, nor any knowledge of its content.

MCI Form and Administration - The MCI consists of 30 conceptual questions printed on four separate pages or administered question by question via Blackboard. For each of the 30 MCI items, the respondents indicated the correct response. Data collection forms where none of the questions were answered or the student failed to complete the over half of the assessment were considered to be not missing at random and were eliminated from the analysis.

Data Analysis- An initial confirmatory factor analysis was first used in the entire sample to evaluate whether there was evidence for the 6 factor structure set by the categories listed above as proposed by Krause et al[6]. Using exploratory factor analysis, it was determined whether there was an underlying structure for the 30 items on the MCI in the exploratory factor analysis (EFA) set. The main use of exploratory factor analysis is to confirm hypothesis of factor structure (in our case, pulling out six factors). In measurement research, when a researcher wishes to validate a scale with a given or hypothesized factor structure, they can use one of many extraction techniques. Suppose we had six families comprised of seven people to a family. Now suppose we had everyone randomized together amongst a crowd of non-family members, an exploratory factor analysis would we easily identify and pull them out according to family. This is essentially what an exploratory factor analysis does.

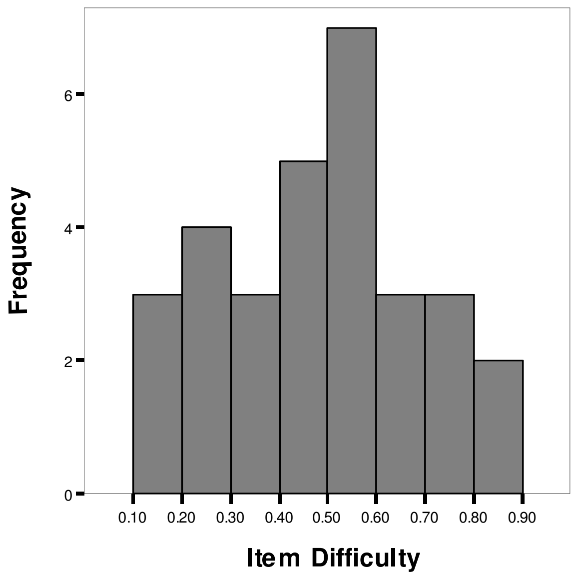
Results

Completeness of Data Collection- Five MCI responses (0.9%) were eliminated from further analysis because they were either completely blank, or because the student failed to complete all or some of the items on the second page. Overall, 98.3% of the 318 MCI forms had data missing from 0–3 of the 30 items. An examination of "missingness" showed that no particular items were favored to go missing. The remaining analyses were therefore based on 318 forms with imputed missing data. Overall, the results of the test had good reliability with Cronbach's alpha of 0.73.

Exploratory Factor Analysis - Even without the evidence from an initial confirmatory factor analysis (CFA), it is hard to conceive that 30 item indicators would reduce to 12 dimensions, which averages only 3.3 items per factor. Instrument development texts recommend far more items per factor. With the EFA data, we staged a series of exploratory common factor models, with solutions ranging from one to six factors. With SPSS v. 14.02, the factoring was principal axis extraction with oblique (varimax) rotation. All EFA programs produce many indices to evaluate such fit. The most widely used include a test of exact fit, the X^2. Because the MCI were conceived around a 6-factor model (according to the categories listed in the lit review), we used the entire sample to perform a 6-factor confirmatory factor analysis, on the full data set. The results of which never coalesced to a six factor solution. Rather, a 12-factor model was extracted with X^2 (435) = 921.51, $p<.001$ (should be nonsignificant); root mean square error of approximation (RMSEA) =.048 (acceptable); and the comparative fit index (CFI) = .77 (should be = .95). Some of the standardized factor loadings were substandard (e.g., .08) and several others were strong but in the wrong direction. Also, there were many substantial correlations (e.g., >.80) among the 6 presumed factors, suggesting considerable redundancy among the claimed factors. In short, the full data set did not support the 6-factor structure proposed by the MCI's developers.

Using a loading criterion of greater than .40, the 7-factor solution showed the simplest and most interpretable structure since five of the twelve extracted factors loaded on with single items (factors 6, 9 10 11 and 12). However, noting Table 1, 5 items failed to load on any of the twelve factors for the varimax rotated factor solutions of less than 0.40 (Q5,Q8, Q16, Q17, and Q22). Some item crossloadings (Q13 and Q 24) making the items somewhat difficult to interpret. Several factors showed modest intercorrelations ranging from.02 to .39. The validity is passable for the factor structure was consistent with the theory hypothesis and the factors could explain 60.50% of the entire test.

Item Difficulty and Discrimination - The items on the MCI were too medium to difficult on average (P = 0.49, SD = 0.20) and had a relatively high average discrimination (D = 0.33, SD = 0.12). The ranges of item difficulties and discrimination index can be seen in Figure 1 and Figure 2 respectively.



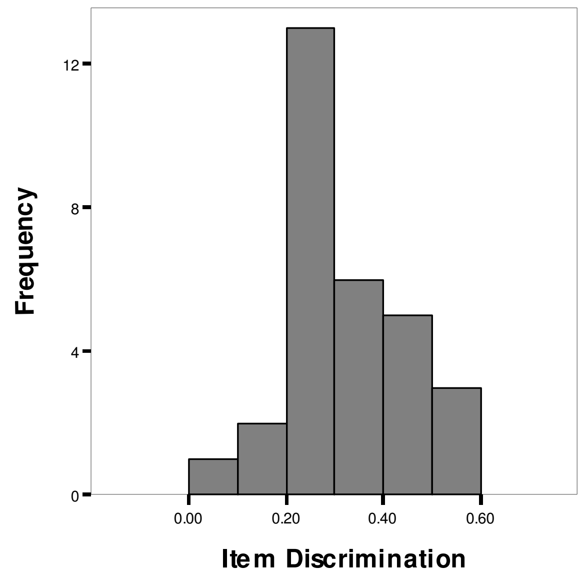


Figure 1. Chart of Item Difficulties.

Figure 2. Chart of Item Discriminations.

Discussion

Our analyses using data collected from a convenience sample of 318 engineering students, did not support the reported theoretical structure of the MCI. The average psychometric properties of the MCI reported here are more likely a function of common cognitive use across most items, rather than original item development (and revision). There may still be kernels of value within the MCI items. Interestingly, students responded to items #1 (crystalline structure), #13 and #14 (electronic properties), and #23 and #24 (macroscopic defects) similarly- factor 1. Factor 2 was loaded upon by items # 18, #19, and #30 which measures defects, but at the atomic level. Perhaps, this is a factor which should be separated from macroscopic level defects, since respondents obviously react differently. Item # 25 and #26 associated with macroscopic level defects loaded on factor 3. Questions #12, #16 and #29 were electrical properties associated with the fourth factor. The fifth factor was loaded by questions #2 (atomic arrangement), #4 (phases) and #9 (crystalline structure), which seemingly have very little to do with each other. Items #7 and #10 loaded upon factor 7 and seem to test solutions, while items #1 and 10 loaded upon factor eight which test atomic arrangement. We found five single-factor structures (item # 3, #20, #21, #27 and #28) that approached a reasonable fit for the MCI data, which will eventually be re-written to fit more with one of the other six factors. Overall, our estimates of how Krause et al[3] had written each item seemingly fell with some disparity into seven factors, rather than the six that were typed in the literature review above.

Students seem to be responding to most of the questions differently, or rather, employing cognitive and background knowledge differently than the item was intended. To cope with this, we shall re-write items so they fit more appropriately into a single definable factor, then retest with a revised version. One advantage of reevaluating instruments is they might be shortened and therefore be more usable. This is especially true for assessments given in classrooms, where instruction time is precious—shorter instruments generally mean greater acceptability, higher completion rates, and less missing data. These advantages have implications for how instruments are subsequently scored. However, scoring is a secondary issue with the MCI. Our findings may be limited by the fact that data were collected from a convenience sample. Whether our sample is representative of other groups of engineers with respect to their knowledge of materials engineering is unknown. The fundamental issue is that the MCI does have some satisfactory psychometric properties (e.g. the good reliability, high discrimination and optimal spread of item difficulties), and, as such, we recommend its continued use in its present form towards *estimating* students' knowledge structure. However, we will move forward with further follow-up evaluations or interviews for a more accurate representation.

Although this study has focused on the MCI, the need to have demonstrated psychometric validity is relevant for any scale that a researcher may choose to use in their work. Before selecting an instrument, researchers and evaluators should determine if the literature provides the necessary information in a variety of areas to assure that the instrument will be applicable to their setting and population. Evidence in the form of a theoretical background, measures of reliability and precision (e.g., internal consistency, test–retest, standard error of measurement), validity (e.g., construct, content, convergent, discriminant, factorial), and usability/dimensionality (e.g., number of items, number of subscales, subscale/ total scoring) were provided in this paper. Only with validated instruments will education researchers will be able to move forward to determine if curricular and instructional innovations truly improve student attitudes towards engineering.

The authors acknowledge the support of this work by NSF IEECI Grant #083641.

Bibliography

1. Griffiths, A. K., and Preston, K. R. (1989, March). An investigation of grade 12 students' misconceptions relating to fundamental characteristics of molecules and atoms. *62nd Conference of the National Association for Research in Science Teaching*, San Francisco, California.

2. Olds, B., Streveler, R., Miller, R., Nelson, M. (2004). Preliminary results from the development of a concept inventory in thermal and transport science. *2004 ASEE Annual Conference and Exposition Proceedings.*

3. ABET (2001). *Criteria for Accrediting Engineering Fields*, Engineering Accreditation Commission.

4. Krause, S. (2003). Assessing conceptual transfer of phase behavior from the domain of chemistry to the domain of materials engineering. *2003 ASEE Annual Conference Proceedings.*

5. Hestenes, D., Wells, M., Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, 30(3): 141-151.

6. Krause, S., Decker, J., Niska, J., & Alford, T. (2002). A Materials Concept Inventory for introductory materials engineering courses. *National Educators Workshop Update 2002*, 17, 1-8.

7. Krause, S. (2007). Diagnosing students' misconceptions on solubility and saturation for understanding of phase diagrams. *2007 ASEE Annual Conference Proceedings.*

8. Krause, S., Birk, J., Bauer, R., Jenkins, B., and Pavelich, M. (2004). Development, testing, and application of a chemistry concept inventory. *34th ASEE/IEEE Frontiers in Education Conference.* Savannah, GA.

9. Peterson, R. F., Treagust, D. F., Garnett, P. (1989) Development and application of a diagnostic instrument to evaluate grade-11 and-12 students' concepts of covalent bonding and structure following a course of instruction, *Journal of Research in Science Teaching*, 26(4): 301-314.

Appendix 1

Table 1. Table of Factor Loadings based on Varimax Rotations.

	Factors											
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
Questions												
q1								0.75				
q2					0.75							
q3										0.78		
q4					0.48							
q5												
q6	0.45											
q7							0.75					
q8												
q9					0.54							
q10								0.68				
q11							0.48					
q12				0.72								
q13	0.48			0.55								
q14	0.64											
q15				0.43								
q16												
q17												
q18		0.69										
q19		0.60										
q20						0.77						
q21									0.73			
q22												
q23	0.63											
q24	0.41											0.40
q25			0.86									
q26			0.84									
q27												0.78
q28											0.84	
q29				0.41								
q30		0.49										

Appendix 2

NAME__________________________

Beta Test: Materials Concepts Inventory

Answer
(choose only one)

1. Atoms in a solid: _______
    a) Cannot move, only electrons can
    b) May move through vacancies in a crystal lattice
    c) May move in the spaces between atoms in a crystal lattice
    d) Can move through both vacancies and in the spaces between atoms in a crystal lattice
    e) None of the above

2. If atomic bonding in metal A is weaker than metal B, then metal A has: _______
    a) lower melting point
    b) lower brittleness
    c) lower electrical conductivity
    d) lower thermal expansion coefficient
    e) lower density

3. Compared to one mole of iron atoms, one mole of oxygen molecules has: _______
    a) the same number of atoms
    b) more atoms
    c) less atoms

4. Nickel can exist as: _______
    a) solid only
    b) liquid only
    c) gas only
    d) liquid or solid only
    e) liquid or solid or gas

5. The melting points of most plastics are lower than most metals because: _______
    a) covalent bonds are weaker than metallic bonds
    b) ionic bonds are weaker than metallic bonds
    c) Van der Waals bonds are weaker than metallic bonds
    d) covalent and Van der Waals bonds are weaker than metallic bonds
    e) ionic and Van der Waals bonds are weaker than metallic bonds

6. Glass transmits light because: _______
    a) it is very brittle
    b) it has low crystallinity
    c) it has high crystallinity
    d) it doesn't interact with electrons in the glass

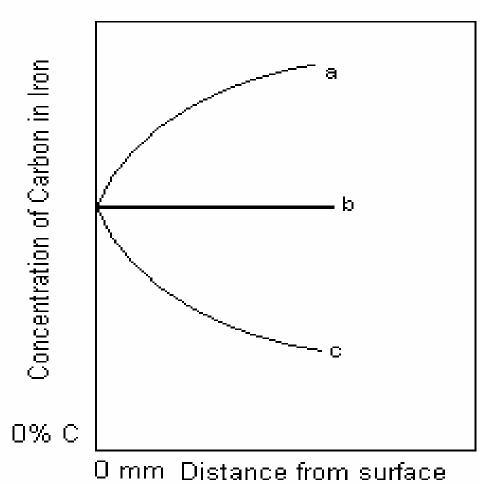
7. Marble feels colder than wood: _______
    a) because its temperature is lower
    b) marble is a better thermal conductor
    c) atoms are more tightly bonded in wood than marble
    d) wood is a better thermal conductor
    e) the water in wood holds in the heat

8. In comparing amorphous SiO2 (glass) to crystalline SiO2, the amorphous SiO2 has: _______
    a) higher thermal conductivity
    b) higher density
    c) higher coefficient of thermal expansion
    d) higher stiffness
    e) all of the above

9. The number of lines that connect opposite corners of a cube through its center is: _______
    a) 2
    b) 4
    c) 6
    d) 8
    e) 12

10. In a cube there are *** sides and *** edges. _______
    a) 4 and 6
    b) 4 and 8
    c) 6 and 8
    d) 6 and 12
    e) 8 and 12

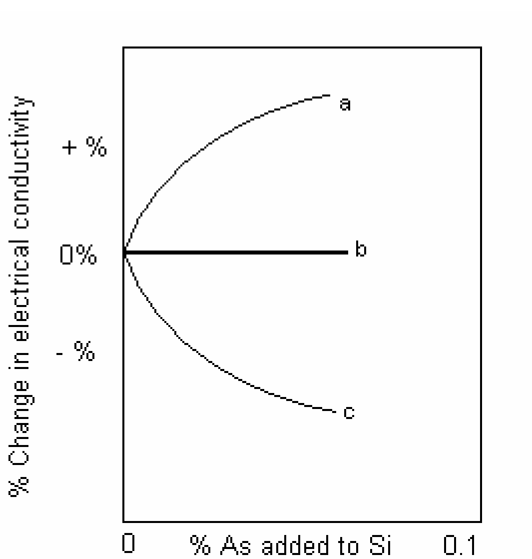
11. If a slab of carbon is placed on a clean surface of iron at a high temperature, the carbon will diffuse into the iron. After a short time the profile of the carbon concentration versus length of diffusion into the iron looks like: _______



12. In a galvanic cell found in the corrosion process: _______

a) electrons move in the electrolyte by being attracted to the protons in solution
b) electrons and protons flow in opposite directions in the electrolyte
c) electrons flow through the electrolyte from the anode to the cathode
d) electrons are drained from the cathode resulting in a lower concentration there
e) electrons move from anode to cathode through an electrically conductive connection

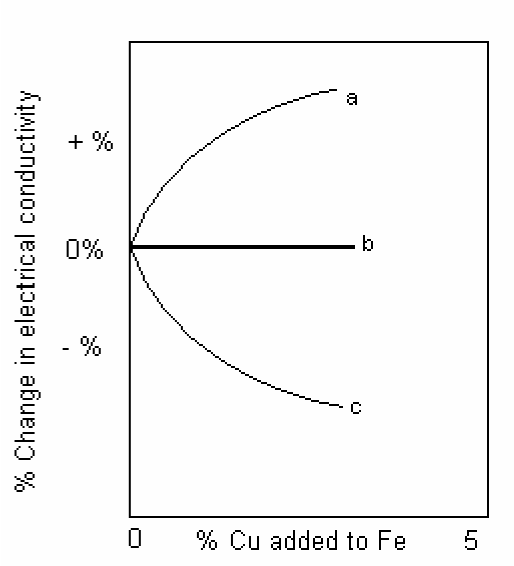
13. Addition of a very small amount of impurity such as arsenic to a pure semiconductor such as silicon will cause a change in conductivity as shown in the graph. _______



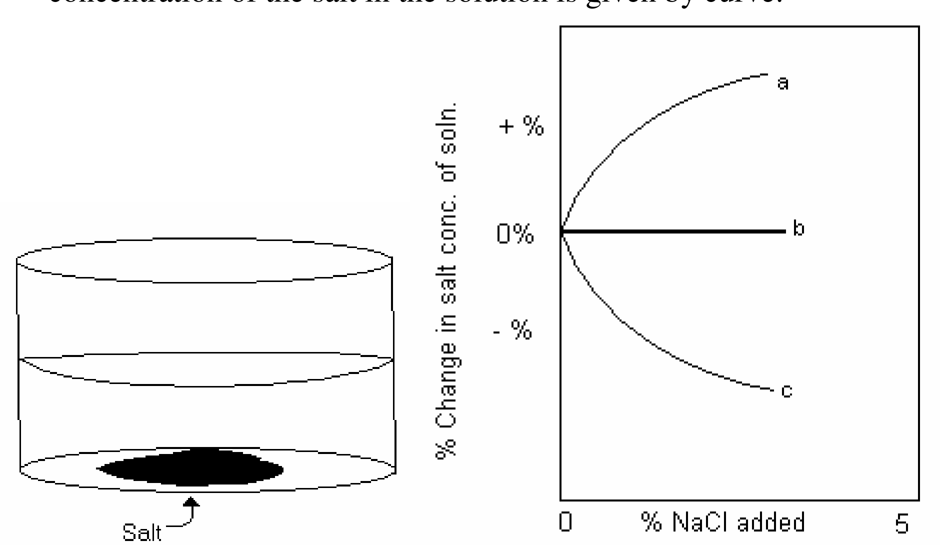
14. Aluminum is a better electrical conductor than is glass because aluminum: _______

a) has more total electrons per volume
b) has more conducting electrons per volume
c) has electrons which move faster
d) has which move slower
e) has more conducting electrons per volume and they move faster than those in glass

15. If a small amount of copper is added to iron the electrical conductivity will change as shown: _______



16. When three tablespoons of salt are mixed into a glass of water and stirred, about a teaspoon of water-saturated salt remains on the bottom. If a small % of salt is slowly added to the glass while stirring the solution, the change in concentration of the salt in the solution is given by curve: _______

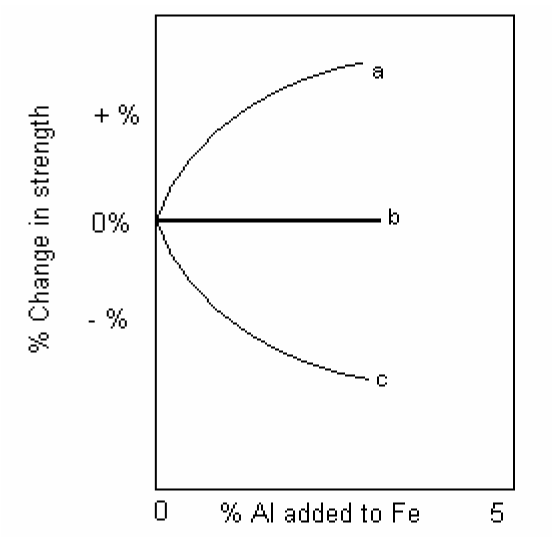


17. If the melting point of metal A is greater than metal B, then when a few % of metal A is added to metal B, the melting point could be given by: _______
   a) may increase
   b) may decrease
   c) can increase or decrease

18. After a piece of copper wire from a hardware store is heated it becomes softer. This is because: _______
    a) the bonds have been weakened
    b) it has fewer atomic level defects
    c) it has more atomic level defects
    d) the density is lower
    e) there is more space inside the crystal lattice

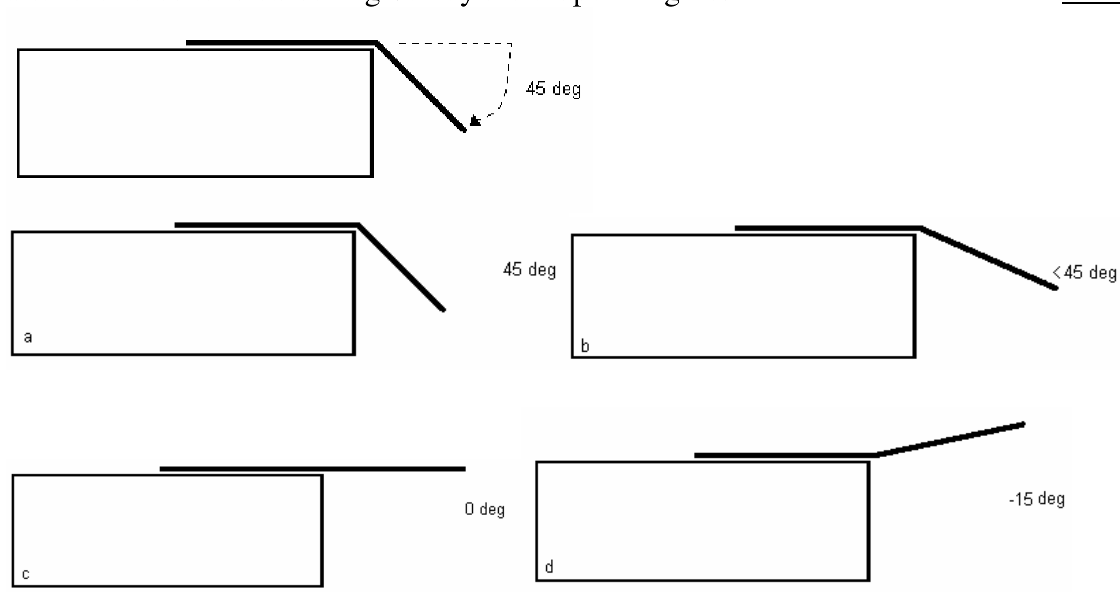
19. If a rod of metal is pulled through a tapered hole smaller than the diameter of the rod, the strength of the metal in the rod increases. This is because: _______
    a) the density has increased
    b) there are more atomic level defects present
    c) there are less atomic level defects present
    d) the bonds have been strengthened
    e) the bonds have been compressed

20. The addition of a few % of aluminum to iron will change the strength of the material as shown below: _______



21. If a pure metal has mixed in 1% by volume of spherical particles of a different, harder material, then the resulting material would be hardest if the particles had a size of: _______
    a) 100 microns
    b) 10 microns
    c) 1 micron
    d) 0.1 microns
    e) 0.01 microns

22. If a small steel rod, 4 inches long and 1/16 inch in diameter is rigidly attached to a block and a force is applied to the end of the rod that causes the rod to deflect to an angle of 45 degrees, the final position of the rod after the force is released is given by the shape in figure:



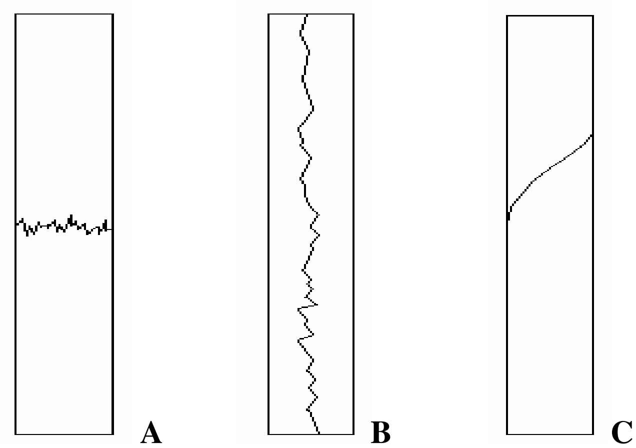
23. Materials which have significantly different strengths in tension and compression are:

a) metals
b) ceramics
c) polymers
d) metals and ceramics
e) metals and ceramics and polymers

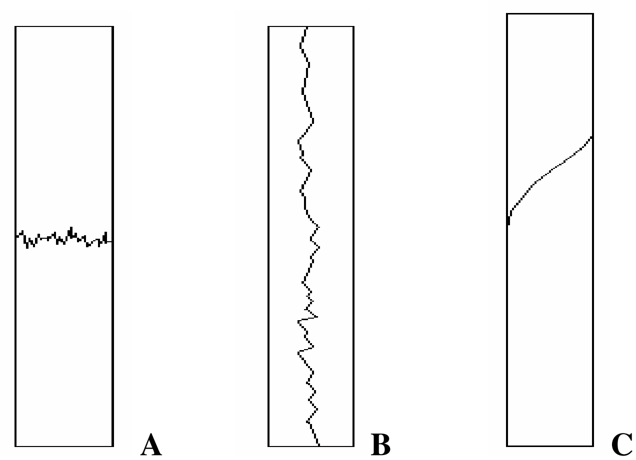
24. Why does copper dent when hit with a hammer whereas glass breaks?

a) copper has higher density
b) copper has stronger bonding
c) copper is more crystalline
d) coppers atomic level defects move more easily
e) copper has weaker bonding

25. When a rod of ductile material like a metal is pulled in tension, the pieces after fracturing will look like: _______



26. When a rod of brittle material like a ceramic is pulled in tension, the pieces after fracturing will look like: _______



27. When two molecules react in the formation of a polymer: _______
   a) There is a net amount of heat absorbed by the reaction
   b) There is a net amount of heat given off by the reaction
   c) There is no net heat absorbed or given off by the reaction

28. The following materials are polymers: _______
   a) human skin
   b) vinyl car seat
   c) tree limb
   d) all of the above
   e) a) and b) above

29. A polymer rubber band can stretch more than a metal paper clip because: _______
a) Covalent bonds along polymer chains can stretch and rotate
b) Covalent bonds along polymer chains can rotate and the Van der Waals bonds between chains allow chain slippage
c) Covalent bonds along polymer chains can break and the Van der Waals bonds between chains allow chain slippage
d) Covalent bonds along polymer chains can stretch and the Van der Waals bonds between chains allow chain slippage
e) Covalent bonds along polymer chains can rotate and break

30. In the figures shown below the same force is applied to a composite which is reinforced with fibers running in different directions.
The composite that deforms the least is: _______