

**AC 2007-2459: STUDENT UNDERSTANDING OF STATES OF STRESS IN
MECHANICS OF MATERIALS**

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Reviewer's Comments

1.

- a) The manuscript is not organized and poorly written.
- b) While it can be expanded to topics other than "mechanics of material," the lack of proper presentation of the methodology makes it difficult to understand to educators outside this field.

2.

- a) The paper exhaustively discusses the interview process for a small group of students. It concludes with a discussion of their analysis of stresses in a member exposed to three different loading cases.
- b) This paper will be of interest to those involved with solid mechanics (Mechanical and Civil engineers).
- c) There are some grammar and spelling issues that need to be addressed.
- d) The abstract should indicate the study outcome.
- e) I think the author overstates the case by saying students "consistently show a deep and widespread lack of understanding of the most basic principles." For example heat transfer is discussed and how heat is viewed as a substance. As we know this view is reinforced by everyday language (for example you keep the oven closed to 'keep the heat in'). And, these problems are perpetuated in classes that talk about 'heat flow' instead of 'transmission'.
- f) The paper begins by making a case for misperceptions about underlying causes, but the outcome of the interviews seems to focus on the issues arising from students unable to extrapolate beyond theory.
- g) I find it interesting that the author is trying to systematize misunderstandings, but does not use any exhibits to summarize, or illustrate the findings. This will also make it difficult to make this an interesting presentation.

4.

- a) Provide an Abstract for the paper.
- b) Well organized manuscript.
- c) Good Literature Review section on the subject.
- d) Existing concept has been taken and applied to "States of Stress in Mechanics of materials.
- e) Explain the "Delphi process", is it the same as "Demonstration interviews"?
- f) Provide a short summary or conclusion for the reader easily grasp after reading the manuscript.

Responses to Reviewer's Comments:

1.

- a)** Portions of the paper have been rewritten and reorganized to make the paper easier to follow and to address specific reviewer comments.
- b)** Additional sub-headings were included in the Results section to emphasize that in this study a well-defined methodology was a desired result. A summary conclusion was included to clarify key aspects of the paper.

2.

- a)** This comment did not require specific changes.
- b)** This comment did not require specific changes.
- c)** The paper was proofread again and grammatical and spelling issues were corrected.
- d)** An abstract was provided at the beginning of the paper to indicate study outcomes.
- e)** The statement was rewritten to read, "...consistently show that a majority of students cannot qualitatively analyze the most basic situations. These difficulties are most often attributed to a lack of deeper, conceptual understanding of the topics."
- f)** The study objective and results discussion were clarified to emphasize more the preliminary nature of this pilot study. Possible guidelines for future research to identify specific misconceptions were included in the Implications and Conclusions section.
- g)** Because the results are largely qualitative, sentence-level statements, a figure or table does not seem to be an appropriate way to summarize them. A brief summary of the results was included in the first paragraph of each subsection in the Results section, as well as an overall summary of the study in the Conclusion section.

4.

- a)** An abstract was provided at the beginning of the paper to indicate study outcomes.
- b)** This comment did not require specific changes.
- c)** This comment did not require specific changes.
- d)** This comment did not require specific changes.
- e)** The irrelevant reference to the Delphi process was removed.
- f)** A Conclusion section was added at the end of the paper.

Student Understanding of States of Stress in Mechanics of Materials

Abstract

Students often have far less conceptual understanding in core engineering courses than faculty assume. The first wide-spread application of the Force Concept Inventory in the early 1980's highlighted students' lack of understanding in fundamental physics principles. Recently, educators have been reevaluating student understanding of concepts in the standard science and engineering curriculum using concept inventory instruments in topics such as thermodynamics, mechanics, and fluid mechanics. The objective of this study is to develop a methodology to observe specific examples of difficulty in conceptual understanding which could be used to infer specific student misconceptions. To achieve this task a pilot study was undertaken using students in mechanics of materials (alternately known as strength of materials). The general topic of stress states was chosen for more intensive study. Exploratory interviews using three basic loading cases, pure axial tension, pure shear, and a simply supported beam in bending, revealed that the students interviewed were unable to relate internal stresses to loadings. The students had just completed a summer session of mechanics of materials, but most were unable to define stress. They rarely differentiated between internal and external forces when answering conceptual questions or performing calculations. These difficulties suggest student misconceptions within the topics of stress, and stress distributions. Results of this study augment the poor results that university educators find when implementing concept inventory tests, while providing some general guidance in developing new curriculum materials.

I. Introduction

It has been shown that most students do not gain fundamental knowledge in introductory science and engineering courses.¹ The high graduation rates and successful completion of standardized tests such as the Fundamentals of Engineering exam show that the majority of students graduating from accredited universities have some form of understanding of the subjects, but concept inventories and student interviews consistently show that a majority of students cannot qualitatively analyze the most basic situations. These difficulties are most often attributed to a lack of deeper conceptual understanding of the topics. Application of validated concept inventories also suggests that standard instruction does not significantly improve student understanding of these basic concepts. In order to address these issues new instructional methods are being developed. These new approaches are based on theoretical and applied studies of why some concepts are more difficult to learn than others.

II. Literature Review

A simple theory that explains many aspects of student learning and suggests plausible solutions is Micheline Chi and Rod Roscoe's theory of misconceptions.² Building upon the commonly accepted theoretical backgrounds of constructivism and Piaget's theory of

cognitive development, Chi and Roscoe define misconceptions as a “type of naïve knowledge [that] seems highly resistant to change.... [which] persist strongly even when they are confronted by ingenious forms of instruction.” A commonly used example is that many students think of heat as a substance. This is classified as a misconception because it pervades students’ entire mental models of thermodynamics, and because it requires students to create a new ontological category—one that Chi and Roscoe call “emergent processes”—in order to form a correct model. The process of creating new mental categories is difficult even when undertaken consciously, but Chi and Roscoe suggest that most students are unaware of when it is necessary.

Concept change, as the process of creating new categories and rearranging mental models is known, requires that students be aware of its necessity. Traditional lecture- and homework-based education, however, does not usually identify misconceptions. A student who believes heat is a substance will interpret lectures about heat transfer in terms of the substance heat flowing from object to object. This will happen even while the implications of the lecture contradict the students’ internal representations of the phenomena. This persistence of false information is one of the characteristics of misconceptions defined by Chi and Roscoe. Students are more likely to misinterpret, alter or ignore new information that contradicts their mental models than to adjust the mental model itself.

The Force Concept Inventory (FCI) inspired researchers to create concept inventories in a range of different fields. In recent years concept inventories have been developed for topics such as dynamics ³, strength of materials ⁴, and thermodynamics ⁵. The focus of this research has been to demonstrate the inventories’ statistical validity and reliability. This process most often involves administering the inventory to similar groups of students, verifying responses with interviews and student and faculty review procedures such as attitude-assessment interviews or surveys.

While concept inventories are a necessary tool in assessing individual’s and group’s misconceptions, they can only collect data in one dimension. If every sophomore student in the nation were to take the Dynamics Concept Inventory, we would know a great deal about how many students’ understandings of dynamics differ from Newtonian physics, but we would not know anything about their understandings, how they were developed, how persistent they are or how to adjust their reasoning. Therefore, a combination of qualitative and quantitative research methods are required to identify, describe and measure students’ misconceptions.

A particularly successful methodology for addressing student misconceptions has been developed by the University of Washington’s Physics Education Group. In addition to large-scale applications of validated concept inventories and collecting faculty input, the UW Group uses what they call “demonstration interviews” to elicit student understandings of the topics studied. In demonstration interviews, an individual student is “confronted with a simple physical situation and asked to respond to a specified sequence of questions.”⁶ These interviews are constructed around Jean Piaget’s famous clinical interviewing process in which the primary purpose is to draw out the

interviewee's thinking without applying the interviewer's own understandings. The UW Group has applied this methodology—and shown statistically significant improvement after applying the designed curricular modules—to topics such as one-dimensional velocity⁶; the work-energy and impulse-momentum principles⁷; Archimedes principle⁸ and the ideal gas law.^{9, 10}

III. Purpose of Study and Research Questions

This study is an application of the research philosophy theoretically grounded by Chi and Roscoe, and best exemplified by the UW Physics Group to the relatively new subject matter of mechanics of materials. This preliminary study aims primarily to develop a practical, effective methodology to identify student misconceptions within the students' own contexts. While the UW Physics Group's basic research model is being used, the application to a different type of subject matter and a different set of basic assumptions necessitate the development of a new methodology.

The general question under study is “how do students understand stress states in mechanics of materials?” This study is the first in a series directed at answering that question and designing curricular materials based on those findings. This portion of the study is intended to guide the research methodology of later portions and to generate preliminary findings in student understanding which will be used to guide future interviews aimed at identifying specific student misconceptions.

IV. Methods

In the following section the data collection will be explained first by describing the sample selection and the interview procedures. Then the data analysis procedures will be explained.

The study sample consists of three students who were chosen by convenience from a summer session of Mechanics of Materials at Washington State University. Six students were approached with a brief description of the research and offered a \$20 incentive gift certificate to participate in an hour-long interview. The original group of six were chosen by their instructor as likely to be willing to be involved in the study.

Misconceptions in similar fields have been shown to be nearly universal in classroom settings ranging from honors high schools courses to upper-level college courses in large universities^{7, 10-13}. Though this sample will not be sufficient to describe the student population, previous knowledge of the population allows researchers to make inferences about the sample. It can be inferred that only exceptional students differ significantly in their conceptual understanding, and that a student's performance in class is not correlated with their conceptual understanding^{6, 14}.

The selection of the sample was intended to help situate the study. Each student interviewed received a B or better in their summer session, and were described as “good

students.” Obviously, characterizing what qualities make “good students” is beyond the scope of this study, but it is enough to know that these students made a good impression on their professor through their appearance of attentiveness, effort and natural proclivity to the subject matter. Conclusions drawn specifically about these three students’ understandings of stress states will have an increased effect on engineering faculty. It would be a significant finding to describe even one passing student with an insufficient conceptual understanding of stress.

Although high-performing students were chosen to increase the impact of the study’s findings, it is important to emphasize that any students could have been selected for the purposes of this research. It is not assumed that these three students represent any population other than themselves. It had been induced from theory that very few students in any class would have a conceptual understanding of stress states, so case studies were undertaken with the goal of finding and describing their particular understanding and approach to solving problems.

Possible threats to internal validity resulting from the selection process include diffusion, maturation, and experimenter effects. Diffusion is the spread of information by research participants between their involvements in the interviews. This sharing of information may allow a particular student to be more prepared for the interview than other students. Diffusion is not considered a serious threat because the students interviewed did not appear to know each other, and in the time-frame of the interviews (all were performed within three days), significant changes in conceptual understanding are unlikely. For this same reason, maturation is not considered a serious threat. The interviews did reveal a lack of consistency and a growing conceptual awareness apparently caused by the interview itself, however, that will need to be accounted for in further studies.

The primary threats are experimenter effects. Expert-novice theory suggests that interviewers who could be considered experts in mechanics would have inherently different understandings of the subject, and would probably be unable to phrase appropriate questions to track the novice’s understanding. These problems were consciously addressed by focusing the interviews on responding to the interviewees responses. Also, as the primary intention of these interviews was to compare students’ ways of thinking with professors’, researchers were sensitized to differences in vocabulary, phrasing, symbolic representation or gesticulation that could stem from a differing student conception. It is questionable if the primary interviewer is an expert in this content area. As a graduate student focusing on a different area of civil engineering, he has had limited class work in the area and no direct applications of the knowledge. Finally, the true threat of experimenter effects biasing the conclusions of the study would imply that students’ conceptions of stress states are so different from the researchers that they are unrecognizable. This extreme difference has not been observed in any comparable research and is not expected from theory.

The exploratory, open-ended interviews were centered on physical demonstrations of loading conditions. The basic structure of each interview was the same; a wooden beam and dowel were used to demonstrate three different loading states, and students were

asked to describe the stresses developed from those loading states. The three loadings under investigation were pure tension (demonstrated by pulling outwardly on the dowel), pure shear (demonstrated by twisting opposite ends of the dowel), and bending (demonstrated by supporting the beam with pins on either end and pressing down on the center). It should be noted that in none of these cases was there visible deflection or failure of the demonstration members. The loadings were simply described, and demonstrated repeatedly by hand.

Interviews were performed in a deliberately non-standardized, outcome-oriented manner. The purpose—to gain descriptive, unbiased data on the students' reasoning—was clear, and a general approach was suggested by Herbert Ginsburg's description of Piaget's clinical interviewing procedure.¹⁵ The personnel performing the interviews were different in each case. In order to establish an agreed upon interviewing procedure, the first interview was administered by all three researchers, with Dr. Brown leading and asking most of the questions. The second interview was performed by a single interviewer, Devlin Montfort, and the third was performed by Devlin with Dr. Findley supporting.

In each case, the interviewee was seated at the end of a conference table in the civil engineering department's conference room. Interviewers sat on either side, and supplied the student with scratch paper. The demonstration materials were placed on the table between the interviewers and directly in front of the interviewee. The interviews began with a brief discussion of the research, and the presentation and signing of the IRB form. Each interview was audio and video recorded. The interviews each took approximately 50 minutes, with 10 minutes at the end to clarify the situations and answer any content questions the students had after the interview. These sessions were also recorded and considered data, though not specifically evidence of the students' own understanding.

The first step in analyzing the interview data was transcribing the interviews from the audio recordings. Each interview was transcribed by the primary researcher and initial impressions of patterns of misconceptions were formed. The transcriptions include annotations of tone of voice and pauses. These annotations were confirmed and expanded by a secondary transcription process using the video of the interviews. The primary researcher watched each interview video and annotated the printed transcripts by hand sufficiently to describe the interviewees general physical attitude at each moment in the interview. The primary purpose of this process was to distinguish between pauses in speech where the interviewee was not communicating from pauses where the interviewee was writing or working on their note sheet. These note sheets were collected, scanned, and included in the qualitative analysis later.

Once the transcripts were transcribed and annotated, the researchers met to discuss and recapitulate the first impression of the interviews. These meetings were primarily brainstorming sessions of impressions that would need to be checked against the actual interviews during later analysis. There were three such meetings: in the first the researchers decided upon the methodology and meeting schedule, in the second the transcripts were delivered and a section of interview was watched and discussed.

Approximately 15 minutes of interview was discussed over an hour with the purpose of comparing analysis and observation methods among the researchers. In the third meeting each of the individual researchers brought their independent interview analysis. These were collected, and a new analysis was undertaken.

Each researcher performed a qualitative pattern-seeking analysis using qualitative data analysis software. The purpose of beginning the analysis independently was to broaden the analysis, and to make a basic check about the reliability of this analysis method. In this case, each of the three interviewers formed the same general annotation groups, but coded different sections of the interviews with those annotation groups. Each researchers' analysis was incorporated in to the main analysis document, and the primary conclusions were checked against the interview transcripts.

V. Results and Discussion

The following discussion of the results will be divided into two main sections: the first will discuss the findings relating to the interview and analysis methodologies, and the second part will present and discuss some of the preliminary results in student understanding.

Preferred Methods for Interviews in Areas of Student Difficulty

The interviewing process outlined by Ginsburg and Piaget worked well in this non-standardized application, but the analysis could be deepened if some sections of the interview were more standardized.

The tone of the interviews was informal with frequent breaks in the intensity of questions. Students were encouraged to think aloud, and affirming statements or gestures were used to elicit further elaboration as well as clarifying questions. If a student began to appear uncomfortable about their statements, the interviewers attempted to relax them, but continued in the line of questioning.

The interviews generally proceeded as a slow progression from open-ended to more leading questions. Interviewees were asked with each leading case to describe the stress states. Depending on the response, more structured questions were asked in a vein of discussion until progress slowed due to student lack of knowledge, or the need to approach the student's conceptions from a different angle. Most questions were framed to ask students to describe a physical phenomenon or their probable approach to solving a problem posed by the interviewers.

The most pervasive and important methodological finding from analyzing the interviews was the importance of repetition. Repeating and rephrasing questions is vital to the goal of uncovering the student's particular understanding for the following reasons: it allows the researcher to form and test hypotheses regarding the student's understanding, which is a vital component of Piaget's clinical interviewing process; it bypasses many possible miscommunications caused by vocabulary or interviewer bias and forces the interviewer

to use varied, non-standard terminology; and because the boundaries of knowledge are not concrete or fixed, it allows the researcher to qualitatively rate the strength of the student's knowledge.

Throughout the interview process the interviewer is constantly forming and revising his idea of the student's understanding. For example, in the beginning of her interview Kate answered the first few questions quickly and confidently. When asked "Can you describe, or how would you think about the stresses that would develop," Kate paused, but then asked a clarifying question about where to describe the stress. Because stress is partially determined by the area under question, this brief confusion actually indicates competence in the material. The interviewer allowed Kate to continue her reasoning and she eventually stated, correctly, that "...this square would be under tension on the horizontal..." Although Kate's understanding of this concept isn't as flexible as an expert's might be (indicated by the hesitation to answer the general question), at this point it appears that she has a multi-layered and robust understanding of how the forces demonstrated result in stresses in the member. In order to test the hypothesis that the facility Kate had shown in answering the first question indicated a deeper understanding, the interviewer then commented on how quickly Kate had answered the question. Her reply, that "for all the problems we did in class that was basically the first thing you had to do. Look at the situation and see if you had just a little square how that square would deform," showed that Kate's understanding might be more computational than conceptual, so a new hypothesis was formed. This hypothesis, that Kate relied on imagined deformations to infer internal stresses was tested with further questions, and lead to more hypotheses and more questions.

In the process of comparing a student's understanding of a topic to your own, it is all too easy to assume that superficially similar statements indicate deeper commonalities. Repetition of questions, however, can prevent these faulty assumptions by forcing both the interviewer and the student to rephrase their statements. For example, in Stan's interview he related axial tension to turnbuckles on a cable. When asked if he made any adjustments to his mental model if the material wasn't a cable, he responded "In the basic deal of just what, what type of force we're dealing with no." This answer, given quickly and confidently, suggested to the interviewers that Stan agreed with their definitions of stress as a force over an area. Under further questions, however, Stan said "Uhm, if I was then considering...what might *happen* as a result of that stress I'm gonna start taking a look at the grain, grain angles." This response reveals a basic vocabulary difference—Stan apparently uses the words "stress" and "force" interchangeably—which may or may not be significant, but the sudden jump from the theoretical discussion to the extremely practical considerations of "grain angles" indicates that Stan's reasoning was quite different from the interviewers'.

Repeating, rephrasing and posing the same questions in relation to different example situations is vital to gauge the persistence of the students' knowledge. During the bending beam portion of Kate's interview she concluded "and then you'd have internal...forces counterbalancing that [the beam's deflection]." The idea that internal forces during deformation resist external loadings is the most important foundational

concept in mechanics of materials, and Kate's obvious uncertainty in this statement led the interviewer to pursue it. It can be difficult sometimes to state an idea involving paired words like external and internal, even if the concept is mentally clear. In the next ten minutes the interviewer asked about internal forces in the contexts of free-body diagrams, failure states, deformation, and the words "stress" and "force." Only at the end of this series of questions did it become clear that Kate's difficulty was in distinguishing external and internal forces.

Though the three students interviewed ranged in levels of comfort with both the material under discussion and the interview process, they all expressed concern that they make correct statements. In many cases the students approached open-ended questions as if there were a single, correct answer. Kate in particular expressed concern and frustration when she was uncertain of the validity of her answers, saying "Were you trying to prompt a specific answer from me?" after a particularly focused line of questioning.

Areas of Student Difficulty in MoM

These students received A's and B's in their Mechanics of Materials (MoM) course, but the understandings of mechanics of materials expressed in these interviews is significantly different from what would have been described in the lectures or homework. The following section will discuss the two primary themes of the interviews: students' reliance on equations and memorization, and the most persistent and common of the many difficulties students expressed with the content of the interviews.

In many cases through all three interviews the students responded to conceptual questions by either quoting or searching for an equation. Most of the equations the students referred to were only tangentially related to the questions. One of the most interesting examples of this was when Kate was first asked about the bending beam situation. She was asked "...can you describe the stress in the beam under that loading?" She first responded by describing the deformation, which was typical of her approach but not a direct answer to the question. She then volunteered information for the first time in the interview by saying, "Do you want to know stuff about, like first and second derivatives will give you slope and greatest deformation?" This surprised the interviewer because these complex equations are often considered one of the most difficult parts of the Mechanics of Materials course. Eventually, the interviewer responded, "No. It's just enough that you, that comes to mind...How are those related to stress? For you?" Kate tried to answer this question, but is unable to finish a line of reasoning and says "let's see if I can remember the equations." She then spent approximately a minute writing out the equations to describe the beam's deflection, once again avoiding any conceptual discussion of stress and loading.

Each student remembered a few equations, but it appeared as if they weren't related to the conceptual background of the course. Equations were often misapplied, such as when Kris reasoned that the shear stress would be equal across the cross-section "because, isn't the equation just...[laughing slightly] tau equals the v over a ?" (This is used as a gross simplification based on the faulty assumption that shear stress is equal across a cross-

section, and therefore shouldn't be used to try to describe the shear stress distribution across a cross-section.) Stan also used the same faulty reasoning when asked to describe the shear stress distribution on a face. He revealed a possible underlying cause for this common mistake; he said that his strategy for answering conceptual questions is usually "...to just go ahead and take a look at the equation." For Stan, at least, his conceptual understanding of the topic is dependent on his recall of the appropriate equations.

The students' equation-based, algorithmic approach to mechanics of materials produces some predictable and common difficulties with the content itself. While the equations probably do cover all the conceptual content of the course, this is only possible through skillful interpretation. As shown in the previous quotes and examples, these students did not differentiate between internal and external forces unless asked specifically to do so. This difficulty is predicted by the fact that internal and external forces are not usually differentiated symbolically in the equations: F is force whether it is caused by a brick or an internal reaction. In general, the students did not relate reactions to their causes. Kate, for example, expected the bending beam to break with a vertical crack starting at the outside of the bend and propagating inward. She did not realize that her description of the forces and stresses involved did not involve any possible causes for such a crack, however, even when confronted directly with the contradiction.

VI. Implications

The clinical interview is sufficient to reveal student reasoning and understanding in the content of foundational engineering courses. It requires certain skills to conduct the interviews and analysis, but if those skills are applied every interview can produce valuable data.

It is possible that the setting or rapport of the interviews prevented students from fully expressing themselves. It is, in fact, supported by the transcripts and videos of the interviews that students were uncomfortable and attempted to frame their responses toward an idealized "correct" response. This fact however does not invalidate the conclusions drawn from the interviews, but helps to sharpen their focus. Students do not learn or perform in a vacuum, and awareness of the context they perceive in these interviews may reveal a great deal about their understandings of mechanics of materials as a subject. For example, each interviewee was told repeatedly that the students' reasoning was not being evaluated, but recorded. Two of the interviewees were even told that in most cases, there was no single correct answer, and the primary interviewer consistently expressed his own confusion about the topic. Even after these repeated statements, each student exhibited worry that they would make a mistake. The obdurate persistence of this belief—that the interviewers were evaluating the students in a right-or-wrong environment—indicates the existence of a student culture. Further interviews with these or other students could be undertaken to examine their own perceptions of the culture, as well as to potentially identify key factors in establishing that culture.

While this slight tension in the interviewees may interfere with the free-association, first-intuition type of answers we expected at first, it is actually probably beneficial. In the

first place, it is indicative of the students' overall attitude toward the subject. Secondly, the intensity of student thought provides more useful data than offhand consideration would. The responses Stan, Kate and Kris give—especially those answers proceeded by stalling, hemming and hawing—represent the best they could do at that time. Each interviewee was led to stating two of their contradictory beliefs in close proximity. In each case the student noticed the contradiction on their own, and attempted to adjust their statements. None of the students were able to reconcile their beliefs even with further input from the interviewers. This difficulty can be explained by Chi and Roscoe's definition of a misconception: the student's models for understanding stress states were flawed in a fundamental way, and even when the beliefs resulting from that model were directly contradicted, the students continued to express confusion.

The patterns of student difficulties may outline some of their misconceptions in this topic. For example, even after completing a course about how external loads result in internal stresses, students expressed hesitancy to distinguish between internal and external forces, coupled with a belief that the minimum stress is always farthest away from the point load. It is important that the three interviewed students had the same difficulties, but in order to be evidence of a misconception it must also "seem highly resistant to change," as Chi and Roscoe define it. It is unlikely that these patterns of student misunderstandings simply indicate the more difficult portions of the course: first because these are some of the core ideas of the class and the students interviewed displayed mastery of more complex ideas in the content area, but also because the interviewers were unable to clarify them. In the example above where Kate believed a crack would form, but did not believe any stresses would be present which could cause it, the interviewer explained the stress states after the end of the formal interview. Kate responded, "There, there was a point where I was like, uh, it would make more sense if it were horizontal [in the direction of the crack] but I didn't, I didn't have anything else to base it off of." When faced with a contradiction in her reasoning, and even after being provided the answer in her own terminology, Kate was unable to resolve the contradiction. This suggests that the underlying cause of the difficulty is not a lack of knowledge, but the presence of a persistent, incorrect belief—what Chi and Roscoe would call a misconception.

Obviously more interviews are needed. If some portions of the interviews were standardized it would be more possible to compare analyses between students. Further interviews with a larger sample of students would be directed at identifying the underlying beliefs that create the student difficulties observed in these interviews. These interviews would have the same basic format, but would focus on statements of fact as opposed to specific loading cases.

These three students are sufficient to make the statement that conceptual understanding is not required to succeed in their course. None of the interviewed students were able to define or use the concept of "stress," which was most likely covered in the first lecture of the course. Their reliance on equations, memorized processes and incompletely understood relations may interfere with their conceptual understanding, but it apparently aids in successfully completing their homework and exams.

This disparity suggests again that computational ability may not be related very strongly to conceptual understanding. This possibility has wide-reaching implications in assessment, but it would also affect future research in this area. Written concept inventories or surveys intended to identify misconceptions must be designed carefully, and would, at best, only identify possible possessors of particular misconceptions.

VII. Conclusion

Although this pilot study has demonstrated the benefits of a more standardized interview procedure, it has also revealed the basic value of clinical student interviews. A great deal can be learned about how students think and what students know by simply asking them. Any interviewing protocol, however, must evolve to incorporate new information. These preliminary interviews have uncovered some patterns in student abilities—for example an inability to distinguish between internal and external forces in a bending beam, but future interviews need to be adapted to use that information to reveal the underlying patterns in student beliefs and reasoning. Once future interviews have identified likely misconceptions, surveys can be developed to measure how widespread these misconceptions are in a much larger population of students.

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